ISSN 1028-334X, Doklady Earth Sciences, 2026, Vol. 531:18. © Pleiades Publishing, Ltd., 2026.

STRATIGRAPHY

First Data on the Age and Sedimentary Cover Environments for the Laptev Sea Basin near Taimyr Based on Stratigraphic Drilling Data

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Received July 6, 2026; revised August 12, 2026; accepted August 14, 2026

Abstract—Shallow boreholes penetrated upper horizons of the sedimentary cover of the Laptev Sea basin off the coast of Taimyr. The borehole cores were studied using a combination of stratigraphic methods, including paleontological, paleomagnetic, Sr-chemostratigraphic, and other methods. Data were obtained on the Jurassic–Early Cretaceous and Oligocene–Early Pliocene ages of the two main complexes drilled by the boreholes and identified on seismic profiles. New data on the age of the complexes differ significantly from earlier ideas based solely on the interpretation of seismic data. The sedimentary cover of the Laptev Sea sedimentary basin near Taimyr is significantly older than that of other areas of the Laptev, East Siberian, and Chukchi seas studied by stratigraphic drilling.

Keywords: stratigraphy, sedimentary cover, drilling data, Mesozoic, Jurassic, Cretaceous, Cenozoic, Laptev Sea, Taimyr

DOI: 10.1134/S1028334X26601975

INTRODUCTION

Discussions about the stratigraphic age of the sedimentary cover on the Laptev Sea shelf, as well as the nature of the folded base, have been ongoing for several decades ([2, 3, 8, 15, 18], etc.). The main complicating circumstance is that in the southwestern continental frame of the Laptev Sea, two folded systems are connected: the Early Mesozoic systems of Taimyr and the Late Mesozoic systems of the Verkhoyansk belt. The age of the lowermost horizons of the sedimentary cover, overlapping the folded basement, varies from Aptian–Albian over most of the Laptev Sea shelf to Middle Jurassic (?) in its western, Taimyr part. In eastern Taimyr, there are known outcrops of Middle and Late Jurassic rocks in the cover ([6] and others), and on the Severnaya Zemlya (Bolshevik Island) both bedrock outcrops of Jurassic deposits and finds of Upper Jurassic and Lower Cretaceous fossils have been noted [7]. In Eastern Taimyr, in the Gulf of Teresa Klavekness, survey wells were drilled, which revealed not only Middle–Upper Jurassic but also Lower Jurassic sandstones and siltstones [1, 5]. This diversity confirms that determining the age of the sedimentary cover of the Laptev Sea shelf is still a pertinent task.

In 2024, three stratigraphic wells were drilled from the Bavenit drilling vessel (Marine Arctic Geological Exploration Expedition, Murmansk) in the western part of the Laptev Sea shelf, designed to clarify the age of the sedimentary cover in this part of the basin.

MATERIALS AND METHODS

The object of the study is the cores from three stratigraphic wells–SSD-V2_PH, SSD-V2-2_PH, and SSD-V2-3_PH––drilled in the western part of the Laptev Sea shelf (Fig. 1). These wells were drilled at specifically defined intervals selected based on CDP seismic data. The upper horizons of the sedimentary

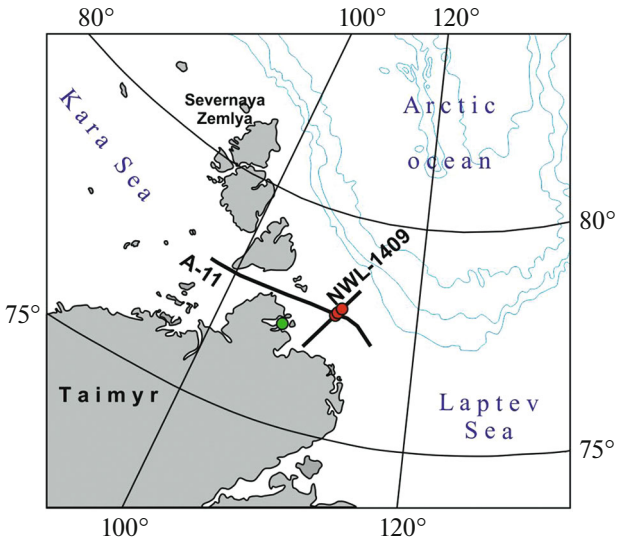


Fig. 1. Map showing the location of seismic profiles and boreholes. The green circle shows the location of boreholes drilled from the ice off the coast of Taimyr and exposing Jurassic deposits [1, 5]; the red circles show the boreholes discussed in the article.

cover were passed without core sampling, while the core recovery in the target intervals was 60–100%. Minor losses and omissions of core in a number of cases were due to the presence of loose sandy rocks and layers of soft, non-water-resistant rocks in the section.

