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STRATIGRAPHIC DRILLING IN THE NORTHEASTERN LAPTEV SEA: MAIN RESULTS AND FURTHER DEVELOPMENT

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The Russian sector of the Eastern Arctic is characterized by large basins with thick sedimentary filling, primarily on the shelf and continental slope of the seas of the Arctic Ocean. A number of geological, geophysical, and geochemical features point to a hydrocarbon potential. At the same time, the age and composition of the sedimentary infill of the shelf basins have been controversial until now due to the lack of wells drilled in the shelf area. Six stratigraphic wells were drilled with core sampling in the eastern Laptev Sea (Anisin–Novosibirsk block owned by Rosneft) with a depth of 100 to 199.5 m during the Rosneft Stratigraphic Drilling in Arctic (RoSDAr) project in 2021. The results of complex biostratigraphic studies of the core show that the oldest strata in the well sections are Upper Barremian – Lower Aptian deformed silty mudstones (folded basement assemblage) overlain with angular unconformity by sands, silts, and clays of the Paleocene. The wells also penetrate the Eocene, Oligocene, and Miocene-Quaternary clastic rocks. A comprehensive analysis of stratigraphic drilling and seismic data refines the geological models of the region and provides better understanding of its hydrocarbon potential. The data show that Cenozoic strata play a more significant role in the sedimentary cover of the Laptev Sea than was previously assumed.

Arctic shelf, core, hydrocarbon potential, biostratigraphy, seismic stratigraphy, rift basins

INTRODUCTION

The Eastern Arctic is one of the most poorly studied regions of the world not only due to its inaccessibility, but also because of its harsh climatic and ice conditions. The absence of wells drilled in the shelf region until recently gives rise to numerous discussions about the geological structure and history of the Eastern Arctic offshore sedimentary basin development..

Two fundamentally different concepts of the geological structure and age range of the sedimentary cover of the Laptev Sea have developed over the past decades. According to the first concept, the ancient Siberian platform continues in the western and central parts of the shelf, so the age range of the cover should include sequences from the Precambrian to the Cenozoic (the older cover concept). According to the second concept, almost the entire offshore region, except for the Khatanga Gulf, has a Late

Mesozoic folded basement, so the age of the basal sedimentary sequence should not be older than the Aptian (the younger cover concept). Within the eastern (northeastern) part of the shelf, the Late Mesozoic folded basement of the Novosibirsk-Chukotka folded system is developed, overlapped by recent Aptian-Cenozoic sediments. Therefore, there is a significant divergence of opinion regarding the stratigraphy of this region.

Radical changes have occurred in solving this problem since 2020 due to the Rosneft Stratigraphic Drilling in Arctic (RoSDAr) program. These operations were carried out for the first time in Russia within the North Kara sedimentary basin in the 2020 season: 10 wells were drilled with a depth of 40 to 90 m and sediments were dated in the age range from Cambrian to Jurassic – Early Cretaceous [Malyshev et al., 2023]. This work was continued in the Laptev Sea in 2021, in the Chukchi Sea in 2022, and in the East Siberian and Chukchi seas in 2023. In 2022 the Federal Agency for Mineral Resources (Rosnedra) jointly with the Rosneft stratigraphic drilling program in the Chukchi Sea and with its assistance drilled the first well in the northwestern part of the East Siberian Sea in the De Long High region as part of the program to substantiate the outer limit of the continental shelf of the Russian Federation [Petrov et al., 2023]. This paper describes the key results of drilling carried out in 2021 in the northeastern part of the Laptev Sea as part of the Rosneft program.

GEOLOGY OF THE REGION

The Laptev Sea shelf attracts the attention of researchers due to a number of fundamental and applied aspects of its geological structure. The unique tectonic position of this region has been mentioned in the numerous works of previous researchers. The Laptev Sea shelf is a junction of heterochronous and heterogeneous tectonic elements – the ancient Siberian platform and the imposed three orogenes, including: the Late Paleozoic–Mesozoic Taimyr, as well as the Late Mesozoic Verkhoyansk–Kolyma and Novosibirsk–Chukotka fold belts. The largest rift system stands out here, occupying almost the entire shelf area, except for the Khatanga Bay region. Most researchers assume that the rift was formed throughout the Cenozoic (possibly Cretaceous-Cenozoic?) age and is associated with spreading in the Eurasian Basin, transformed into the tension of the adjacent continental lithosphere of the Laptev Sea shelf. At the same time, the present-day geodynamics of the region is also controlled by the interaction of the ultraslow spreading Gakkel Ridge with the Eurasian continental margin [Gaina et al., 2015]. This is expressed on the Laptev Sea shelf as a belt of scattered modern seismicity up to 600 km in width. Here, various authors distinguish one or several boundaries of lithospheric plates and microplates. Thus, many researchers conclude that the Laptev Sea sedimentary basin resulted from the completion of the Late Mesozoic folding and subsequent rifting [Drachev et al., 1998; Franke et al., 2000, 2001; Avetisov, 2002; Grachev, 2003; Franke and Hinz, 2009; Drachev et al., 2010; Vernikovsky, 2013; Zavarzina et al., 2014; Mazur et al., 2015; Imaeva et al., 2016, 2019; Drachev and Shkarubo, 2017; Nikishin et al., 2017, 2021; Piskarev et al., 2018; Krylov et al., 2022; Sokolov et al., 2022].

The concept of a significant hydrocarbon potential of the sedimentary basin infill of the Laptev Sea is based on a number of known geological factors. The first of them is the presence of a series of large rift basins separated by horsts identified on marine seismic survey data [Gramberg et al., 1990]. The rifts extend to the northwest, from the continental coast to the Eurasian Basin the average thickness of the sedimentary basin infill is 5–6 km, exceeding 10–12 km in some graben depocenters. Numerous potential hydrocarbon (HC) traps were mapped the 2D seismic survey data. The traps are mostly associated with rift structures (inversion structures in some cases) and can predominantly be categorized as fault related or combined types. The 2D seismic anomalies in the sedimentary cover, possibly associated with hydrocarbon saturation, also were repeatedly noted [Kazanin, 2020]. Moreover, it is necessary to note the presence of oil and bitumen occurrences on the adjacent continental and island territory in a wide stratigraphic range: from the Upper Proterozoic to the Jurassic [Ivanov, 1979; Kos'ko et al., 1985; Kashirtsev et al., 2010; Safronov, 2013; Frolov et al. 2017; Evdokimova and Kharitonova, 2018; Zueva et al., 2019; Kontorovich et al., 2019; Khudoley et al., 2022]. In addition, gas occurrences are identified in the Jurassic–Cenozoic sediments in mapping wells on the New Siberian Islands and the adjacent shelf [Yashin and Kim, 2007; Evdokimova et al., 2008].

Many small fields and oil shows (Yuzhno–Tigyanskoye, Nordvikskoye, etc.) were discovered quite a long time ago in the Khatanga Bay in the western part of the Laptev Sea region. In 2017 Rosneft drilled an exploration well in this part of the region from the shore of the Khara–Tumus Peninsula, thereby discovering the Tsentralno–Olginskoye oil field. This is the first oil field on the Russian Eastern Arctic shelf. The main HC accumulations in this region are confined to the Permian and Triassic strata corresponding to the main reservoirs of the Anabar–Khatanga saddle, located in the eastern part of the Yenisei-Khatanga regional trough. Sedimentary infills characterized by this age and having developed in the Khatanga Bay region correspond in the central and eastern parts of the shelf area to the pre-rift complex (folded basement) and cannot directly indicate the hydrocarbon potential of the entire Laptev Sea cover.

An important sign of active hydrocarbon systems in the Laptev Sea shelf can be gas seeps identified on the bottom of and within the water column. These gas seeps are underwater methane emissions [Yusupov et al., 2010;

Sergienko et al., 2012; Lobkovsky et al., 2015; Baranov et al., 2019; Ruban et al., 2021, 2022] and the results of gas-geochemical studies of bottom sediments, indicating the thermogenic origin of migrating HC gases [Yashin and Kim, 2007; Bogoyavlensky and Bogoyavlensky, 2021]. Thus, the totality of geological, geophysical, and geochemical data indicate a significant hydrocarbon potential of the Laptev Sea shelf.

Both solving fundamental questions about the geological structure and evolution of the Laptev Sea region and the well-founded forecast of its hydrocarbon potential rely on the determination of the age range and lithological composition of the rocks of its sedimentary sequence. Ideas about the latter in the absence of direct drilling data have remained controversial until now and have constituted the key geological uncertainty for the Laptev Sea shelf.

Until recently, the primary basis for predicting the age of the sedimentary infill of the Laptev Sea basins was information about the geological structure of the New Siberian Islands archipelago and the adjacent continental land, including Taimyr, northern Eastern Siberia, and Verkhoyanye. Before stratigraphic drilling, all the models used for dating sedimentary sequences were based only on the integration of the interpretation results of 2D marine seismic data and geological materials on the continental and island frames of the shelf area.

