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The Lithological-Geochemical and Paleogeographic Characteristics Mesozoic–Cenozoic Deposits of the Yenisei-Khatanga Trough

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Abstract—The lithological and geochemical characteristics of the Meso-Cenozoic interval of the Leskinskaya borehole section (the mouth of the Yenisei River) and its paleogeographic and paleoclimatic characteristics are given.

Keywords: lithology, geochemistry, paleogeography, paleoclimatology, Mesozoic, Cenozoic, Yenisey, the Kara Sea

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INTRODUCTION

There are no deep wells in the estuary of the Yenisey River, thus the information obtained during drilling of the Leskinskaya well in the Yenisei–Khatanga Trough by PAO Gazpromneft in 2021 is highly relevant for regional and historical geology, paleogeography, and paleoclimatology. Our research team studied the drilling cores and sludge from this borehole drilled near the southern boundary of the Kara Sea water area. The 1 : 1000000 state geological maps of the Russian Federation, sheets R-43-45 (Gydan-Dudinka), S-44-46 (Ust-Tareya) issued in 2000, as well as sheet S-41-43 (Bely Island) issued in 2004 were taken as a stratigraphic base.

Stratigraphic division was performed by R.R. Gabdullin (Moscow State University) based on logging and paleontological analysis. The latter included microfaunal analysis performed by M.A. Ustinova (Geological Institute RAS) and S.I. Bordunov (GIN RAS, Moscow State University), and palynological analysis by Yu.I. Rostovtseva and D.A. Mamontov of Moscow State University.

The lithological and stratigraphic characteristics of the borehole section. The following stratigraphic units were distinguished in the Mesozoic–Cenozoic interval of the borehole section from bottom to top: Tampeiskaya Formation (Triassic), Bolshekhetskaya Formation (Lower-Middle Jurassic, Callovian), Danilovskaya Formation (Callovian–Berriasian), Lower Khetskaya Formation (Berriasian–Valanginian), Sukhodudinskaya Formation (Valanginian–Hauterivian), Malokhetskaya Formation (Hauterivian–Aptian), Yakovlevskaya Formation (Aptian–Albian), Dolganskaya Formation (Albian–Cenomanian), Nasonovskaya Formation (Turonian–Santonian) and Leskinskaya Formation (Quarternary).

Let us briefly describe the stratigraphic units identified in the Mesozoic–Cenozoic interval of the borehole section. Formational analysis was made by R.R. Gabdullin.

Tampeiskaya Formation (T*tm*). Argillites, sandstones, siltstones and clays with biotite and muscovite, interlayers of coals with subordinate interlayers of gravelites and conglomerates after basalts and tuffs of basic composition. Thickness up to 150 m. The formation corresponds to the oligomictic variegated formation according to (Sinitsyn, 1980) and to the sandstone formation according to the tectonic code (TC).

Bolshekhetskaya Series (J_{1-2}bh, Lower Jurassic–Callovian). Silty clays, sandstones, siltstones, with subordinate interlayers of conglomerates and gravelites after basalts and tuffs of basic composition, and coals. The thickness is up to 20 m. Clayey formation according to TC and marine carbonate-free formation according to (Sinitsyn, 1980).

Golchikhinskaya Formation (J_2–K_1*gl*, Callovian-Berriasian). Silty clays with pyrite and carbonate nodules. Bottom part is composed of clayey sandstones and siltstones with subordinate interlayers of conglomerates after basalts and tuffs of basic composition. The thickness is up to 110 m. Clayey formation according to TC and marine carbonate-free formation according to (Sinitsyn, 1980).

Nizhnekhetskaya Formation (K_1*nh*, Berriasian–Valanginian). Argillite-like clays with layers of siltstones and fine-grained sandstones, at the base there are same rocks with subordinate interlayers of conglomerates and gravel conglomerates after basalts and tuffs of basic composition. The thickness is up to 100 m. Sandstone formation according to TC and marine carbonate-free formation according to (Sinitsyn, 1980).

Sukhodudinskaya Formation (K_1*sd*, Valanginian–Hauterivian). Sandstones and clays with interlayers of coal. At the base there are gravelites and conglomerates after basalts and tuffs of the basic composition. The thickness is up to 100 m. Sandstone formation according to TC and marine carbonate-free formation according to (Sinitsyn, 1980).

Malokhetskaya Formation (K_1*mh*, Hauterivian–Aptian). Sands and sandstones, interlayers of siltstones and carbonaceous clays, at the base there are conglomerates after basalts and tuffs of the basic composition. The thickness is up to 110 m. Sandstone formation according to TC and marine carbonate-free formation according to (Sinitsyn, 1980).

Yakovlevskaya Formation (K_2*jak*, Aptian–Albian) combines interbedded clays (in places carbonaceous) and siltstones, sandstones with carbonaceous detritus. There are also isolated interlayers of coal. The thickness is up to 100 m. The formation was classified as a mesomictic carbonaceous formation according to (Sinitsyn, 1980) and a clayey formation according to the TC.

The Dolganskaya Formation (K_{1-2}*dl*, Albian–Cenomanian) consists of sands and siltstones with carbonized fossil plants, with rare fine-grained pyrite aggregates and subordinate interlayers of silty-pelitic clays, the lower part is composed of silty gray clays with scarce carbonized fossil plants, fine-grained pyrite aggregates, and mica flakes. Organic matter in the form of bitumen was found throughout the formation. The age of the formation correspond to the Middle Cretaceous oil- and gas-bearing complex (OGC). The thickness is up to 170 m. The formation corresponds to the mesomictic carbonaceous (Sinitsyn, 1980) or sandstone formation according to the TC.