Well SSD-V2-PH was drilled at coordinates 77°52′38.69″ N and 111°49′27.92″ E at a sea depth of 294.5 m, the well bottom is at a depth of 282.0 m from the bottom surface. Core sampling was carried out in the intervals of 103–114, 123–138, 139–141, 141.6–144, 145.2–147, 156.7–159, 160–162, 164.6–165, 167.8–168, 186–188, 195–196, and 281–282 m.

Well SSD-V2-2-PH was drilled at coordinates 77°46′53.33″ N and 111°33′14.46″ E at a sea depth of 278.0 m, the well bottom is at 136.0 m from the bottom surface. Core sampling was carried out in the intervals of 89.5–92 and 125.2–135 m.

Well SSD-V2-3-PH was drilled at coordinates 77°45′04.88″ N and 111°28′07.51″ E at a sea depth of 274.3 m, the well bottom is at 160.5 m from the bottom surface. Core sampling was carried out in the interval of 148–160 m.

The intervals penetrated by three wells make it possible to obtain a direct estimate of the age of the seismic complexes identified on seismic profile No. NWL1409 passing through them, as well as on seismoacoustic profile 1907 (Fig. 2). The seismic profile clearly shows that the section is divided by an angular unconformity into two parts penetrated by wells.

Subsequently, core samples were studied using paleomagnetic, chemostratigraphic, lithological, and paleontological methods.

The Sr isotopic composition was measured on a Triton TI multi-collector mass spectrometer. Average $^{87}Sr/^{86}Sr$ values in standard samples SRM 987 and EN-1, normalized to the ratio $^{86}Sr/^{88}Sr = 0.1194$, amounted to 0.710279 ± 0.000008 and 0.709206 ± 0.000009 during the work period, respectively($2\sigma_{avg}$, $n = 6$). All measured $^{87}Sr/^{86}Sr$ values in samples corrected to the value of $^{87}Sr/^{86}Sr$ in standard EN-1 = 0.709175.

RESULTS

Structure of the Section, Lithological Composition

The SSD-V-2-PH and SSD-V2-2-PH wells exposed the Cenozoic interval of the section, represented by interlayering of refractory dark greenish-gray loams, gray sands, sandy loams with inclusions of gravel and pebbles, and brownish-gray loose sandstones. The textures of the rocks are uniform, weakly layered, and brecciated. Throughout the section, coal chips, carbonized plant remains, and rare fragments of mollusk shells are found. Well SSD-V-2-3-PH opened up a presumably Mesozoic interval of the section, represented by gray argillite-like clays and argillites, refractory to hard. The texture is generally massive, but there are traces of bioturbation with carbonate ferruginous pseudomorphs along the burrow passages. Carbonate, siderite, and pyrite concretions and nodules, shell detritus, and whole mollusk shells are also found.

Stratigraphic Age of the Exposed Section. Mesozoic Interval

The greatest intrigue was determining the age of the most ancient complex of Mesozoic rocks uncovered by the SSD-V-2-3-PH borehole. In all four samples from the 149.08–159.40 m interval studied by micropaleontologists, they discovered benthic agglutinating and secretory foraminifera, ostracods, pyritized radiolarians, pearls, and echinoderm fragments. At a depth of 159.4 m, the most representative complexes of benthic foraminifera are found; the species of greatest stratigraphic significance are *Verneuilinoides borealis* Tappan, 1957 (subsp. saniasensis Mjatliuk, 1988), *Haplophragmoides* (Ammosiphonia) *nonioninoides* Reuss, 1863, *A. beresoviensis* (Bulatova, 1976), characteristic of the Albian of Western Siberia, as well as the Aptian–Albian of the Barents Sea region and the Canadian shelf. The foraminiferal complex identified here indicates accumulation in favorable conditions of the middle sublittoral of the shallow shelf.