The New Siberian Islands located on the Laptev Sea shelf is the western part of the Late Mesozoic New Siberian-Chukotka fold and thrust belt. The latter contains the intensely deformed Ordovician – lowermost Lower Cretaceous strata overlain with angular unconformity by weakly deformed Uppermost Lower Cretaceous strata (the Aptian–Albian) and by Late Cretaceous (Cenomanian–Coniacian) and Cenozoic [Kos’ko et al., 1985; Trufanov and Vakulenko, 1978; Trufanov et al., 1979; Kuzmichev et al., 2018; Prokopiev et al., 2018].

On the New Siberian Islands archipelago, the oldest rocks are exposed on the Kotelny Island and represented mainly by the Ordovician – Lower-Middle Devonian carbonate deposits overlain with angular unconformity by the Middle-Upper Devonian – Jurassic carbonate-clastic and clastic strata [Parfenov and Kuzmin, 2001; Prokopiev et al., 2018]. The Devonian–Permian deformed strata are identified on the Belkovsky Island located to the west of Kotelny Island [Kos’ko et al., 1985].

The intensely deformed Paleozoic carbonate-clastic and Triassic-Jurassic clastic rocks of the Kotelny Island [Kos’ko et al., 1985; Kos’ko and Korago, 2009; Prokopiev et al., 2018] are overlain by Aptian–Albian continental clastic-volcanogenic strata. These Lower Cretaceous rocks fill small depressions (gentle brachysynclines) in the central part of the Kotelny Island and are also exposed by mapping wells in the south of the Novaya Sibir Island and on the Bunge Land. These strata have been studied in most detail in the central part of the Kotelny Island. There is a relatively weakly deformed sequence (the dip angles of the beds vary from 2 to 60° [Kuzmichev et al., 2009b]) of interbedded sandstones, argillites, siltstones, and coals with interbeds of ignimbrites, ash tuffs, liparites, and tuffite lenses and beds up to 1000 m in thickness, belonging to the Balyktakh Formation [Trufanov et al., 1986; Kuzmichev et al., 2009; Nikitenko et al., 2017]. The K-Ar dating of ignimbrite glasses from the uppermost Lower Cretaceous section of Kotelny Island reveals an Early Albian age of 110–107 ± 2.5 Ma [Kuzmichev et al., 2009b].

The overlying Bunge formation (Cenomanian-Turonian) is often separated from the underlying Jurassic or Lower Cretaceous deposits by a 5– to 11-m thick weathering crust [Trufanov et al., 1986]. As revealed in one of the mapping wells on the Faddeyevsky Island, the formation lies on a weathering crust developed over Lower Cretaceous (presumably Albian) liparites [Trufanov et al., 1986].

This formation is widespread in the northern and southern parts of the Bunge Land, as well as in the central part of the Faddeyevsky Island (Gedenshtrom Bay) and on the Novaya Sibir Island. This formation is composed mainly of siltstones and argillite-like clays, among which are individual beds and packs of laminated sands, gravel-pebble material, tuffaceous sandstones, and brown coals. The results of palynological and paleofloristic analyses make it possible to specify the age of the formation as Cenomanian – Lower Turonian [Nikitenko et al., 2017]. The thickness of the formation reaches 150–400 m [Trufanov et al., 1986; Burguto et al., 2016].

The most recent Cretaceous deposits known on the New Siberian Islands (Novaya Sibir Island) belong to the Turonian-Coniacian Derevyannogorsk formation [Trufanov and Vakulenko, 1978; Trufanov et al., 1979]. The formation reaching 100-110 m in thickness is composed of interbedded silts, clays, tuffaceous sands, tuffaceous sandstones, tuffites, and brown coals. According to many researchers, the analysis of spore-pollen and macrofloristic assemblages from the deposits of the formation indicates its Turonian age [Trufanov et al., 1979; Nikitenko et al., 2017, 2018]. According to the latest U-Pb dating of detrital zircon grains from volcanogenic-clastic formation (the average weighted age of the most recent population of grains is 88 ± 0.9 Ma), its lower age limit is the Lower Coniacian [Kostyleva et al., 2022].

Cenozoic (pre-Quaternary) deposits with angular and stratigraphic unconformity lie on the Paleozoic-Mesozoic heterochronous sequences characterized by a weathering crust at the base and a thickness of 0.5–25 m [Burguto et al., 2016]. The oldest Cenozoic strata on the New Siberian Islands include a sequence represented by clays, brown coals, sands, and pebbles characterized by a thickness of up to 90 m and Selandian – Lower Ypresian palynological assemblages [Grinenko et al., 1998]. They are overlain by the Lower–Middle Eocene Anjouian formation having a thickness of up to 70–100 m thick and composed of clays and sands containing beds and lenses of brown coal, as well as rare thin interbeds and lenses of pebbles. It is mainly represented by nonmarine deposits. However, remains of mollusk shells in the formation on the Novaya Sibir Island and dinocysts of the genera *Wetzeliella* and *Deflandrea* are found in the Nerpalykh Lagoon on the Kotelny Island [Aleksandrova and Kuzmichev, 2011].

The subdivision of the higher intervals of the section into formations is controversial. The age of the Nerpichiy Formation and the Kanarchak sequence of marine and coastal-marine genesis, initially identified in the Oligocene – Quaternary interval [Trufanov et al., 1979], is eventually revised and now considered as Neopleistocene [Basilyan and Nikolsky, 2007]. As noted in [Kuzmichev et al., 2013], the Nerpichiy Formation includes sediments of different ages, but similar lithological composition.

The Eocene–Oligocene deposits are identified in the west of the Kotelny Island, where they are distributed in a series of small graben-like depressions. The Lower Eocene clastic coal-bearing rocks with a visible thickness of several meters are exposed in the Reshetnikov River region in the northwest of the Kotelny Island [Ershova et al., 2022]. The Oligocene clastic formations are exposed along the western coast of the island in small graben-like depressions [Ershova et al., 2022].

The Upper Eocene – Lower Miocene rocks of the Belkovsky Island consists of clays with interbeds of sand and pebbles, as well as individual horizons of tuff, silt, and peat [Kuzmichev et al., 2013]. An important feature of the structure of the Upper Eocene – Lower Miocene deposits of the Belkovsky Island is the widespread development of NS- and NW-trending post- and syndepositional normal faults [Kuzmichev et al., 2013]. Thus, the distribution and structure of the Cenozoic assemblages developed on the Belkovsky and Kotelny islands are largely controlled by fault tectonics, which is typical (as will be shown below) for the cover of the 2021 stratigraphic drilling region located to the north.

The presence of two sedimentary successions with angular unconformities at the base on the New Siberian Islands (Aptian–Albian and Cenozoic) leads the existence of different models of possible stratigraphic execution both for the eastern part of the Laptev Sea basin under consideration and for the central part not characterized by drilling. The first group of models is based on the known fact of the development of postfold Aptian–Albian volcanogenic-clastic rocks in the central part of the Kotelny Island and suggests that the rift basins of the Laptev Sea began to form in the Aptian–Albian age, respectively [Kos'ko and Trufanov, 2002; Shkarubo and Zavarzina, 2011; Shkarubo et al., 2014; Vinogradov et al., 2016; Nikishin et al., 2014, 2017, 2020, 2021, 2022].

In the second model group, the deposit age of the Laptev Sea grabens is compared with the known Cenozoic graben-like depressions on the adjacent land. For example, the latter filled with Cenozoic deposits are described on the Kotelny and Belkovsky islands [Kuzmichev et al., 2013; Ershova et al., 2022]. The continental frame of the Laptev Sea contains a series of superimposed graben-like depressions filled with Paleocene and Eocene deposits [Grinenko et al., 1989]. According to this model group, the formation of the rift troughs of the Laptev Sea basin began in the Late Cretaceous (Maastrichtian?) – Paleocene [Drachev et al., 1998, 2010; Franke et al., 2000, 2001; Franke and Hinz, 2009; Drachev and Shkarubo, 2017]. As assumed in [Kuzmichev et al., 2013] and [Ershova et al., 2022], the filling of the rift basins of the Laptev Sea adjacent to the Belkovsky and Kotelny islands should be categorized as Eocene and Oligocene.

Drilling data from the polar part of the Lomonosov Ridge as part of the 2004 Arctic Coring Expedition (ACEX) are additionally used for the stratification of the sedimentary succession [Backman et al., 2008]. Based on the results of the work, a consolidated section of the exposed part of the 428 m thick sedimentary cover at the drilling point was compiled, represented by alternating silts and clays of various compositions and genesis, with rare interbeds and lenses of sand. The age range of the selected sediments is established in an interval between the Late Cretaceous and the Holocene [Backman et al., 2008; Poirier and Hillaire-Marcel, 2011; Chernykh and Krylov, 2017].

It is noteworthy that it is impossible to unambiguously convey the age correlation of seismic horizons along the existing profile network from the ACEX well to the Laptev Sea sedimentary basin due to the fairly large distance of the well from the region under study and sharp changes in the thickness of the sedimentary cover and fault tectonics.