Nasonovskaya Formation (K_2*ns*, Turonian–Santonian) is composed by interbedded silty clays with subordinate amounts of carbonized plant detritus, rare mica and silty flakes with scarce carbonized fossil plants, roughly rounded quartz grains, and fine-grained pyrite aggregates. The thickness is up to 180 m. The formation is classified as carbonate-free marine formation according to (Sinitsyn, 1980) and clayey formation according to TC.

Leskinskaya Formation (Q_{II}*ls*) is represented by terrigenous sandy–clayey deltaic sedimentary formations. The lower part is composed of clays with coarse quartz grains, mica flakes, containing foraminifera, mollusk shells, ostracods and plant detritus. The middle part is composed of silty clays with carbonized fossil plants, roughly rounded quartz grains, rare mica flakes, pollen grains of *Betula* sp, mushroom hyphae; in the upper part there are siltstones and silty clays with fossil plants (pollen grains of *Betula* sp., *Quer-qus*), roughly rounded quartz grains, rare mica flakes, in the terminal part - sand or sandy clay. The thickness is up to 140 m. The sequence is classified as a carbonate-free marine formation according to (Sinitsyn, 1980) and a clayey formation according to the TC.

Campanian deposits are absent in the borehole section; their characteristics are taken from (*Gosudarstvennaya*..., 2004) and are described below.

The Campanian–Danian seismic subcomplex (C_3–C_1), up to 560 m in thickness, is represented by clays and siltstones with calcite concretions at the bottom. It is attributed to the carbonate-free marine formation or clayey formation by TC.

It is overlain by the Paleocene sequence (C_1–C') composed of clayey siltstones, siltstones, sands, with brown coal interlayers at the top (140–800 m). The sequence belongs to terrigenous carbonaceous formations according to TC and mesomictic carbonaceous formation according to (Sinitsyn, 1980).

The section is topped by 300-m Upper Paleocene–Eocene sequence (C–D_0), composed by clayey siltstones, silty clays, and sands, followed by silica clays and diatomites. Its lower sandy–clayey part is a clayey formation according to TC and carbonate-free marine formation, while the upper siliceous part is classified as carbonate-free marine formation according to (Sinitsyn, 1980). This stage was followed by a sedimentation hiatus in the Oligocene synchronous with the uplift of the Pai-Khoi–Novaya Zemlya Fold Belt.

The hiatus was followed by the Oligocene–Miocene(?)sequence (D_0–D_2), which combines clays, siltstones and sands, and corresponds to the carbonate-free marine formation according to (Sinitsyn, 1980) and a clayey formation according to the TC.

MATERIALS AND METHODS

Complete geochemical analysis of 116 samples of Mesozoic–Cenozoic sediments from the borehole section was performed using BRUKER X-ray fluorescence spectrometer S8 Tiger (Analyst A.Yu. Puzik). Preparation of the samples was performed by M.D. Kazurov and I.R. Migranov.

The paleotemperature was determined using the weathering index of S.I. Merenkova. Weathering indices usually show the depletion of rocks in mobile elements relative to stationary ones during chemical weathering. The CIA index was first proposed in (Nesbitt and Young, 1982) and is widely used as an indicator of the chemical weathering intensity:

$$\mathrm{CIA} = 100\mathrm{Al_2O_3}/\left(\mathrm{Al_2O_3} + \mathrm{CaO^*} + \mathrm{Na_2O} + \mathrm{K_2O}\right),$$

where CaO* is non-carbonate CaO, all oxides are given in molar amounts.

$$T = 0.56\mathrm{CIA} - 25.7\ \left(r^2 = 0.50\right),$$

where T is temperature, °C

The method is described in more detail in (Gabdullin et al., 2021).

To construct the paleo climate curve, we used both new and published data, including mean annual temperature (MAT) calculated from palynological data (Zakharov et al, 2011), from climate indicator plants (Mogucheva, 2015; Lebedeva et al., 2019) with quantification of paleotemperatures using (Cantrill, 1998; Yamada et al., 2018; Guo et al., 2021; Zhang et al., 2021); from climate indicator insect taxa and on plesiosaur finds (Golbert et al, 1977); from lithological features (bauxites) (Golbert et al., 1977); from compilation MAT curves (Volkova, 2011); from data set (Golbert et al., 1977; Kontorovich et al., 2013), from qualitative determination of climate type (Goryacheva, 2018) followed by quantification using (Golbert et al., 1977), as well as the paleotemperature values calculated from weathering index (for the borehole). Sea surface temperature (SST) was calculated using geochemical (isotope) data were also plotted (Kontorovich et al., 2013; Marinov et al., 2015).

RESULTS AND DISCUSSION

Paleogeographic conditions. Paleogeographic curves (Figs. 1a; 2a) for the southern part of the Kara Sea were compiled by R.R. Gabdullin based on the available data. Two more fragments of paleogeographic curves for the Leskinskaya borehole section and the southern part of the Kara Sea (Figs. 1b; 2b) were constructed using the stratigraphic basis described above. These curves mostly correlate with each other.

During the Middle Triassic–Carnian, the paleotopography changed from 300 m at the very beginning of the Middle Triassic to 50 m at the end of the interval. From the Norian to the Toarcian, there was a continental setting with the accumulation of continental (including mottle and coal-bearing) formations. The following Middle Jurassic transgression had a maximum in the Kimmeridgian–Tithonian (up to 300 m)) and regression followed in the Late Tithonian, closer to the Jurassic–Cretaceous boundary. At that time, in conditions of lowering the sea level organic-rich oil-source bituminous clayey sediments were formed.