Some more information was obtained from the shells of marine mollusks found in the same intervals. The remains of bivalve mollusks can be dated to the Late Jurassic (Fig. 3). Most likely, this interval belongs to the Upper Oxfordian–Middle Volgian. The most

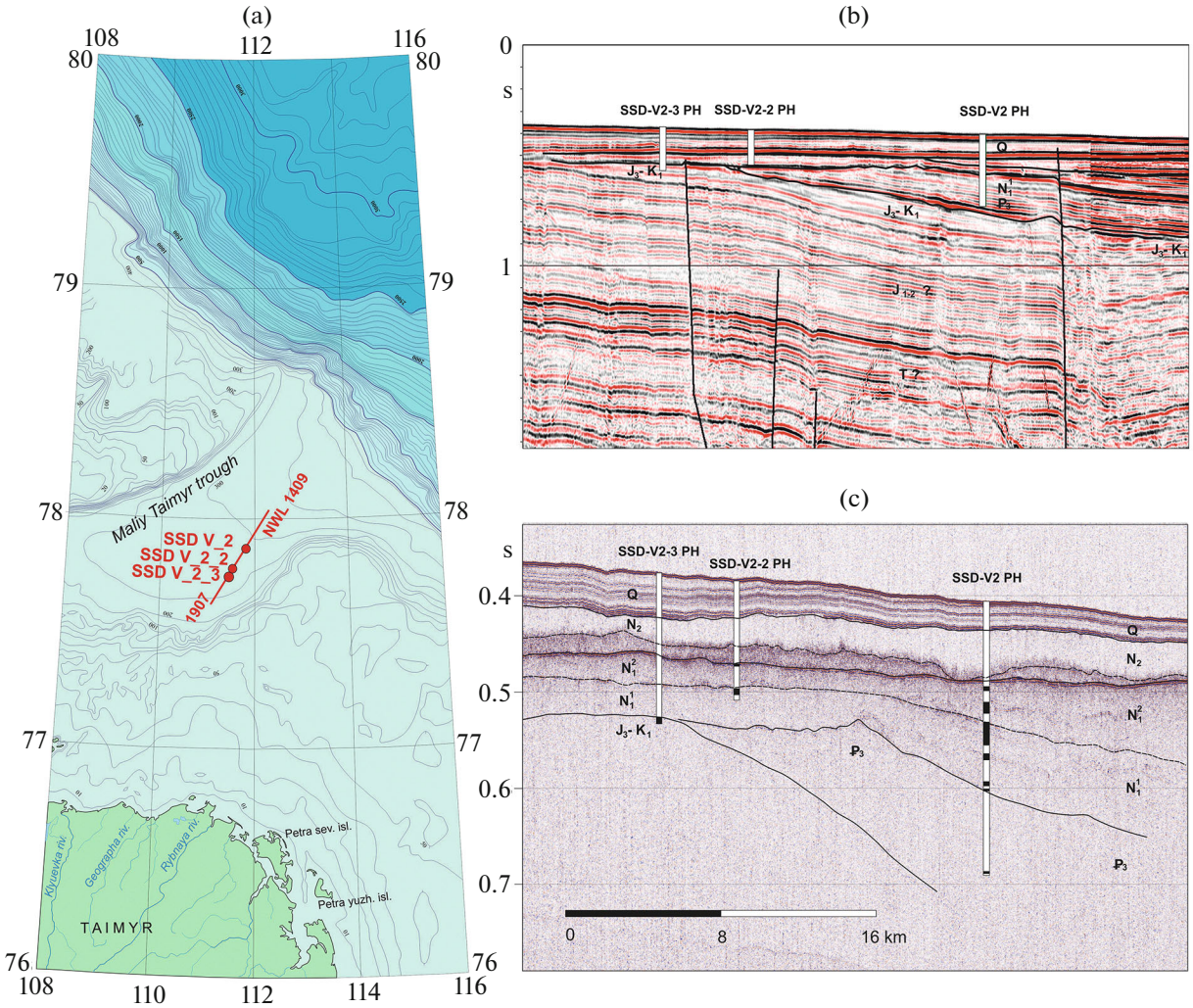


Fig. 2. Map showing the location of wells and geophysical profiles (a), correlation of wells to reflecting horizons on seismic profile NWL 1409 (b) and on the seismoacoustic profile 1907 (c).

reliable evidence for this age is provided by *Aguilerella* cf. *varians* (Zakharov, 1966). This specimen, with its subquadrate shell outline, subquadrate for the genus, and small size, resembles a species from the Middle Volgian deposits of the Khatanga Depression [9]. V.A. Zakharov also reported this species from Northern Taimyr (Kamennaya River).