CHARACTERISTICS OF FIELD STUDIES

Shallow stratigraphic wells have been drilled in 2021 as part of the Rosneft project using the Bavenit drilling vessel (Russian geological exploration holding (ROSGEO)) in order to remove key geological uncertainties in the structure of the Laptev Sea shelf, primarily related to the age and composition of sedimentary infills, as well as elements of hydrocarbon systems. All wells were laid within the Anisinsk–Novosibirsk block (Rosneft) located in the north of the New Siberian Archipelago (Fig. 1). A total of six wells were drilled, which exposed from 100 to 199.5 m of sedimentary section, and 415 m of the core was recovered, characterizing various stratigraphic sequences (Figs. 2 and 3). Moreover, during the field studies, high-resolution shallow engineering seismic survey was carried out on profiles passing through the planned drilling points of stratigraphic wells to increase the resolution of the seismic image of the upper part of the section. Shallow wells were laid at different points of the block to possibly characterize the entire section of the sedimentary cover from the surface of the folded basement (with exposure of the latter). The vessels used for

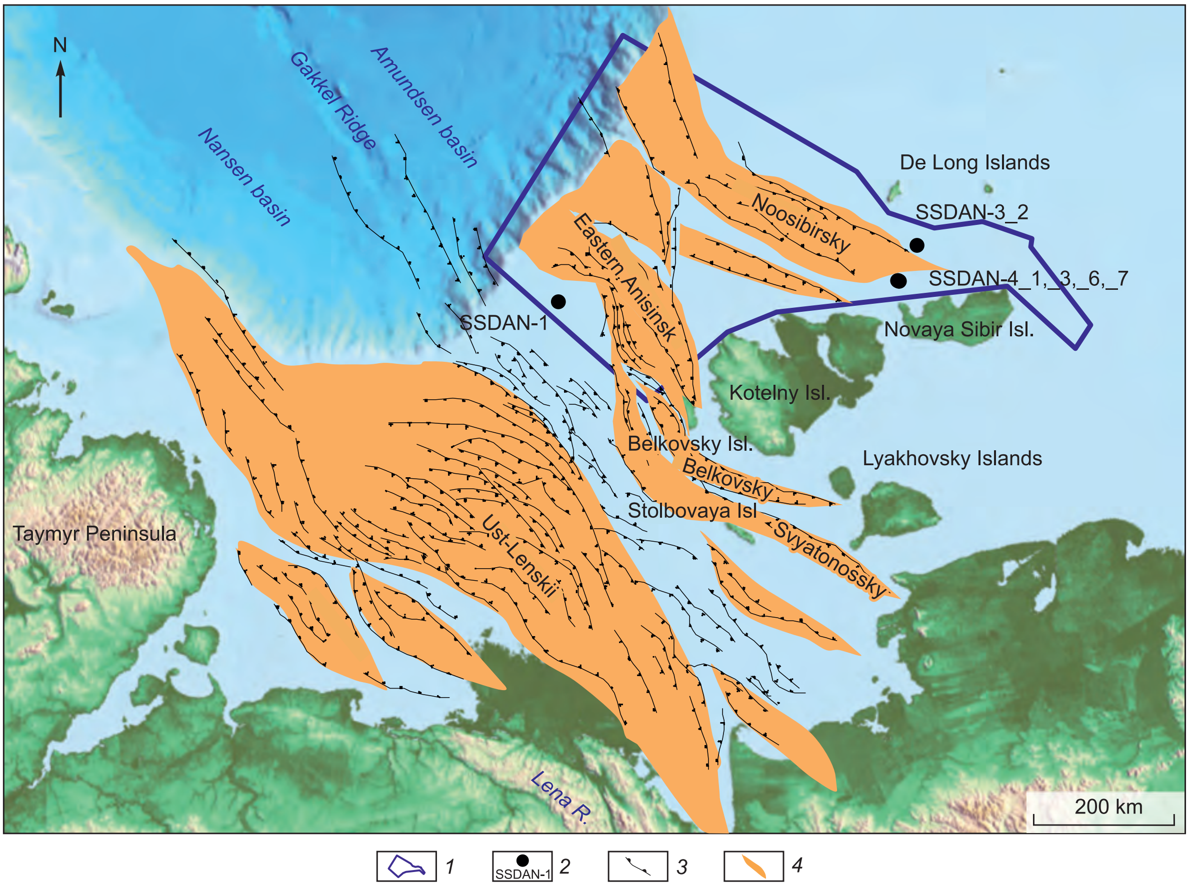


Fig. 1. Map showing the main structural elements of the Laptev Sea region, compiled using data from [Drachev and Shkarubo, 2017; Nikishin et al., 2019] and materials of the Arctic Research Center of Rosneft. *1* – outline of the Anisinsk-Novosibirsk block, *2* – well and its number, *3* – normal faults, *4* – rift basins.

engineering and geophysical work are Kapitan Voronin (from September 24 to October 13, 2020) and Kern (from September 10 to September 15, 2021).

In view of the shallow depths of the wells in the field study region (the holes made in the ground are a few hundred meters deep), a set of seismic survey studies used in engineering and geological practice is carried out. The following types of operations are performed simultaneously (in one pass of the vessel): bathymetric survey with a multibeam echosounder, side-scan sonar, high-frequency continuous seismoacoustic profiling, and two-dimensional ultra-high-resolution seismic survey (2D-UHR) with a near-surface seismic streamer.

RESULTS

The well sections are represented mainly by loose, subhorizontal, weakly consolidated clastic sediments. Two wells (SSDAN-4_1 and SSDAN-4_3) expose inclined (monoclinally) deposits in the lower parts of the section, represented by argillites and siltstones with subordinate interbeds of fine-grained sandstone.

Palynological analysis is performed to determine the age of the rocks from the core of all wells, and foraminifera are identified in well SSDAN-1. As a result of these studies, the presence of Lower Cretaceous, Paleogene, and Neogene-Quaternary sediments is identified in the well sections (Fig. 2).

Foraminifera. The SSDAN-1 samples contain 59 species of foraminifera, including 16 species of agglutinating forms and 43 calcareous ones. Planktonic foraminifera are not identified in any sample. According to the systematic composition of foraminifera, the well section is clearly divided into two parts: the lower part that contains only agglutinating forms and the middle and upper parts with a calcareous shell. Foraminifera assemblages are poor in both species composition and the number of shells in the sediment. The shells are generally well preserved, so their species can be identified.

Seven foraminifera assemblages are found in well SSDAN-1 (Fig. 2). The lowermost part of the section contains the FC-I assemblage, consisting only of agglutinating taxa, such as *Hemisphaerammina apta*, *Placentammina placenta*, *Haplophragmoides excavatus*, *H. walteri*, *H. horridus*, *Reticulophragmium amplectens*, *Cyclammina pusilla*, *Gravellina dawsoni*, *Verneuilinoides paleogenicus*, *Annectina grzybowskii*, etc. Determining the age of *Hemisphaerammina apta* seems to be of greatest interest. This opportunistic species is endemic to the Arctic and has a narrow stratigraphic distribution interval [McNeil and Neville, 2018]. It inhabited the Arctic seas after the Paleocene-Eocene temperature maximum (PETM) and existed until the *Azolla* event, i.e., the flourishing of the *Azolla* aquatic fern in the Arctic Ocean. Therefore, the lowermost part of the section is assigned to the Ypresian stage of the Lower Eocene.

The overlying assemblage FC-II with *Reticulophragmium amplectens* has a significantly less diverse composition as compared to FC-I, but all the encountered species pass from the underlying assemblage. The FC-III assemblage with *Elphidiella brunnescens* is presumably dated to the Early Oligocene, and the younger FC-IV assemblage with *Turrillina alsatica* is dated to the Late Oligocene. The rocks identified higher in the section contain foraminiferal assemblages that correspond to the lower (FC-V with *Asterigerina guerichii*) and Middle-Upper (?) (FC-VI with *Elphidiella groenlandica*) Miocene. The FC-VII Pleistocene assemblage with *Cribroelphidium clavatum* is identified at the uppermost section.

Palynological assemblages. The earliest stratigraphic interval identified in the wells drilled at the Anisinsk-Novosibirsk block (SSDAN-4_1 and 4-3) is represented