The maximum paleo depth (up to 200 m) of the next Late Berriasian–Aptian transgression was reached during the Late Berriasian–Early Barremian. At that time the paleobiocoenosis included ammonites, bivalves, belemnites and gastropods as well as horizons with foraminifera. Shallowing of the basin up to 50–100 m occurred during the Late Barremian–Early Aptian.

In the Albian–Cenomanian time, the area was elevated and coals were accumulated.

During the Selandian time, sedimentation was occurring in a continental setting with the formation of brown coals and the accumulation of sediments of sandy–clayey continental formation.

Sedimentation in the Thanetian–Eocene interval took place in a marine basin of about 50-m depth. The following uplift of the Pai-hoi–Novaya Zemlya Fold Belt in the Oligocene was replaced by a tectonic sinking of the area in Oligocene–Quaternary time and the formation of ~100-m deep marine basin.

Paleosalinity. R.R. Gabdullin determined salinity variations and constructed a paleo salinity curve (Figs. 1, 2). The normal salinity occured in the basin

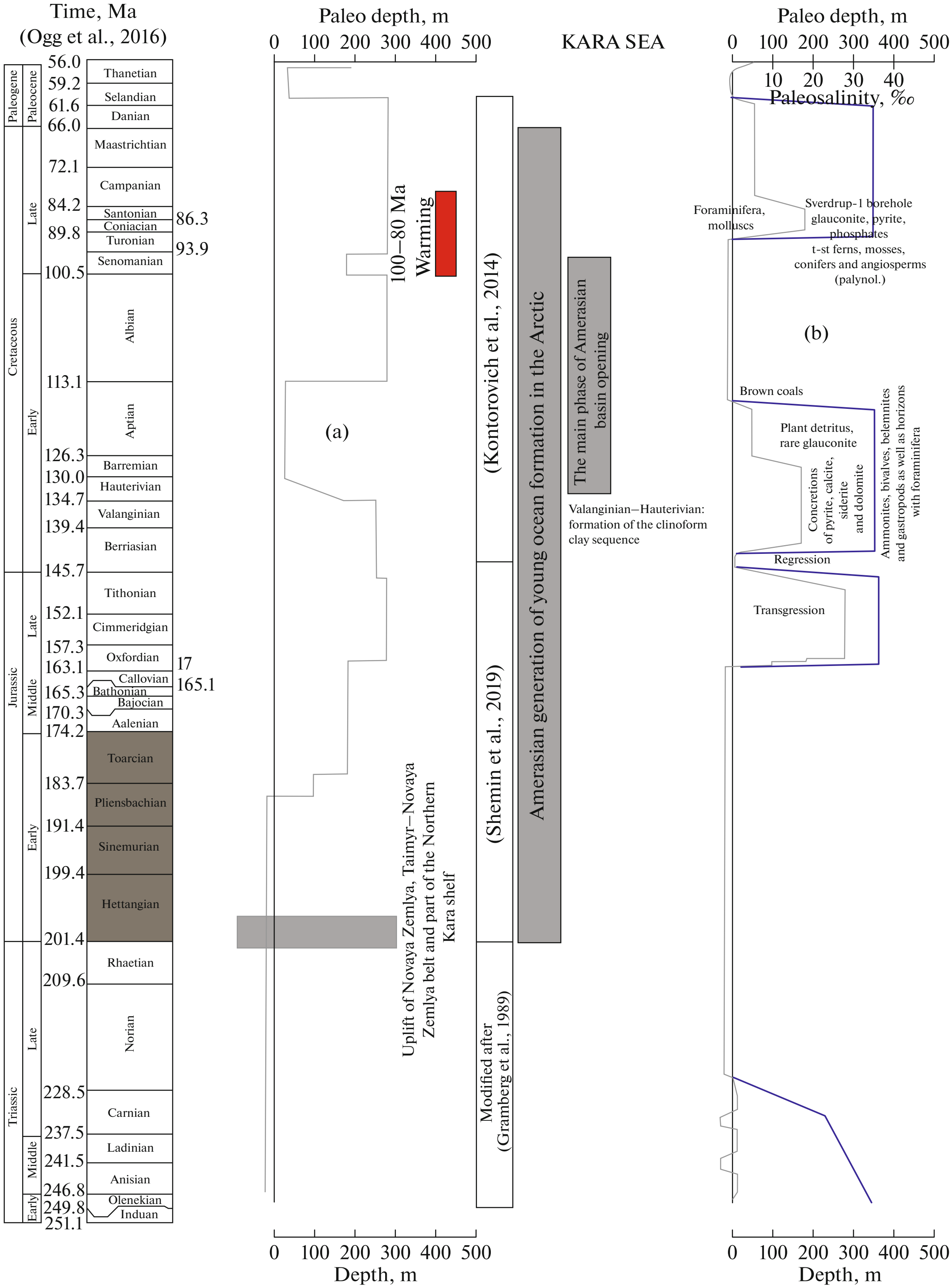


Fig. 1. The paleogeographic and paleosalinity curves for the Triassic–Paleocene history of the southern Kara Sea.