The $^{87}Sr/^{86}Sr$ ratio in two fragments of marine mollusk shells collected from the core of borehole SSD-V2-3-PH at depths of 154.3 and 153.9 m fell within the range of 0.707016–0.707037 (Table 1). According to strontium isotope stratigraphy (SIS), these values, within the measurement error, correspond to the Kimmeridgian-Tithonian interval [11, 20]. Given the Early Cretaceous age of the foraminifera, the fragments of the studied shells may have been redeposited, although their number suggests a close source of Late Jurassic rocks.

Paleomagnetic studies were carried out on 30 samples from the Mesozoic interval of the section (Fig. 4). Along the Mesozoic part of the section, an alternation of intervals of direct and reverse polarity is recorded. This variability indicates that sediments formed in an interval older than 120 Ma, that is, before the onset of the Cretaceous superchron.

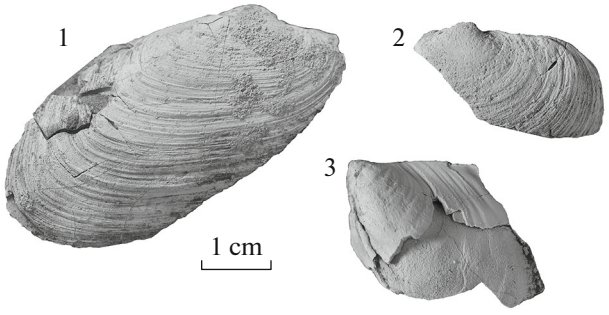


Fig. 3. Bivalves from borehole SSD-V2-3-PH: 1—right valve of *Quenstedtia* cf. *parallela* (Trautschold, 1866); 2—right valve of *Quenstedtia* cf. *parallela* (Trautschold, 1866); 3—left valve of *Aguilerella* cf. *varians* (Zakharov, 1966).