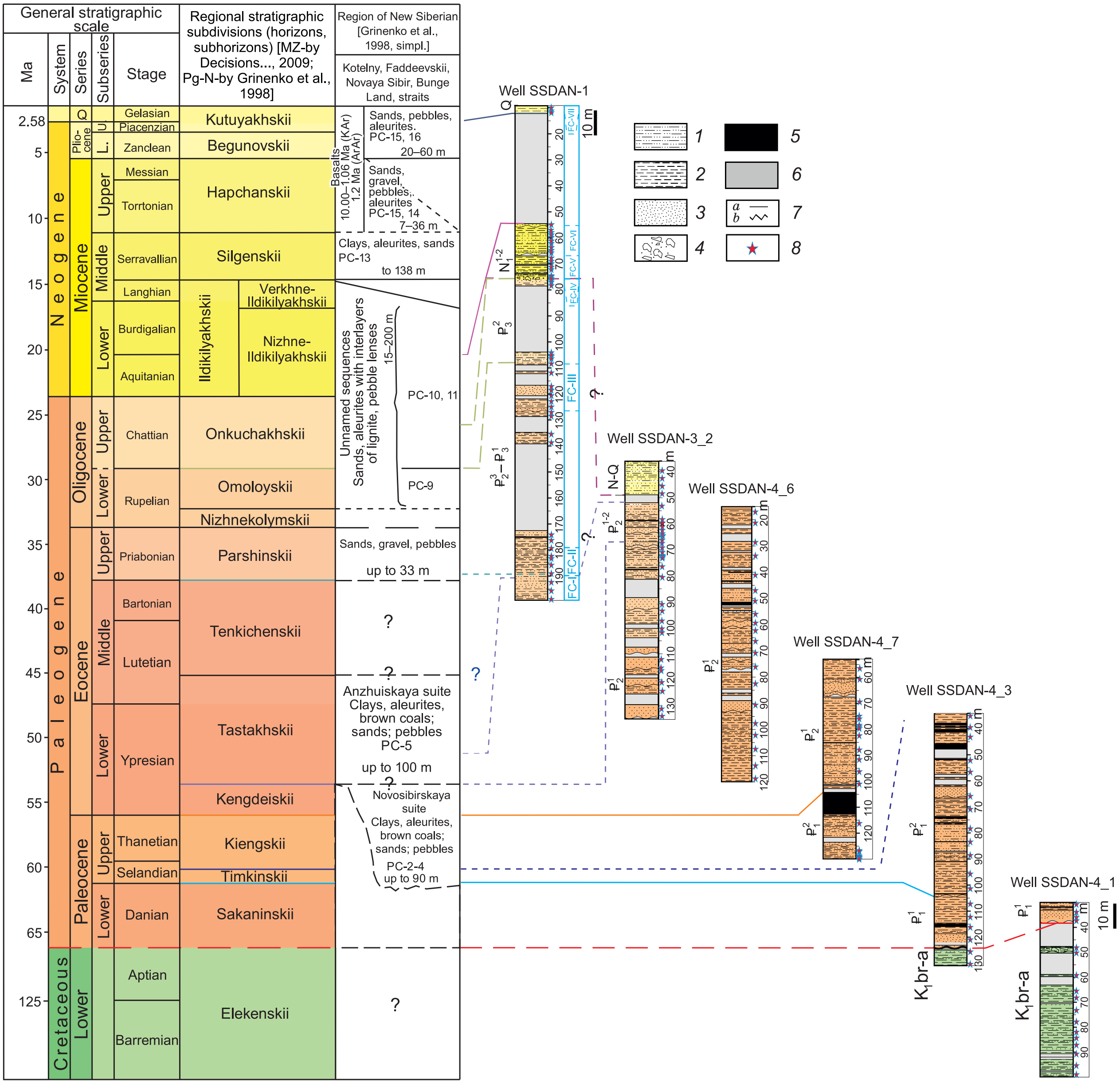


Fig. 2. Correlation of the shallow stratigraphic wells. *1* – Silts, siltstones; *2* – clays, mudstones; *3* – sands, sandstones; *4* – breccias; *5* – coals; *6* – intervals of the section without coring; *7* – boundaries: *a*, conformable; *b*, erosional. Meters below the sea bottom. PA is a palynological assemblage and its number in the regional stratigraphic chart [Grinenko et al., 1998]. The colors on the columns show the correlation of intervals of the well section with the regional strata. The foraminifer assemblages (FC-I–FC-VII) described in the text are marked in blue color to the right of well SSDAN-1.

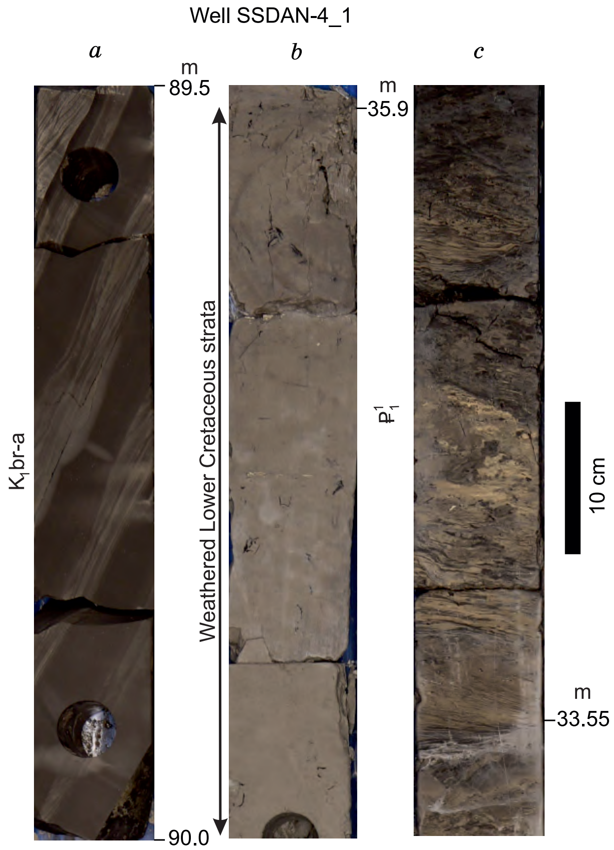


Fig. 3. Photographs of the core of well SSDAN-4_1: *a* – deformed Upper Barremian – Lower Aptian sediments represented by interbedded siltstones and mudstones (interval 89.5–90 m); *b* – weathering crust on the Lower Cretaceous sediments composed of massive brown clays with fragments of plant roots (interval 35.9–36.4 m); *c* – the Lower Paleocene sediments represented by a member of sand and siltstone interbedding with coal detritus enriched laminae (interval 33.1–33.55 m).

by steepy inclined strata below the top of the folded basement. The lower part of the section of well SSDAN-4_3 and the larger part of the cored section of well SSDAN-4_1 contain an Upper Barremian – Lower Aptian palynoassemblage most fully represented in the section of well SSDAN-4_1 (Fig. 3).

The palynomorphs identified in this assemblage are quite poorly preserved. Spores and pollen dominate among them (more than 85%). Most samples contain dinocysts, but their content is low (0.7–12.6%). The assemblage of spores and pollen is characterized by the absence of angiosperms and the dominance of bisaccate pollen of gymnosperms (Disaccites). The following dinocysts are identified: *Apteodinium* sp., *Aptea polymorpha*, *Batioladinium* spp. (*B. longicornutum*, *B.* cf. *exguum*, *B.* cf. *jaegeri*, *B.* cf. *reticulatum*, *B.* sp.), *Gardodinium trabeculosum*, *Gardodinium* sp., *Odontochitina* spp. *(O. nuda*, *O. operculata*), *Oligosphaeridium complex*, *Palaeoperidinium cretaceum*, *Pseudoceratium anaphrissum*, *Pseudoceratium* sp., *Circulodinium* sp., *Cribroperidinium* cf. *cornutum*, *Cribroperidinium* sp., *Florentinia* sp., *Hystrichosphaeridium* sp., *Kallosphaeridium* sp., and reworked *Nannoceratopsis deflandrei* and *Phallocysta* sp. The joint occurrence of the species *P. cretaceum*, *O operculata*, *O. nuda*, *G. trabeculosum*, and *O. complex* in the high latitudes of the Northern Hemisphere varies in an interval from the Barremian to the Albian [Brideaux, 1977; Århus, 1991; Nøhr-Hansen and McIntyre, 1998; Galloway et al., 2022]. The distribution of *O. nuda* in the Greenland sections is limited to the Upper Barremian – Lower Aptin, and the vanishing of *B. longicornutum* is recorded in the uppermost Barremian [Nøhr-Hansen, 1993, 2019]. Similar dates are obtained in high-latitude sections of Spitsbergen and northern Norway [Śliwińska et al., 2020; Smelror, 2021]. As suggested by the dinocyst data, the sequences are dated to the Late Barremian – Early Aptian.

The palynoassemblage of the Sakaninskii horizon of the Lower Paleocene of Northeastern Russia is identified higher in the sections of wells SSDAN-4_3 (interval 120.7-112.24 m) and SSDAN-4_1 (interval 37.77-30.64 m) [Fradkina, 1995; Grinenko et al., 1998] (Figs. 2, 3). Single dinocysts of *Apteodinium sp*., *Batiacasphaera sp*., and *Membranosphaera maastrichtica*, having a wide stratigraphic age; occur in some intervals of the section.

The overlying rocks in the SSDAN-4_3 section (interval 107.5-39.1 m) are characterized by the spore-pollen assemblage of the Timkinsky horizon of North-East Russia, comparable with the lower part of the Upper Paleocene [Fradkina, 1995; Grinenko et al., 1998] (Fig. 2). Dinocysts are present in single quantities (0.3–0.4%) in the lower part of the section.

Higher Paleocene horizons are exposed in the lower part of the SSDAN-4_7 section (interval 129.67–115.2 m) and are characterized by the palynological assemblage of the Kiengskii horizon of North-East Russia, comparable with the uppermost Upper Paleocene [Fradkina, 1995; Grinenko et al., 1998] (Fig. 2). The palynological association is characterized by the dominance of spores and pollen (94–98%). Dinocysts and acritarchs are not identified, the content of green algae ranges from 4.9 to 1.7%, and the content of fungal fruiting bodies, spores, and hyphae ranges from 0.4 to 3.9%.

Wells SSDAN-4_7 (interval 100.38-56.77 m), SSDAN-4_6 (interval 119.9–15.85 m), SSDAN-3_2 (interval 134.91-70.09 m), and SSDAN-1 (interval 199.36–188.95 m) reveal the palynoassemblage of the Kengdei horizon of northeastern Russia, comparable with the lower part of the Lower Eocene [Fradkina, 1995; Grinenko et al., 1998] (Fig. 2). The palynological association is characterized by the dominance of plant spores and pollen (74.3–95.4%). Dinocysts and green algae are constantly present in small quantities (a maximum of 19.7% of the sum of all palynomorphs); also, single acritarchs and scolecodonts are identified. The amount of fungal fruiting bodies, spores, and hyphae ranges from 3.1 to 10%.