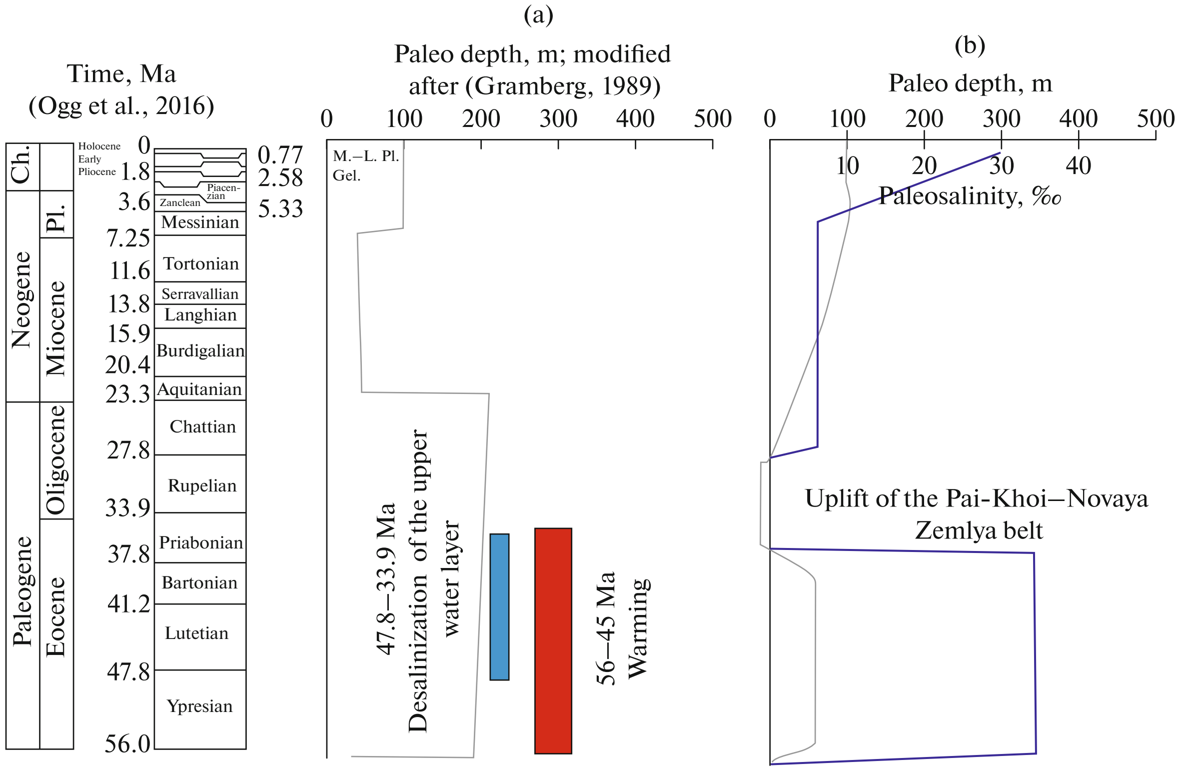
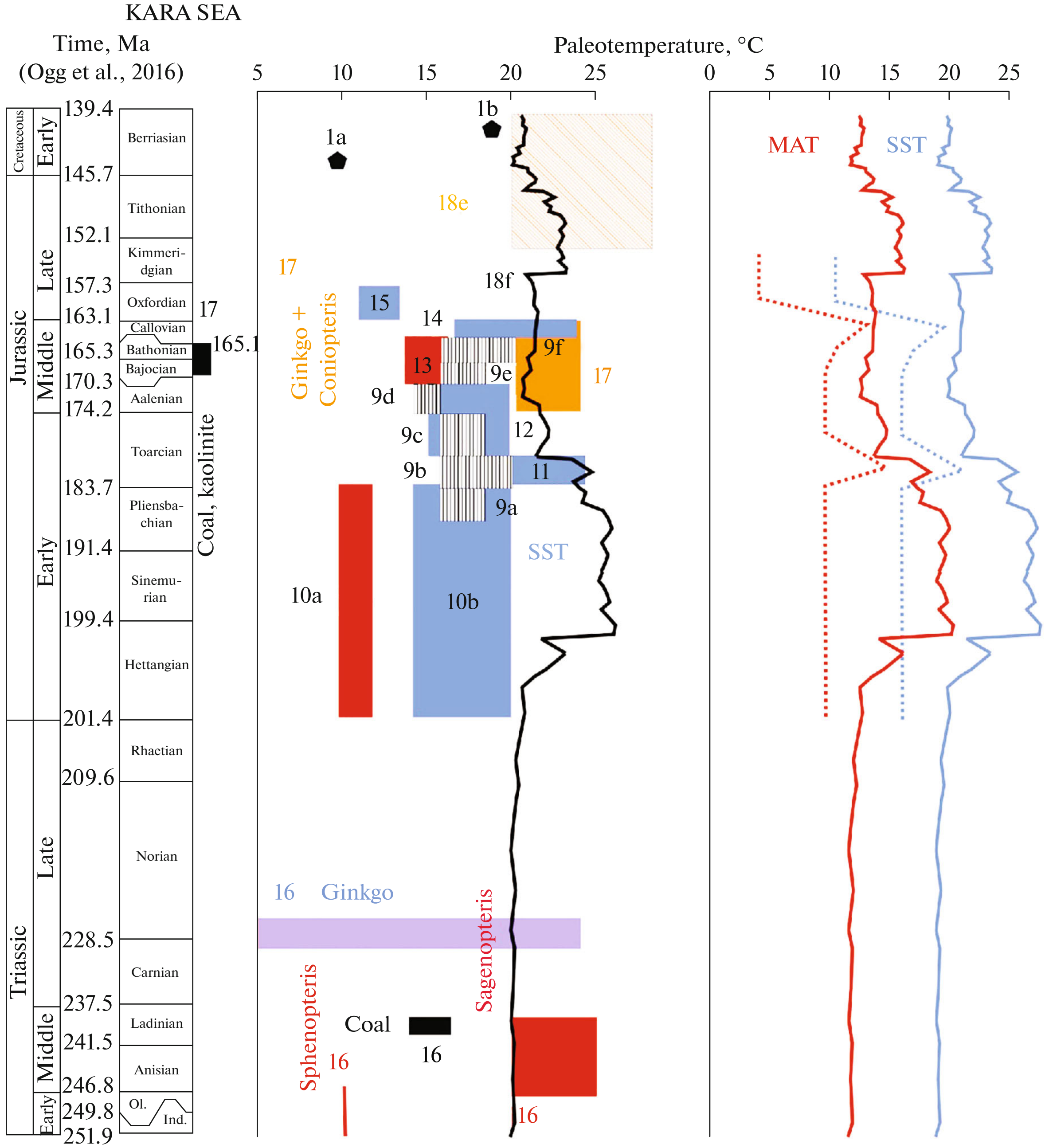