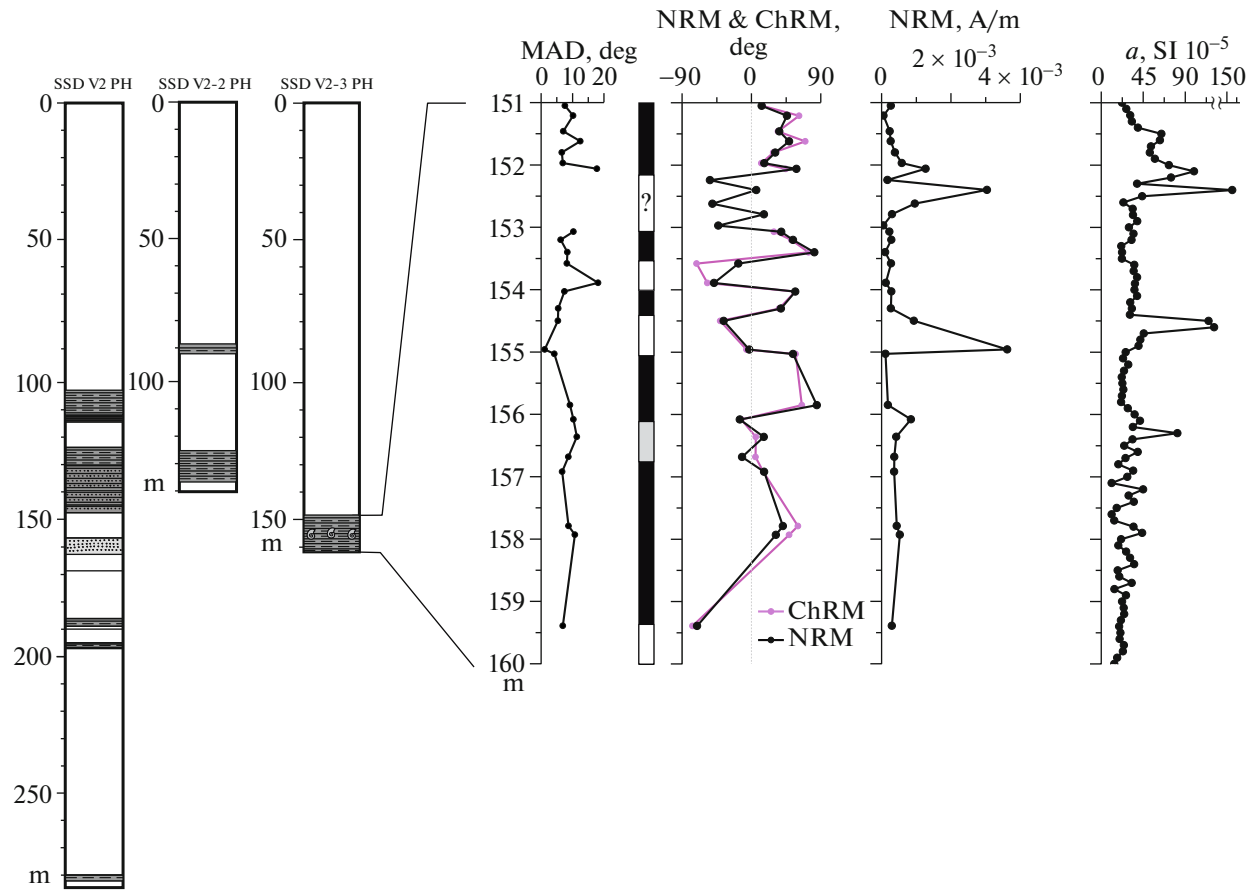


Fig. 4. (a) Lithological columns of intervals drilled by the boreholes . Paleomagnetic characteristics of Mesozoic rocks from borehole SSD-V2-3-PH: (b) maximum angular deviation, (c) inclination of natural remanent magnetization and characteristic remanent magnetization, (d) value of natural remanent magnetization, and (e) magnetic susceptibility.

In borehole SSD-V2-3-RN, four samples were studied using the palynological method in the 149.08–159.40 m interval. All samples were very well enriched in palynomorphs of poor and satisfactory preservation. The general taxonomic composition of the studied spectra allows us to identify one palynocomplex here. Dominants are the two-saccate pollen of gymnosperms *Disaccites* gen. indet., indefinable even to the family, many *Pinuspollenites* spp., there is noticeable content of *Alisporites* spp., *Cycadopites* spp., and *Ginkgocycadophytus* spp. Found in large quantities were dinocysts *Nannoceratopsis* sp. and *N. pellucida* Defl. Also present are *Pareodinia halosa* (Filat.) Prauss, *Evansia* spp., and *Sirmiodinium grossii* Alberti. A cyst of dinoflagellates *Wanaea acollaris* Dodek was found in a sample from a depth of 159.40 m. Dinocysts of the species *Nannoceratopsis pellucida* Defl. and *Wanaea acollaris* Dodek. are of Jurassic age. Thus, palynological spectra have been established, the composition of which, as well as the absence of characteristic and diagnostic forms, allows them to be considered only as Jurassic-Lower Cretaceous. The presence of likely redeposited, well-preserved, characteristic Jurassic dinocysts in the spectra further complicates age determination.

Palynological associations similar in composition have been described by various palynologists from the Tuguttakh Formation and the lower subsuite of the Balyktakh Formation on Kotelnyi island [13]. For the Kotelnyi Island sections, it has been shown by geologists that the complex of sediments of the Aptian–Albian age (the Tuguttakh Formation and the Lower Balyktakh subsuite) is largely composed of clay rocks, which are Upper Triassic and Lower Jurassic clays that have been washed off or slid down from the hills [12]. This substantiates the presence in the Aptian–Albian rocks of well-preserved palynological remains, redeposited from more ancient rocks. If we assume that the section of the SSD-V2-3_RN well in the interval of 149.08–159.40 m penetrated deposits of similar age and material composition, then, based on the obtained palynological data, it can be assumed that the rocks were formed in the Early Cretaceous period.

All these rather contradictory data on the Mesozoic part of the section force us to look for an explanation for the significant discrepancies in the age of the

deposits. Apparently, we are dealing with Aptian–Albian rocks containing fragments and lenses of redeposited, lithologically similar, clayey rocks of the Jurassic age, containing shells of marine mollusks and dinocysts of the Jurassic age.

The lithologically studied interval of the section differs from that characteristic of the marine Upper Jurassic–Lower Cretaceous deposits of Taimyr, where the Mukhinskaya suite stands out, composed mainly of sands, sandstones, and gravelstones [17]. At the same time, based on the composition of the nodules with Kimmeridgian, Volgian and Ryazanian fossils from Bolshevik Island, it can be assumed that the deposits containing them were represented mainly by clays or argillites.

Marine sediments of the Albian age in the study region were previously unknown. The finds of Albian foraminifera closest to the location of the studied borehole were previously known only in the northeastern part of Western Siberia, at the place where it connects with the Yenisei-Khatanga regional trough [10].

Cenozoic Interval of the Section

The upper, Cenozoic, interval of the section is penetrated by wells SSD-V2-PH and SSD-V2-2-PH. The core sample taken from this interval in well SSD-V2-PH is represented by sediments containing a large amount of redeposited material. Well SSD-V2-2-PH exposed a part of the section better suited for stratigraphic studies.