The spore-pollen assemblage of the Kengdeiskii horizon is close to the assemblage from an interval of 330.01–380.38 mcd in the section of well M0004A on the Lomonosov Ridge [Willard et al., 2019; Suc et al., 2020], as well as partially to the palynospectra identified on the Faddeevsky Peninsula [Suan et al., 2017], in the lower reaches of the Lena River [Bondarenko and Utescher, 2022], and palynozones **I** and **H** from the Margaret Formation in Arctic Canada [Sudermann et al., 2021]. All of them are dated to the Early Eocene. In the Beaufort-Mackenzie Basin, spectra similar to the Kengdei palynoassemblage characterize the time interval from the Early Eocene part of the Aklak Sequence to the lowermost Middle Eocene Richards Sequence [Norris, 1986, 1997; McNeil and Parsons, 2013].

At this level the maximum number and diversity of dinocysts among which peridinioid taxa predominate quantitatively is revealed (*Saeptodinium* sp., *Apectodinium parvum*, *Apectodinium homomorphum*, *Apectodinium* sp., *Cerodinium sibiricum*, *Cerodinium* sp., *Lejeunecysta hyalina*, *Lejeunecysta* sp., *Senegalinium* cf. *dylwinense*, *Senegalinium* cf. *obscurum*, *Senegalinium* sp., *Wetzeliella* (*Dracodinium*) cf. *astra*, *Wetzeliella* aff. *articulata*-group, *Wetzeliella* (*Stenodinium*) *meckelfeldensis*, *Wetzeliella* sp., et al.). The abundance and diversity of heterotrophic taxa indicate strongly desalinated paleoenvironments at this age. Goniaulacoid taxa are relatively diverse, but their number is small. They are represented by *Achomosphaera sagena*, *Achomosphaera* sp., *Areoligera* sp., *Dioxya pignerata*, *Elytrocysta druggii*, *Glaphyrocysta ordinata*, *Hystrichisphaeridium tubiferum*, *Membranosphaera* sp., cf. *Caligodinium* sp., *Cometodinium* sp., *Spinidinium* sp., *Spinidinium* cf. *densispinatum*, *Spiniferites* sp., *Thalassiphora delicata*, *Tectatodinium pellitum*, *Tectatodinium* sp., *Operculodinium* cf. *microtrianium*, *Operculodinium* sp., *Palaeocystodinium lidiae*, and unidentifiable forms.

In well SSDAN-1, in the Early Eocene foraminiferal assemblage FC-I with *H. apta*, dinocysts are dominated by *Phelodinium* sp. A and *Senegalinium* cf. *obscurum*, while *Spiniferites sp.* and *Impagidinium sp.* are relatively common. They are accompanied by rare *Cerodinium depressum*, *Dioxya pignerata*, *Lejeunecysta* spp., *Batiacasphaera* spp., *Pthnanoperidinium obscurum*, *Selenopemphix* spp., *Cometodinium comatum*, and *Phthanoperidinium* sp.

The frequent presence and diversity of peridinioid dinocyst taxa found in the sections of the studied wells suggest that these associations are closer to those identified in the Early-Middle Eocene part of the section of well M0004A on the Lomonosov Ridge [Backman et al., 2006; Sluijs et al., 2008, 2009]. The dinocyst assemblage identified in wells SSDAN-4_7, SSDAN-4_6, and SSDAN-3_2 can also be compared with the Wetzeliella articulate – Cordosphaeridium Zone from the Beaufort-Mackenzie Basin, which is dated to the Early-Middle Eocene [Harrison et al., 1999].

The spore-pollen spectra of the uppermost well SSDAN-3_Fradkina2 (interval 68.6–48.54 m) are somewhat conventionally attributed to the palynoassemblage of the Tastakhskii horizon of the second half of the Lower – the first half of the Middle Eocene [Grinenko et al., 1998] (Fig. 2). They are characterized by an abundance and quite high diversity of angiosperm pollen, including the most thermophilic evergreen plants. Dinocysts (0.4–6.4%) and prasinophytes (1.8–6%) are rare, and the content of each of them exceeds 10% only at certain assemblages. Heterotrophic taxa still predominate in the dinocyst composition.

Biostratigraphic data from the middle and upper parts of well SSDAN-1 are observed as isolated assemblages, which prevents one from obtaining a continuous change in foraminiferal assemblages and palynoassemblages. According to palynological data, the spore-pollen assemblage established at the FC-II assemblage with *R. amplectens* of the Middle (?) – Upper Eocene (interval 185.8–179.1 m) corresponds to the palynoassemblage of the Parshinskii horizon of northeastern Russia of the second half of the Middle – the first half of the Upper Eocene [Fradkina, 1995; Grinenko et al., 1998]. The taxonomic composition of dinocysts in this assemblage changes sharply: *Komewuia sp.* is abundant at the very bottom and absent higher up, and there are rare, often single samples of *Phelodinium* sp. A, *Senegalinium* sp., and *Batiacasphaera* sp.

Palynological data indicate that well SSDAN-1 contains no palynoassemblages of the Tastakhskii and Tenkichenskii horizons [Fradkina, 1995; Grinenko et al., 1998] (Fig. 2), which suggests the presence of a hiatus in the section, covering the uppermost Early – lowermost Middle Eocene. The foraminifers also suggest the existence of this hiatus, but its extent is unclear and requires confirmation.

The spore-pollen assemblage in an interval of 176.4–119.1 m of the section, whose upper part is characterized by the FC-III foraminiferal assemblage, is similar to the palynoassemblages of the Atlymskii and Novomikhailovskii horizons of Western Siberia, the Omoloiskii horizon of the territory of northeastern Russia and the Siberian platform [Fradkina, 1995; Oshurkova et al., 1990; Volkova et al., 2002]. This also attributes the sequences to the Early Oligocene.

The spore-pollen assemblage from the overlying rock strata in well SSDAN-1 (interval 117.5-76.84 m), containing the FC-IV Upper Oligocene foraminiferal assemblage with *Turillina alsatica* in its upper part, corresponds to the palynoassemblage of the Zhuravskii horizon of Western Siberia and its analogs in northeastern Russia in terms of systematic composition and quantitative characteristics and is attributed to the first half of the Late Oligocene [Panova, 1971; Oshurkova et al., 1990; Volkova et al., 2002]. Dinocysts are identified in some samples, and their content is very small: 0.8–3.8% of the total of all palynomorphs. At the same time, there are mainly unidentifiable destroyed forms, as well as *Pthnanoperidinium* sp. 1, *Operculodinium centrocarpum*, *Operculodinium* sp., *Lejeunecysta* sp., which do not provide specific ages.

There are diverse dinocysts in well SSDAN-1 in an interval of 76.4–54.9 m, which is characterized by the FC-V foraminiferal assemblages with *A. guerichii* and FC-VI with *E. groenlandica* of the Lower-Middle Miocene. The assemblage is characterized by the presence of *Lejeunecysta* sp., *Batiacasphaera* spp., *Cleistosphaeridium placacanthum*, *Gelatia* sp., *Heteraulacacysta campanula*, *Hystrichosphaeropsis complanata – Hystrichosphaeropsis obscura* group, *Impagidinium* spp., *Labyrinthodinium truncatum*, *Lingulodinium machaerophorum*, *Operculodinium* spp., *Votadinium* sp., *Palaeocystodimium golzowense*, *Palaeocystodimium* cf. *miocaenicum*, *Spiniferies* spp., *Tuberculodinium vancampoae*, and brown spherical shells related to the protoperidinioid genus *Brigantedinium*. Some taxa are not identified due to poor preservation.

In general, this interval of the section can be compared with Unit ¼, which is a part of Unit 3 in well M0002A on the Lomonosov Ridge, which, according to the study of dinocysts and foraminifers, belongs to the Early-Middle Miocene [Sangiorgi et al., 2008; Kaminski et al., 2009]. The comparison of the dinocyst assemblage from well SSDAN-1 shows that the stratigraphic interval of joint occurrence of dinocysts *H. complanata – H. obscura* group, *L. truncatum*, *P. golzowense*, and *P.* cf. *miocaenicum* in the zonal scale of northwestern Europe covers the Burdigalian – Middle Tortonian interval [King, 2016]. These data indicate the presence of of a gap in sedimentation, covering the stratigraphic interval of the uppermost Late Oligocene – lowermost Early Miocene, which is confirmed by the presence of conglomeratobreccia and phosphorites in well SSDAN-1.

The uppermost part of well SSDAN-1 consists of the sediments characterized by a Pleistocene spore-pollen assemblage, which reconstructs tundra landscapes with a predominance of herbaceous groups (grass, grass-sedge, and grass-forb).