Fig. 2. The paleogeography and paleosalinity curves for the Eocene–Quaternary history of the southern Kara Sea.

in middle Late Jurassic, Late Berriasian–Middle Aptian (ammonites, bivalves, belemnites and gastropods, as well as foraminifera horizons and scarce glauconites were found (*Gosudarstvennaya*..., 2004), in Late Cretaceous–Danian (foramenifera and clams, glauconite, pyrite and phosphates are found in the

Fig. 3. The paleotemperature characteristics of the Triassic, Berriasian deposits in the area of the Leskinskaya Borehole: 1, MAT, palynology, Northern Siberia, Polar Urals (66°N and further north (Zakharov et al., 2011)); 2, MAT 14–15°C, Uyedineniya Island, *Plesiosaurus latispinus* (*Paleoklimaty*..., 1977); 3, MAT 18°C, Turukhan River, redeposited bauxites (*Paleoklimaty*..., 1977); 4, MAT 18°C, Solenaya River (a tributary of Malaya Kheta), redeposited bauxites (*Paleoklimaty*..., 1977); 5, SST, West Siberian Epicontinental Sea (Marinov et al., 2008); 6, MAT, West Siberian Plate (55° N and further north (Volkova, 2011)); 7, MAT 16–18°C, Taimyr Peninsula, Dolganskaya and Begicheskaya Formations, insects, temperate warm climate (*Paleoklimaty*... , 1977); 8a, MAT 16–20°C, amplitude 4–6°C (Aptian, Albian (*Paleoklimaty*..., 1977)); 8b, MAT 16–18°C, amplitude 4–6°C (Cenomanian, Turonian (*Paleoklimaty*..., 1977)); 8c, MAT 16–18°C, amplitude 6–8°C (Coniacian, Santonian (*Paleoklimaty*..., 1977)); 8d, MAT 14–16°C, amplitude 8–10°C (Campanian, Maastrichtian (*Paleoklimaty*..., 1977)); 8e, MAT 16–18°C, amplitude 8–10°C (Paleocene (*Paleoklimaty*..., 1977)); 8f, MAT 12–14°C, amplitude 10–12°C (Eocene (*Paleoklimaty*..., 1977)); 9a, temperate warm climate (Late Pliensbachian (Goryacheva, 2018)) with our subsequent quantification (MAT 16–18°C) by (*Paleoklimaty*..., 1977); 9b, temperate-subtropical climate (Late Pliensbachian, Early Toarcian (Goryacheva, 2018)) with subsequent quantification (MAT 16–20°C, *Paleoklimaty*..., 1977); 9c, temperate warm climate (end of the Early Toarcian, Late Toarcian (Goryacheva, 2018)) with subsequent quantification (MAT 16–18°C, *Paleoklimaty*..., 1977); 9e, temperate warm climate (Bajocian (Goryacheva, 2018)) latter quantified (MAT 16–18°C, *Paleoklimaty*..., 1977); 9f, temperate subtropical climate (Bathonian (Goryacheva, 2018)) later quantified (MAT 16–20°C, *Paleoklimaty*..., 1977); 10a, MAT 10–12°C, warm humid climate (Hettangian–Pliensbachian (Kontorovich et al., 2013)); 10b, SST 14.4–19.8°C for Hettangian, Aalenian (Kontorovich et al., 2013); 11, SST 16.9–24.5°C, Early Toarcian, warm humid climate (Kontorovich et al., 2013); 12, SST 15–20°C, Aalenian, warm humid climate (Kontorovich et al., 2013); 13, MAT 14–16°C, Bajocian and Bathonian, warm humid climate (Kontorovich et al., 2013); 14, STT 17–23°C, warm humid climate, warming of the Arctic Ocean waters (Callovian (Kontorovich et al., 2013)); 15, STT 11–13°C, isotope paleothermometry from belemnite rostra, Oxfordian (Kontorovich et al., 2013); 16, *Sphenopteris* (Mogucheva, 2015) MAT 10°C (Yamada et al., 2018), *Sagenopteris* (Mogucheva, 2015) MAT >20°C (Zhang et al., 2021); 17, *Coniopteris*+*Ginkgo* plant assemblage (Lebedeva et al., 2019) MAT 20–24°C by (Guo et al., 2021; Zhang et al., 2021); Leskinskaya well (flora determined by Rostovtseva) 18a, Nasonovskaya Formation (Turonian, Santonian), *Gleicheniidites laetus* (Bolch.) Bolch., MAT 8–22°c (Cantrill, 1998); 18b, Dorozhkovskaya Formation (Turonian–Coniacian), ferns *Cyathidites* sp, MAT>20° (Zhang et al., 2021); 18c, Dolganskaya Formation (Albian–Cenomanian), *Cyathidites minor* Couper, *Cyathidites australis* Couper MAT>20°C (Zhang et al., 2021), *Gleichenidites senonicus* Ross emend. Scarby, *G. laetus* (Bolch.) Bolch., MAT 8–22°C (Cantrill, 1998); 18d, Yakovlevskaya Formation (Aptian, Albian), ferns *Cyathidites minor* Couper, MAT>20°C) (Zhang et al., 2021), *Gleichenidites laetus* (Bolch.) Bolch, MAT 8–22°C (Cantrill, 1998); 18e, Danilovskaya (Callovian, Berriasian), *Cyathidites* sp. for Tithonian, Berriasian, MAT > 20°C) (Zhang et al., 2021); 18f, paleotemperature values calculated from the weathering index