Microfaunistic analysis of samples 8 and 11 from the core of borehole SSD-V2-RN was carried out for the depth range of 105.9–281.85 m in two laboratories in St. Petersburg, and similar results were obtained. In the lower part of the borehole section (140–281 m), single redeposited foraminifera of satisfactory preservation were washed out of the samples representing *Haplophragmoides*? sp., *Ammodiscus*? sp., and *Ataxophragmium*? sp.

In situ foraminifera were found in samples from depths of 139.30, 136.6, 132.70, 110.8, 110.2, 106.8, and 105.90 m. Based on the results obtained, two foraminifera complexes can be distinguished:

Interval 139.30–132.70 m. A mixed complex of redeposited Aptian–Albian and in situ Cenozoic foraminifera. Cretaceous forms are represented by single *Ammodiscus rotalarius* Loeblich et Tappan, *Haplophragmoides* sp., and *Ammobaculites fragmentarius* Cushman. Cenozoic foraminifera are represented by a complex with *Cibicides* sp. (*C. perlucidus* Nuttall?), *Ammodiscus* ex. gr. *macilentus* Chapmam, *Haplophragmoides* ex. gr. *laminatus* Volochinova, *Haplophragmoides spadis* V. Kuznetzova, *Haplophragmoides tortuosus* V. Kuznetzova, *Eggerella tumiensis* Volochinova, *Spiroplectammina* cf. *pilvoensis* V. Kuznetzova, *Reophax* cf. *curtus* Cushman, and *Cribroelphidium* sp. (Oligocene-Miocene) with brown shells.

Interval 110.80–105.90 m. A complex of secretory foraminifera, shells of varying preservation, often with broken off last chambers of the shell. Various species of Cibicides dominate: *Cibicides* cf. *refulgens* (Molfort), *Cibicides* ex. gr. *grossus* Ten Dam and Reinfold, *Cibicides rotundatus* Schedrina, *Cibicides lobatulus* (Walker et Jacob), *Cibicides* sp., single *Cassidulina reniforme* Nørwang and *Elphidium* sp. The studied foraminiferal complex with Cibicides has a distinct boreal-arctic character and consists of representatives of genera and some species inhabiting modern northern and Far Eastern seas, which is associated with a new stage of transgression, most likely Pliocene.

A palynological analysis of eight samples from well SSD-V2_RN was also carried out in the interval of 105.90–281.85 m. All samples are enriched to varying degrees with pollen of gymnosperms and angiosperms, spores, and microphytoplankton of satisfactory and poor preservation. Samples from the depth of 281.85 and 186.20 m revealed similar spore-pollen spectra in composition, in which pollen of gymnosperms dominates, represented mainly by the Pinaceae family (32–50%): *Pinus* spp., *Pinus* sg. *Haploxylon*, *Picea* spp., *Tsuga* spp., and *Abies* sp., pollen of Taxodiaceae-Cupressaceae is present in small quantities, and that of *Ginkgo* spp. in single instances. In terms of taxonomic composition and main dominant taxa, the palynospectrum is most similar to the complex established for the deposits of the second half of the Upper Eocene of Northeast Russia. The sample from the depth of 139.30 m is well saturated with palynomorphs of good and poor preservation. In the identified palynospectrum, the leading role is played by pollen of gymnosperms of the pine family (60%). Its quantity increases further due to the decrease in the content of Taxodiaceae-Cupressaceae and pollen of angiosperms and spores. Among the spores, sphagnum mosses and club mosses lead. This palynospectrum can be correlated with Late Oligocene deposits of Northeastern Russia. In the interval of 105.90–132.70 m, the studied samples are characterized by a moderate degree of saturation with poorly preserved palynomorphs. The main background of the spectra consists of redeposited Mesozoic myospores and dinocysts.