DISCUSSION

Before stratigraphic drilling, the interpretation of 2D seismic profiles for the Anisinsk-Novosibirsk region used to be performed with account for data on the geological structure of the surrounding continental land and the New Siberian Islands (see above). The basic model was assumed to be that the Late Mesozoic folded basement, including sedimentary successions from the Ordovician to the Neocomian (pre-Aptian folded basement), is overlain by sedimentary rocks in the Aptian-Albian – Upper Cretaceous – Cenozoic stratigraphic range with a sharp angular unconformity. The Zhokhov foredeep was identified recently [Nikishin et al., 2022] in the region of the shelf section under study immediately to the north of the Novaya Sibir Island. This foredeep developed ahead of the front of the Late Mesozoics of the Novosibirsk-Chukotka folded system and was filled presumably with Upper Jurassic – Barremian sediments. It was accordingly assumed that the accumulation of the postfold cover here also began since the Aptian age of the Early Cretaceous [Nikishin et al., 2022]. The stratigraphic drilling carried out in 2021 by Rosneft for the first time made it possible to obtain direct geological data on the age and composition of shelf sediments in the northeastern sector of the Laptev Sea. Wells to seismic tie allowed to use obtained data to date main seismic stratigraphic units.

Based on the results obtained, it becomes possible already at this stage to expand and correct the earlier model concepts of the geological structure and the development stages of the studied Laptev Sea region and part of the adjacent northwestern waters of the East Siberian Sea.

Seismostratigraphic observations in 2D seismic survey data suggest that the Anisinsk–Novosibirsk block studied by stratigraphic drilling is comprised of two structural complexes: a folded basement and an unconformably overlapping cover separated by a surface of clearly expressed angular unconformity (RH Fa). The bottom complex is characterized by inclined (monoclinally lying) and wavy (crumpled into folds) reflector packages and regions that contain no regular seismic records. Moreover, there are closely spaced blocks with a wave pattern that is sharply discordant with respect to each other, thereby indicating tectonic contacts between them. The angles of incidence of reflectors vary from a few degrees on individual monoclines to 40° and more on fold limbs, with coherent reflections vanishing at large angles. The RH Fa surface cuts off all elements of the internal (deformation) structure of the bottom assemblage and corresponds to the regional erosional boundary. All of this indicates that this assemblage exhibits a seismic image characteristic of regions of fold-thrust tectonics. Accordingly, the bottom assemblage itself belongs to the folded basement overlapped by the overlying sedimentary complex, which is characterized by fundamentally different seismic stratigraphy and tectonics.

Seismic stratigraphy suggests that the section of the Anisinsk–Novosibirsk sedimentary assemblage is comprised of two structural stages separated by boundary I (RH confined to Upper Miocene deposits). Three reflecting horizons filling the rift basins are correlated within the lower structural tier: RH IV at the base of the Eocene deposits, RH III within the Eocene deposits, and RH II at the base of the Miocene strata. The top structural tier (Upper Miocene–Pleistocene) overlaps the underlying deposits in a mantle-like manner. The main part of the identified tectonic faults that mostly represent normal faults with a visible displacement amplitude cannot be traced above RH I. At the same time, the seismic unit of the Upper Miocene (?) – Quaternary deposits seems to have signs of low-amplitude displacements for individual

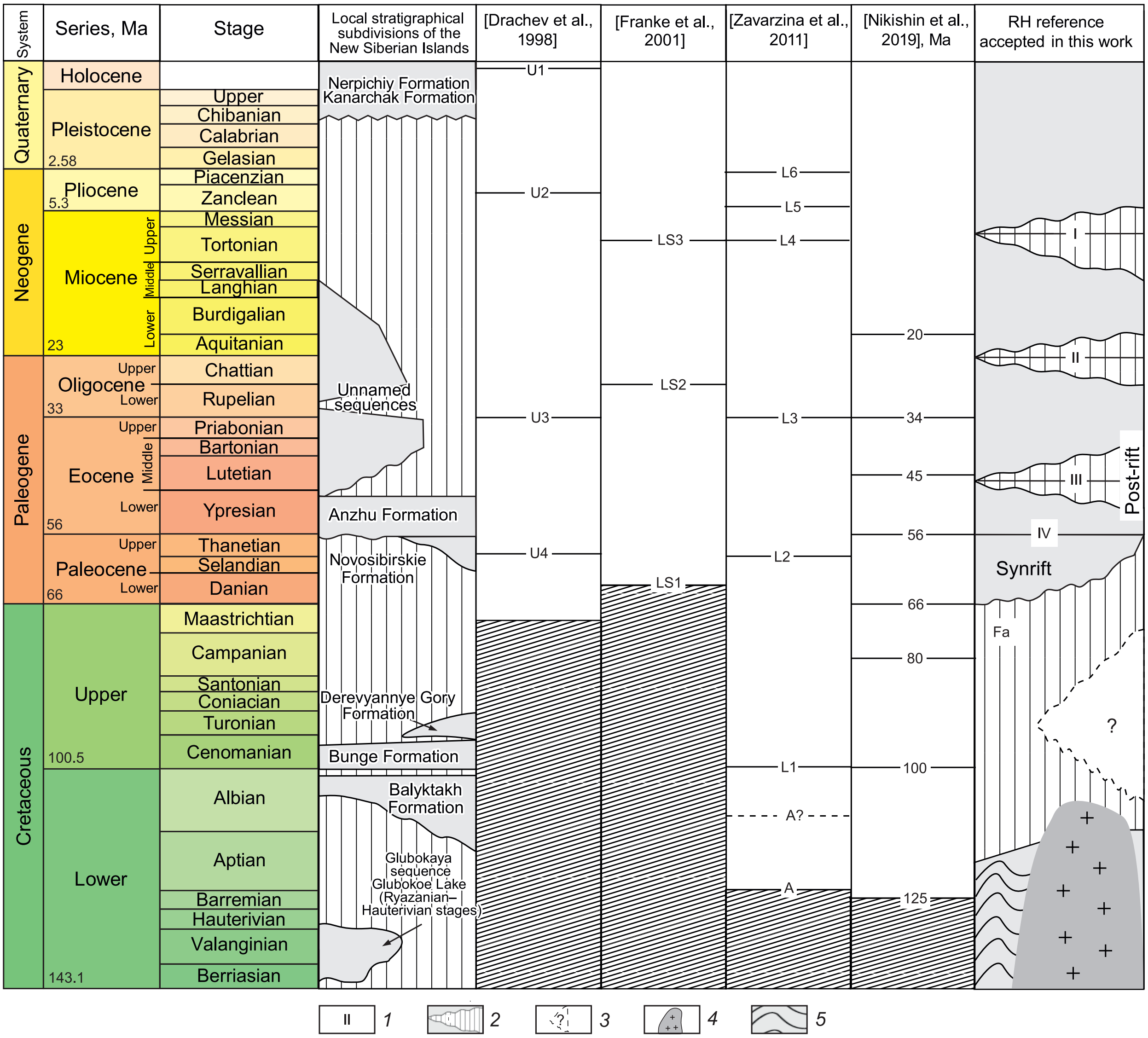


Fig. 4. Comparison of the seismic stratigraphy of the Laptev Sea region according to [Drachev et al., 1998; Franke et al., 2001; Zavarzina and Shkarubo, 2012; Nikishin et al., 2019] with the one adopted in this work for the northeastern Laptev Sea on the basis of the shallow drilling results. *1*– reflecting horizon index, *2* – sedimentation gap, *3* – assumed sedimentary assemblages, *4* – Aptian-Albian granitoids of the Bolshoy Lakhovsky Island, *5* – deformed succession (Barremian-Lower Aptian).

faults and indirect signs of the presence of faults: for example, anomalies, such as gas pipes above faults in the underlying assemblages, differences in the amplitudes of seismic reflections on fault branches, and the presence of anomalous forms of the bottom relief (Neptunian structures?), etc. Apparently, these features reflect the modern tectonic activity of the studied segment of the Laptev Sea shelf, also recorded by modern seismological observations [Avetisov, 2002; Imaeva et al., 2016; Krylov et al., 2022]. Thus, five seismic units are distinguished in the section separated by four regionally consistent reflecting horizons (IV, III, II, and I; Figs. 4–6).

The rocks of the folded basement are recovered in wells SSDAN-4_1 and SSDAN-4_3 at depths of 49.13 m and 123.85 m, respectively. They are represented by the Early Cretaceous, Late Barremian – Early Aptian clastic formations (the earliest of those recovered), which are heavily weathered in the top and fractured. The Lower Paleocene continental clastic formations are located on them with a sharp angular unconformity.