section), as well as in Selandian–Bartonian and Pliocene–Quaternary times.

During the Chattian–Miocene period, a brackish-water basin occurred.

Oil and gas potential. The Jurassic and Lower Berriasian sediments formed the Jurassic oil and gas bearing complex (OGC) due to interstratification of sand-siltstone reservoirs with clay aquitards. The next OGC is Lower Cretaceous (Lower Cretaceous–Lower Albian), the next one is Middle Cretaceous (Upper Albian–Turonian).

Oil and gas matrix sediments. The Tithonian–Cimmeridgian formations contain domanikoid clayey formations similar to the Bazhenov Formation.

Paleoclimatic conditions. Ample data on paleotemperature for this region available in the literature are presented in Figs. 3 and 4. R.R. Gabdullin summarized the literature and new data and compiled paleotemperature curves (water surface temperature SST and mean annual temperature MAT) for the Kara Sea area during Mesozoic–Cenozoic stage.

Temperature variations in **Triassic** were weak, with MAT values of ~12–13 °C and SST values of 18–19°C.

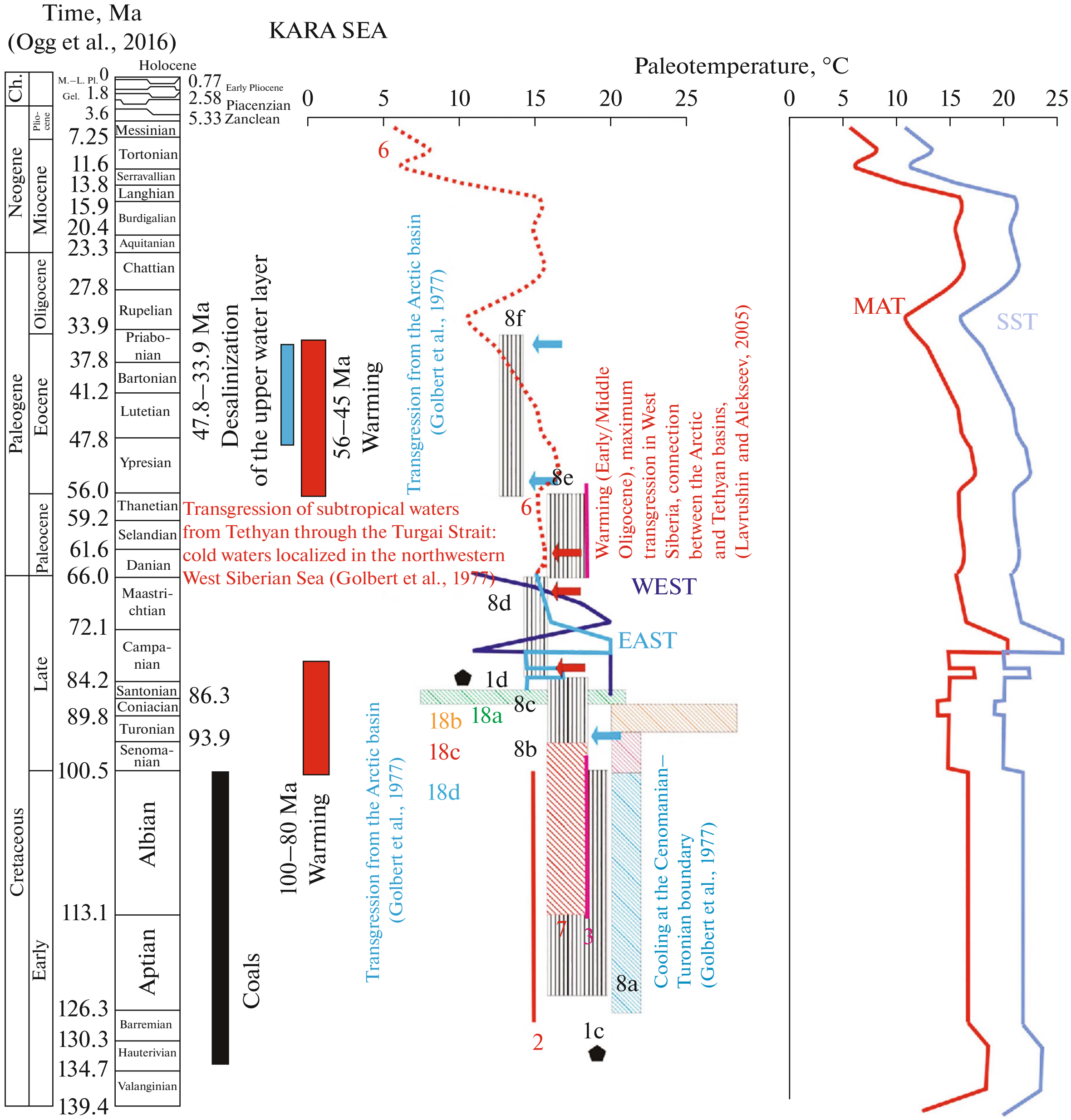


Fig. 4. The paleotemperature characteristics of Valanginian–Pliocene sediments in the Leskinskaya Borehole and southern Kara Sea area. See legend for Fig. 3.

Phytoassociations included ferns and ginkgoids; coal was accumulated during the Ladinian.

Paleotemperatures (MAT) were assessed and a variation curve was constructed for the Triassic–Berriasian interval of the Leskinskaya borehole. It does not contradict the published data on paleotemperature values by climate indicator plants; only perceptible discrepancy (within 5°C) was observed for the Hettangian–Pliensbachian interval.

Hettangian–Toarcian. A warm uniformly humid climate has been established for Hettangian and Pliensbachian, a warm humid climate for early Toarcian (Kontorovich et al., 2013). Other data (Goryacheva, 2018) reconstruct a temperate to warm climate for Late Pliensbachian, a temperate subtropical climate for Late Pliensbachian–Early Toarcian, and a temperate climate from the end of Early Toarcian to the Late Toarcian. This qualitative characteristics of climate type has been quantitatively confirmed using values from (Golbert et al., 1977). In particular, we obtained the following ranges of paleotemperature (MAT) values: Late Pliensbachian, 16–18°C; Late Pliensbachian–Early Toarcian, 16°C; and the end of

Early Toarcian–Late Toarcian 16–18°C. These paleotemperature ranges are in a good agreement with the MAT values determined in the Leskinskaya borehole from the weathering index. We attributed the Hettangian–Early Pliensbachian sediments to the Mesomictic Carboniferous Formation.