In addition, 12 samples from the core of well SSD-V2-PH was subjected to Trautschold analysis. A rich diatom assemblage was identified only in the depth range of 146.6–146.7 m; in the remaining samples, either sponge spicules were found or else no microfossils were detected. The complex is characterized by numerous diatom valves, indicating that it was buried in situ. The species diversity of the diatom association is small and includes 21 species, and 5 taxa currently have an unspecified status. The diatom complex is dominated by species of the genus *Pterotheca* ssp., known from the Upper Cretaceous and extinct in the Neogene. Subdominants include: *Paralia sulcata* (Ehrenberg) Kützing, *Stellarima microtrias* (Ehrenberg) Hasle et Sims, *Ikebea tenuis* (Brun) Akiba, and

Table 1. Sr isotopic composition in fragments of mollusk shells

No.	Sample number	$^{87}Sr/^{86}Sr$	Age
1	SSD-V2-PH 139.5	0.708560	N_1
2	SSD-V2-PH 139.6	0.708547	N_1
3	SSD-V2-PH 140.1	0.708614	N_1
4	SSD-V2-PH 140.5	0.708537	N_1
5	SSD-V2-PH 141.6	0.708530	N_1
6	SSD-V2-PH 142.5	0.708527	N_1
7	SSD-V2-PH 143.37-143.39	0.708543	N_1
8	SSD-V2-PH 167.8	0.708543	N_1
9	SSD-V2-3-PH 153.9	0.707017	J_3
10	SSD-V2-3-PH 154.35-154.36	0.707058	J_3

Sr isotopic composition was measured on a Triton TI mass spectrometer [4, 11]. All measured $^{87}Sr/^{86}Sr$ values in samples are corrected to the value of $^{87}Sr/^{86}Sr$ in standard EN-1 = 0.709175.

Thalassoisira sp. Associated species are present: *Xanthiopyxis* sp., *Chaetoceros* sp., *Stephanopyxis turris* (Gréville et Arnott) Ralfs, *Coscinodiscus oculus-iridis* Ehrenberg, *Coscinodiscus payeri* Grunow, *Pseudotriceratium rusticum* (Mann) A. Gladenkov, *Actinocyclus curvatulus* Janisch, *Porosira glacialis* (Grunow) Jørgensen, *Hyalodiscus obsoletus* Sheshukova, *H.* cf. *elegans* Strelnikova sensu Baldauf, Barron, *Actynoptichus senarius* (*Ehrenberg*) Ehrenberg, *Melosira arctica* (*Ehrenberg*) Dickie, *Thalassionema nitzschioides* Grunow. The significant content, primarily of Paralia sulcata, as well as some other species, indicates the formation of diatom bearing sediments in the shelf zone of the sea.

Most of the identified diatoms have a wide stratigraphic range. Our sample contains only two fragments of typical Eocene diatoms—*Sceptroneis Ehrenberg* spp. and *Pyxilla Gréville* spp., which are redeposited. There are two biostratigraphic markers, *Ikebea tenuis* and *Pseudotriceratium rusticum*, dating the age of the diatom bearing deposits as presumably Late Oligocene–Early Miocene.

All studied fragments of marine mollusk shells from the upper part of borehole SSD-V2-PH is characterized by $^{87}Sr/^{86}Sr$ equal to 0.70853–0.70861 (Table 1). Comparison of the obtained $^{87}Sr/^{86}Sr$ values with the curve of strontium isotopic variations in the Cenozoic seas [20] allows us to preliminarily date the age of the shell fossils of the upper part of the section as Early Miocene (18–20 Ma).

For the SSD-V2-RN borehole, paleomagnetic studies were carried out on only 13 samples, and despite the limited interval (about 3 m), a change in polarities is recorded in the section. According to the isotopic data, this interval belongs to the Early Miocene, which is also characterized by frequent reversals of the geomagnetic field according to the magnetostratigraphic scales.

DISCUSSION

The results of analytical studies on borehole cores do not fit at all into the stratigraphic model of the sedimentary cover of the Taimyr part of the Laptev Sea shelf, developed based on seismic data [16]. It was believed earlier that the main part of the sedimentary cover was made up of Cenozoic rocks, with Upper Cretaceous formations only at the base. The study of cores from boreholes drilled near Taimyr clearly indicates that the main angular and stratigraphic unconformity, representing a deep denudation section with an increase in the age of the underlying complexes to the west, in the direction of Taimyr, recorded on seismic profiles and revealed by drilling, is of the Middle Oligocene age. This unconformity (horizon LS-2 according to [18]) corresponds to an important tectonic boundary with a significant restructuring of the structural plan, marking the beginning of the neotectonic stage in the Arctic [19]. Thus, in the sedimentary cover of the Taimyr part of the Laptev Sea shelf, a long break in sedimentation is recorded, which began in the Early Cretaceous and ended in the Oligocene.