In well SSDAN-4_1, the core has no direct contact with the overlying deposits, but there is significant angular unconformity. Particularly, the dip angles of the Upper Barremian – Lower Aptian deposits measured by the well core reach 60 degrees against the background of nearly horizontal overlying beds (Fig. 3). In SSDAN-4_3, the bedding angles of the Upper Barremian – Lower Aptian deposits do not exceed three degrees, but the boundary with the overlying Paleocene deposits has a clear erosional contact with a pocket filled with gravel and peb-

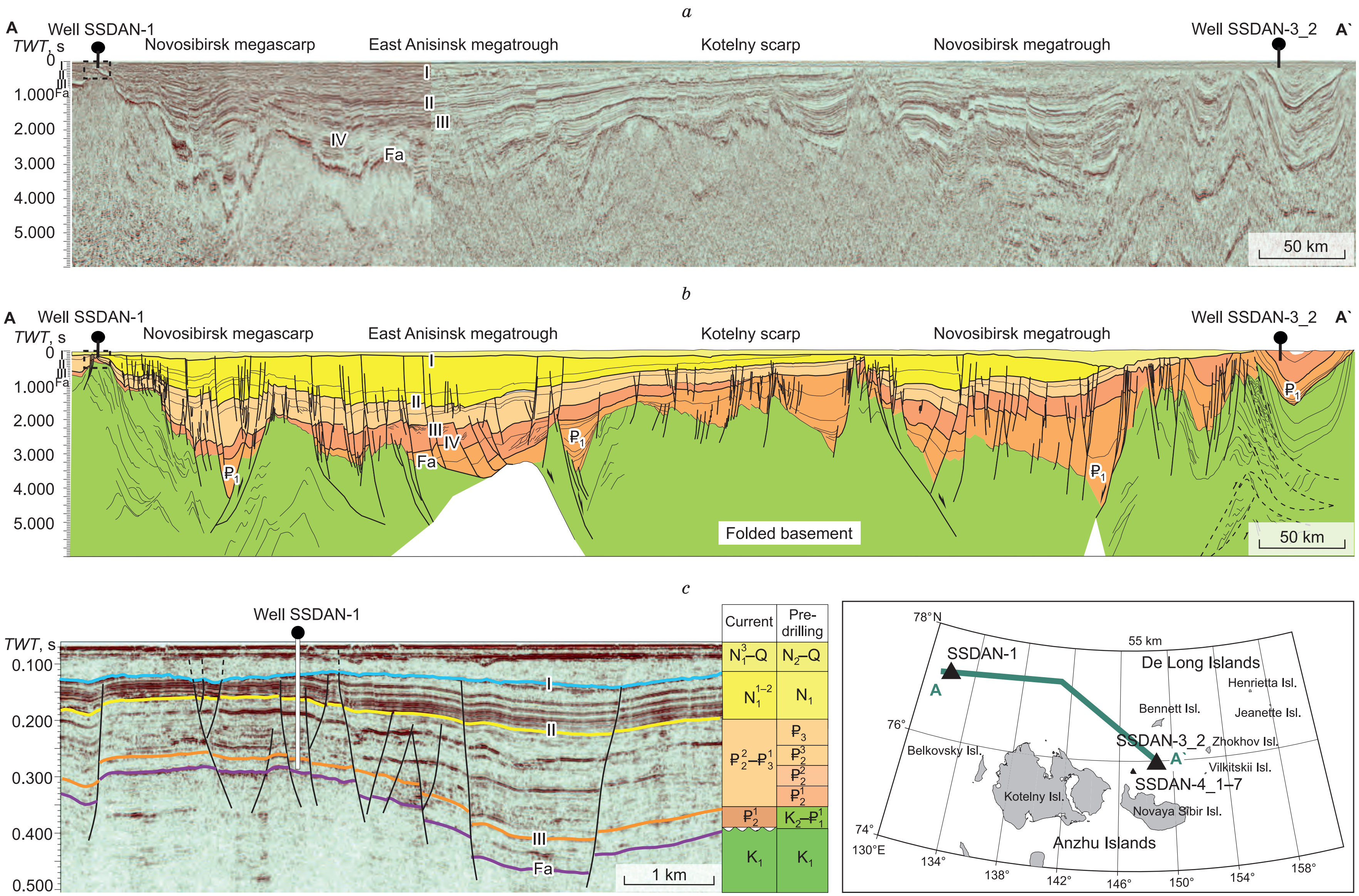
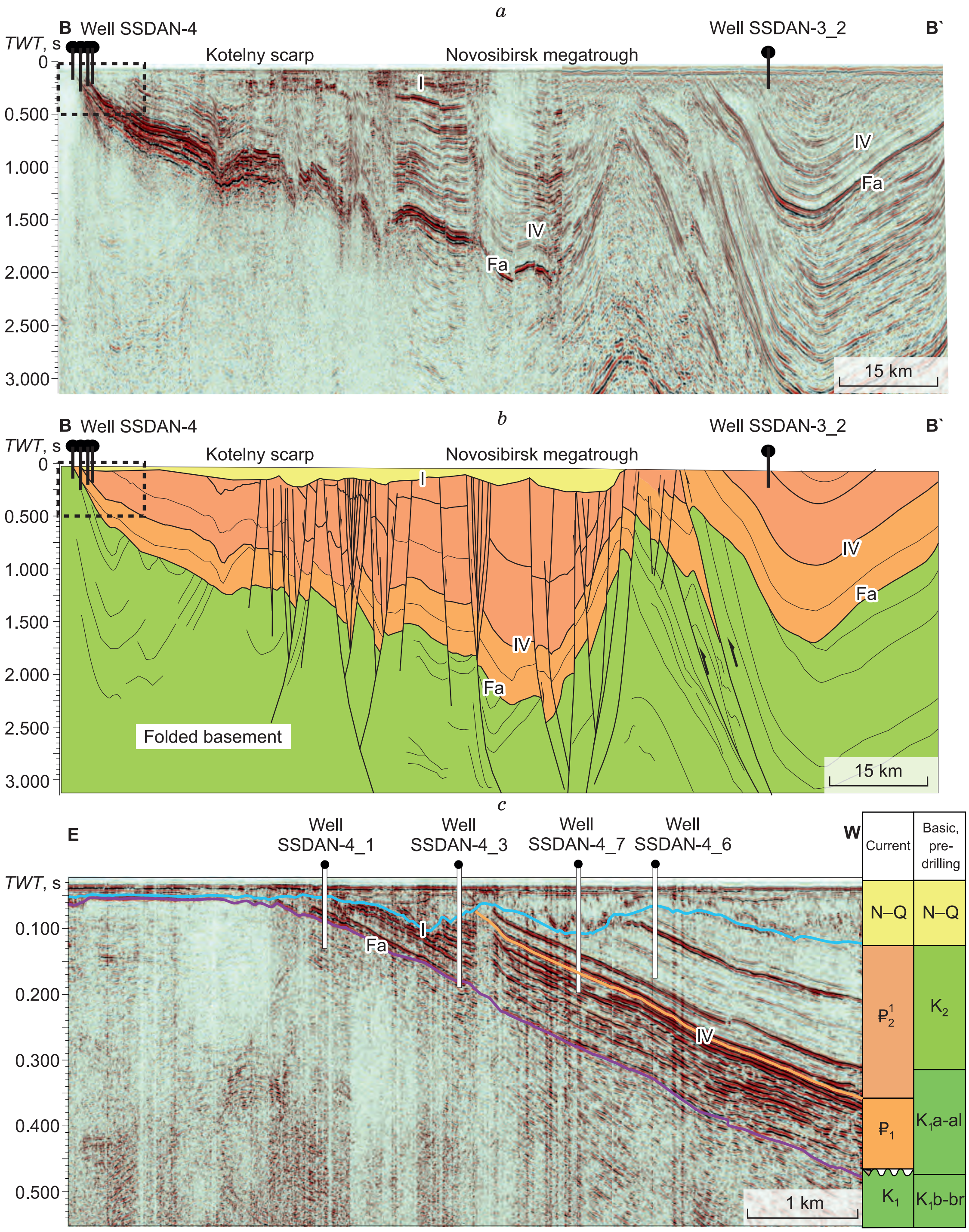


Fig. 5. *a* – 2D seismic image along the A–A’ line, *2* – interpretation profile along the A–A’ line, *3* – 2D UHR seismic image through well SSDAN-1 (see location in the left part of the interpretation profile) with interpretation of the key reflectors and their stratigraphic reference based on the current results of the analysis of shallow drilling data in comparison with the base model made before drilling (columns in the right part of the figure). Here and in Fig. 6, the dashed frame shows the position of the UHR proline in the inset (*c*), the fault kinematics is denoted by the arrows.



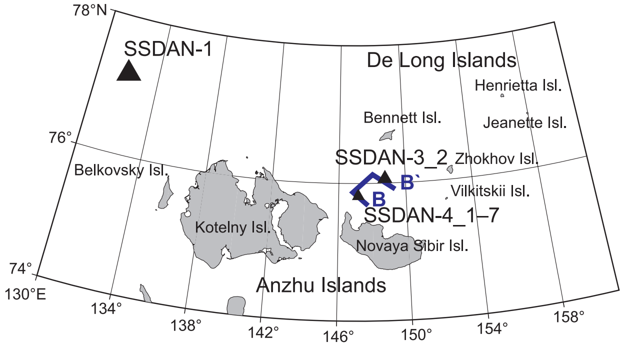


Fig. 6. *a* – 2D CDPM time section along the B-B’ line, *b* – seismogeological profile along the B-B’ line, *c* – super-resolution seismic section through wells SSDAN-4_1, SSDAN-4_3, SSDAN-4_7, and SSDAN-4_6 (see location in the left part of the seismogeological profile) with interpretation of the key reflectors and their stratigraphic reference based on the current results of the analysis of the shallow drilling data in comparison with the base model made before drilling (columns in the right part of the figure).

bles. The material composition of the pre-rift assemblage rocks from both wells is similar, but not identical, and biostratigraphic dates indicate a close composition of the dinocyst and miospore assemblages. The pre-Cenozoic age of the assemblage is reliably recorded by the Lower Paleocene basal beds in the synrift assemblage overlying the angular unconformity.