The climate warming began from the Hettangian: MAT values (in the Leskinskaya borehole section) were about 15–20°C, and SST values were 20–25°C. The climatic maximum falls on the Late Hettangian–Pliensbachian. A decrease in paleotemperature started in the Toarcian. Paleotemperatures from the Leskinskaya borehole correspond to the previously obtained values (Kontorovich et al., 2013)—MAT 10–12°C for Hettangian and Pliensbachian; SST 14.4–19.8°C for Hettangian–Aalenian; SST 16.9–24.5°C for Early Toarcian.

Aalenian–Early Kimmeridgian. Kontorovich et al. (2013) assumed a warm humid climate for the Aalenian–Callovian, and warming of the Arctic Ocean water in the Callovian. Accumulation of coal and kaolinite occurred in the Bajocian and Bathonian (*Gosudarstvennaya*..., 2004).

Goryacheva (2018) identified the Bajocian climate as being temperate warm and the Bathonian as temperate subtropical. We quantified this qualitative characteristic using values from (Golbert et al.,1977). In particular, we obtained a 16–18°C MAT value for Bajocian and 16–20°C for Bathonian, which, however, is a few degrees higher than the ranges of paleotemperatures obtained for the Leskinskaya borehole section.

Paleotemperature values calculated from the weathering index for the Leskinskaya borehole section varied weakly about 11–14°C, and SST values were 16–19°C. They coincide roughly with the previously obtained values (Kontorovich et al., 2013), SST of 15–20°C for the Aalenian and 17–23°C for the Callovian; MAT of 14–16°C for the Bajocian and Bathonian. W note that the SST values of 11–13°C according to isotope paleothermometry from Oxfordian belemnite rostra (Kontorovich et al., 2013) are approximately 2°C lower than the values obtained for the Leskinskaya borehole section.

The paleotemperature curves (shown as dashed lines) constructed for the Hettangian–Kimmeridgian interval of geological history from the published data are similar to the curves constructed for the Leskinskaya borehole section.

Late Kimmeridgian–Berriasian. Paleotemperature values calculated from the weathering index for the Leskinskaya borehole section were: MAT about 13–17°C and SST about 18–22°C. The Late Kimmeridgian and Early Tithonian were characterized by relative climate warming: MAT was about 15–17°C and SST was 20–22°C, followed by a cooling phase in the Late Tithonian–Berriasian, when the MAT values were about 12–14°C and SST was 17–20°C. These values were confirmed by the estimate of paleotemperature using fossil flora growth from the Leskinskaya borehole section determined by Rostovtseva (Lomonosov Moscow State University). Thus, *Cyathidites* sp. found in rocks of the Danilovskaya (Callovian–Berriasian) Formation or, rather, its Tithonian–Berriasian part, were growing at MAT values of more than 20°C (Zhang et al., 2021). MAT values of 10°C and 18°C obtained from palynological data from sections of northern Siberia and the Polar Urals are close to these values (Zakharov et al., 2011).