In contrast to the Taimyr part of the Laptev Sea, in its eastern part, the Eocene-Early Oligocene complex was exposed by drilling in the sedimentary cover [14]. This raises the question of the regional correlation of seismic complexes in the Laptev Sea region, since stratigraphic drilling has led geologists to rejuvenate the age of the complexes in the eastern part, while the data we obtained in the western part, on the contrary, suggest an older age for the complexes. Tracing seismic complexes towards the North Kara sedimentary basin is also problematic. Figure 5 offers an interpretation of a unique, single seismic profile running from the Kara to the Laptev basin, taking into account the obtained drilling data.

At the same time, the stratigraphic data we obtained from the cores of the Taimyr wells are still purely preliminary. Additional research is required on the lower part of the exposed section to determine the time of its formation: Early Cretaceous (Aptian–Albian) or Late Jurassic. For now, we conditionally consider the age of the Mesozoic interval of the section to be Late Jurassic–Early Cretaceous. In the Cenozoic part, there is certainty in the dating of the base of the complex, determined by the surface of the Middle Oligocene unconformity. The formation of the Cenozoic interval of the section exposed by drilling continued from the Late Oligocene to the Pliocene.

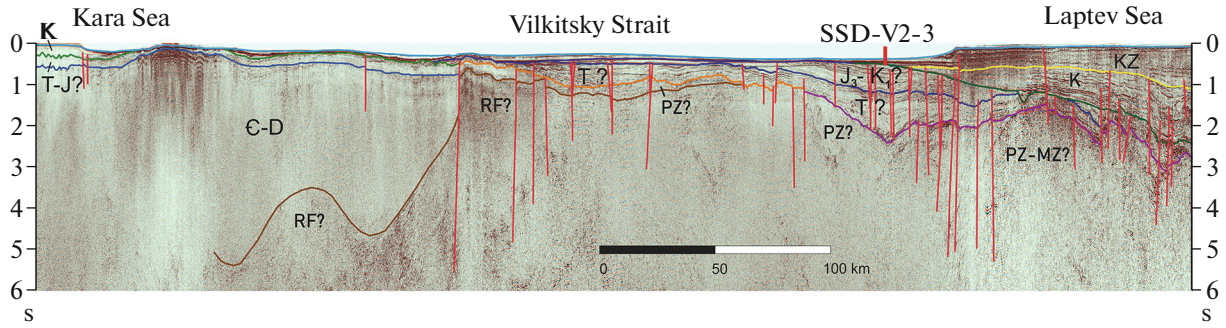


Fig. 5. Interpretation of seismic profile A-11, acquired by the Marine Arctic Geological Exploration Expedition, passing from the Kara Sea through the Vilkitsky Strait into the Laptev Sea. The profile's position is shown in Fig. 1.

CONCLUSIONS

In the Taimyr part of the Laptev Sea shelf, three shallow stratigraphic wells were drilled for the first time in 2024, revealing 12.5, 14, and 53.5 m of a section composed of terrigenous, sandy and silt-clay sediments. The results of core studies obtained to date allow us to draw the following conclusions:

1. In the drilling area, the sedimentary cover is divided into two parts by a clear angular unconformity. The lowest complex, exposed by drilling, has an Upper Jurassic–Lower Cretaceous (?) age according to the biostratigraphic and isotopic data. The section is characterized by marine mollusks, foraminifera, spores, and pollen.

2. Above the unconformity lie Late Oligocene–Pliocene deposits, characterized by microfaunistic, palynological, paleomagnetic, and isotopic data.

3. The results obtained differ significantly from the stratigraphic schemes developed earlier for the sedimentary cover of the western Laptev Sea. Beneath the Jurassic–Cretaceous part of the section, exposed by boreholes, there is at least another kilometer of layered complexes of the sedimentary cover of an even more ancient age. Apparently, in the Taimyr part of the Laptev Sea shelf there is a of submeridional (Taimyr) trough, filled with a thick layer of Mesozoic (Jurassic–Cretaceous) rocks, wedging out to the east and north. Judging by the seismic data, the studied block of the Laptev Sea shelf is separated from the areas to the north and east by a belt of deformations complicating direct correlations of seismic complexes.

The ongoing analytical studies and correlation of the results with available seismic data will help significantly refine of the geological structure model of the Laptev Sea region.

ACKNOWLEDGMENTS

The authors thank the captain and crew of the Bavenit drilling vessel (Marine Arctic Geological Exploration Expedition, Murmansk) for the work in the difficult conditions of the Arctic shelf.

FUNDING

The research was funded by Rosnedra as part of the government assignment No. 049-00004-24-00 to VNIIOkeangeologiya.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflict of interest.

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