Valanginian–Turonian. The published data allows the paleotemperature variations to be estimated at about 13–18°C (MAT), and 18–23°C (SST). At the same time Valanginian and Early Hauterivian were characterized by climate warming: about 17–19°C MAT and 22–24°C SST, followed by a long period of relative cooling in the Late Hauterivian–Albian time, when MAT values were about 17°C and SST about 22°C. Then, in the Cenomanian and Turonian periods, it became even cooler: MAT decreased to 15°C and SST to 20°C. Similar MAT values of 19°C were obtained for the Hauterivian from palynological data from sections in northern Siberia and the Polar Urals (Zakharov et al., 2011). Cooling was recorded at the Cenomanian–Turonian boundary, MAT at the Aptian–Albian was estimated at 16–20°C, and at the Cenomanian–Turonian at 16–18°C with a variation amplitude of 4–6°C (Golbert et al., 1977).

Coal accumulation occurred from the Hauterivian to the Albian (Gosudarstvennaya..., 2004), the deposits from the Hauterivian to the Cenomanian were attributed to the Mesomictic Carboniferous Formation.

These values were confirmed by the paleo temperatures estimated by Rostovtseva using the fossil flora from the Leskinskaya borehole section. Thus, ferns *Cyathidites minor* Couper indicating MAT values of more than 20°C (Zhang et al., 2021), as well as *Gleichenidites laetus* (Bolch.) Bolch. implying MAT values within 8–22°C (Cantrill, 1998) were found in rocks of the Yakovlevskaya Formation (Aptian–Albian). Ferns *Cyathidites minor* Couper, *Suathidites australis* Couper with MAT values of more than 20°C (Zhang et al., 2021) and *Gleichenidites senonicus* Ross emend. Scarby, *G. laetus* (Bolch.) Bolch. indicating MAT values of 8–22°C (Cantrill, 1998) were found in the deposits of Dolganskaya Formation (Albian–Cenomanian) making it possible to estimate MAT values equal to 20–22°C for the Aptian–Cenomanian interval. Ferns *Cyathidites* sp. with MAT values of more than 20°C were also identified in rocks of the Dorozhkovskaya Formation (Turonian–Coniacian) (Zhang et al., 2021), suggesting that paleo temperatures were not less than 20°C.

Coniacian–Maastrichtian. The published and new data for this period of geological history allowed MAT (varying 15 to 20°C) and SST (varying from 20 to 25°C) curves to be constructed. The paleotemperature tends to increase from the Coniacian to the beginning of the Campanian, with stabilization in the Early Campanian, followed by decrease and subsequent increase in the late Campanian. From the late Campanian to late Cretaceous there was a decrease in MAT paleo temperatures from 20°C in the early Campanian to 15°C in the late Maastrichtian. The MAT estimated for the Coniacian–Santonian was 16–18°C with variation amplitude of 6–8°C, while that of Campanian–Maastrichtian was 14–16°C with an variation amplitude of 8–10°C (Golbert et al., 1977). At the boundary of the Santonian and Campanian, as well as in the middle of the Maastrichtian, there were transgressions of subtropical waters from the Tethyan Ocean through the Turgai Strait; cold waters were localized in the northwestern part of the West Siberian Sea (Golbert et al., 1977). There are estimates of SST variations for the West Siberian epicontinental sea (Marinov et al., 2008), varying from 12 to 20°C.

These values were confirmed by the estimated paleo temperature of the paleo flora from the Leskinskaya borehole section determined by Yu.I. Rostovtseva. Thus *Gleicheniidites laetus* (Bolch.) Bolch, with the assumed MAT range of 8–22°C (Cantrill, 1998) was found in the sediments of the Nasonovskaya Formation (Coniacian–Santonian). The Turonian–Santonian rocks of the Sverdrup-1 borehole contained ferns, mosses, conifers, and angiosperms, as well as glauconite, pyrite, and phosphates (*Geologicheskaya...*, 2004).

Cenozoic. At the boundary between the Early and Middle Oligocene there was a relative climate warming, at the same time there was a maximum transgression in Western Siberia, while a connection between the Arctic and Tethic basins was still on (Lavrushin and Alekseev, 2005). The MAT curve for the West Siberian Plate (55° N and northward) compiled for this interval (Volkova, 2011) was used as the basis for the paleo temperature curve. Paleocene MAT values were 16–18°C with variation amplitude of 8–10°C, while in the Eocene these values were 12–14°C and 10–12°C, respectively (Golbert et al., 1977).

In the Paleocene, MAT values were about 15–16°C, then increased at the Paleocene–Eocene boundary to 17–18°C. From the Middle Lutetian, paleo temperatures started decreasing, and reached values of ~12°C at the Eocene–Oligocene boundary. Warming (MAT values of about 17°C) began from the Middle Rupelian and lasted until the end of the Burdigalian. Then there was a period of relative cooling (from 17 to 5°C) with a brief warming peak in the middle of the Tortonian, when the MAT reached 7–8°C.

CONCLUSIONS

The paleogeographic conditions of the Leskinskaya borehole section formation in the Mesozoic–Cenozoic were determined. The proposed paleogeographic and paleoclimatic models of the formation of the borehole section generally correlate with the sedimentation conditions of the section of the southern Kara Sea according to the published data. Climate variations were, as a rule, cyclic; their duration was several million years (Figs. 3, 4), which corresponds to the cycles of eccentricity of the Earth's orbit (Milankovitch) of the third and higher orders (E_{3-5}). Geochemical and paleontological surveys as well as formation analysis of the stratigraphic units allowed at least 19 climate cycles to be established in the Yenisei-Khatanga sedimentary basin of Northern Eurasia during the Mesozoic–Cenozoic interval of geological history.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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