It is noteworthy that the interpretation of 2D seismic survey data suggests an increase in the thickness of the pre-Cenozoic section with distance from drilling points (Fig. 6) toward the northwest, which allows one to assume that it also contains more recent (relative to the dated sequence) rocks of the Lower (?) Cretaceous. The thickness of the strata superimposed on the exposed section of the Lower Cretaceous rocks is at least 250 ms (more than 400 m). This part of the stratified thickness of the folded basement rocks does not contain any angular unconformities that could be compared with the unconformity at the base of the Balykhtakh Formation of the Upper Aptian-Albian of the Kotelny Island. Accordingly, it is conditionally accepted that the folded basement rocks overlying the Upper Barremian – Lower Aptian are also not more recent than the Early Aptian.

Thus, the continuation of the Late Mesozoic folded strata to the north of the New Siberian Archipelago is confirmed for the first time by direct geological data and it is shown that its final formation does not predate the Early Aptian. Taking into account the age of the Post-deformational granitoids, the earliest of which are dated to the Middle Aptian, which is approximately 117 Ma [Katkov et al., 2007; Luchitskaya and Sokolov, 2021], this conclusion indicates the completion of the final phase of collision processes in the Novosibirsk–Chukotka fold-thrust belt at the beginning of the Aptian. The earliest known U-Pb zircon dating of the post-deformational Shalaurov pluton on the Bolshoy Lyakhovsky Island corresponds to 121.2 ± 2.4 Ma [Kuzmichev et al., 2009b], which approximately corresponds to the Barremian–Aptian boundary. As indicated in a few recent studies [Kuzmichev et al., 2009a, 2018; Nikitenko et al., 2017], the post-deformational Lower Cretaceous sequence of the Kotelny Island began to accumulate only at the end of the Aptian and is predominantly Albian (first half).

The most recent deposits involved in collisional compressional deformations used to be dated within the South Anyui Suture as Hauterivian, i.e., ~131 Ma [Bondarenko et al., 2002]. Our dating of the most recent rocks of the folded basement (Early Aptian) marks the lower age limit of its formation in the region. This result is in good agreement with the date of the uplift of the western part of the Anzhu Islands, which, according to low-temperature thermochronology, was determined as ~125–93 Ma, i.e., the Barremian–Turonian [Prokopiev et al., 2018].

The sediment succession occurring at the base of the cover and bordered by RH IV at the top is characterized by the wide development of normal faults and by syntectonic filling of the associated grabens and halfgrabens (Figs. 5 and 6). The amplitude of dislocations on individual faults exceeds hundreds of meters to a few kilometers. The age of this synrift seismic unit between RH Fa and RH IV is determined as Paleocene based on dinocysts and palynological associations. In the sections of wells SSDAN-4_3 and SSDAN-4_1 immediately above RH Fa, there are spore-pollen assemblages of the Sakaninskii horizon of the Lower Paleocene and Timkinskii horizon of the lowermost Upper Paleocene. Well SSDAN-4_7 exposes RH IV, below which the palynological assemblage of the Kiengskii horizon of the uppermost Upper Paleocene is identified. At the base of the overlying unit identified between RH IV and RH III, there are palynological assemblages of the Kengdeiskii horizon of the lowermost Lower Eocene are determined. Thus, RH IV can be categorized as a rift-postrift unconformity and associated with a regional event, which is the onset of spreading in the Eurasian Basin close to the Paleocene–Eocene boundary, about 56 Ma [Nikishin et al., 2014, 2019, 2022; Gaina et al., 2015]. At the same time, the available seismic correlations suggest possible presence of the lowermost Lower Eocene in this unit. The seismic image is characterized by medium- and high-intensity reflections, which is probably associated with the predominantly continental genesis of the sediments identified in our palynological studies and with the presence of coal interbeds and lenses in the well sections. The thickness of this seismic unit varies from a few meters to 3,500 m and more in the central, most deeply submerged parts of the rifts.

The overlying seismic unit distinguished between RH IV and RH III is characterized by intermittent-to-extended reflections and contains individual high-amplitude reflections. Based on the sections exposed by wells SSDAN-1, SSDAN-4_7, SSDAN-4_6, and SSDAN-3_2, this seismic unit is dated to the Early Eocene. The seismic unit may be absent within the uplifts and reaches a thickness of up to 1,100 m in the central parts of the basins.

The seismic unit between RH III and RH II is characterized by various forms of seismic recording: from extended high-amplitude to intermittent reflections. Its maximum thickness reaches 1,000 m. This seismic unit is exposed in the section of well SSDAN-1 and represented by silty-clayey shallow-water marine sediments. The Middle (?) – Upper Eocene foraminifers and the palynoassemblage of the Parshinskii horizon of the second half of the middle and the first half of the upper Eocene is identified here; upward the section, the foraminifers and the palynoassemblage of the Omoloysky horizon of the Lower Oligocene are revealed.

The seismic unit between RH II and RH I is exposed by well SSDAN-1 and dated to the Lower–Middle Miocene foraminiferal assemblages and the dinocysts of the Burdigalian and the middle part of the Tortonian, i.e., the second half of the Early Miocene and the beginning of the Late Miocene. It is represented by extended high-amplitude reflections and characterized by a thickness of up to 1500 m. RH I at the top of the assemblage is an erosional surface with a parallel unconformity and developed incised valleys. The unconformity at the base of the unit is also supported by biostratigraphic data, that show absence of the interval of the uppermost Late Oligocene to the lowermost Early Miocene.

All the listed seismic units are complicated by normal faults (Figs. 5, 6), which indicates the manifestation of a relatively recent extension stage that preceded the formation of the RH I erosion surface.

The youngest seismic unit identified between RH I and the sea floor, is exposed by all the wells, but core sampling is performed only at the top of well SSDAN-1. Here, a Pleistocene palynoassemblage reconstructing tundra landscapes with a predominance of grass pollen and a modern foraminifera assemblage is identified in clay-silt deposits. The seismic unit is characterized by reflections from intermittent to extended. Its thickness varies from 0 to 150 m, reaching 450 m in some regions. The Late Miocene (?) – Quaternary is conventionally accepted to be the age of the rocks of the seismic unit on the basis of the position in the section above the Lower Tortonian and the sharply erosional surface at the base.

It is noteworthy that individual ultra-high-resolution sections (inset in Fig. 6) show that the rocks of the uppermost unit are involved in fairly intense (fold-thrust?) deformations. Apparently, these deformations may be paragenetic to glaciotectonic deformations known on the New Siberian Island and associated with the largest Neopleistocene glaciation [Golionko et al., 2019].

The seismic data interpretation suggests that most of the mapped tectonic faults are listric normal faults with displacement planes flattening out below the top of the acoustic basement. Numerous faults in the Laptev Sea sedimentary basin are the result of the extension associated with the opening of the Eurasian basin, which continued throughout the Cenozoic (or, perhaps, Aptian–Cenozoic?). Based on the seismic data interpretation, the region development history is assumed to have rifting stages, which are apparently associated with the nature of the interaction of the Eurasian and North American plates during the Cretaceous (?) – Cenozoic. According to the stratigraphic drilling results, the sediments filling the rift basins in the region are dated to the Paleocene, so the main, earliest rifting stage must have occurred precisely during this epoch. The post-rift assemblage is dated to the Eocene. The second phase of extension is more recent: Late Miocene (Messinian?) or Pliocene. Its manifestation time is determined by the identified Early Miocene – Tortonian age of the seismic unit between RH II and RH I, displaced by normal and transtensional recent faults. Apparently, the weakly manifested deformations of the most recent seismic unit (RH I is the bottom) reflect the modern tectonic conditions of sublatitudinal extension, particularly expressed by the increased seismicity of the region under study.

The resulting data indicate a significantly greater role of Cenozoic strata in the structure of the sedimentary cover in the northeastern Laptev Sea than previously assumed (Figs. 4 and 6). The obtained core of stratigraphic wells does not contain any Upper Aptian–Albian and Upper Cretaceous post-fold formations known on the New Siberian Islands (see above).

CONCLUSIONS

For the first time, six shallow stratigraphic wells were drilled in the eastern Laptev Sea in 2021, penetrating the section interval 100–199.5 m. The section is composed of mainly silty-clayey clastic sediments. The laboratory operations, analytical studies, and subsequent correlation of the results with the available seismic survey data made it possible to significantly update the existing seismogeological and basin models of the region studied. The results obtained to date lead to the following conclusions.

Firstly, according to the biostratigraphic studies of the core, the oldest rocks penetrated by the wells are the Lower Cretaceous (Upper Barremian – Lower Aptian) deformed strata. This assemblage is represented by silty-clayey sediments being the youngest rocks involved in regional Late Mesozoic (Late Jurassic–Neocomian) compression al deformations. Thus, they are part of the folded basement of the basin in the region studied by stratigraphic drilling. The sedimentary succession of the Lower Paleocene to Pleistocene overlays the Lower Cretaceous with a significant hiatus and angular unconformity.

Secondly, the extension of the Late Mesozoic folded complex to the north of the New Siberian Archipelago is confirmed for the first time by direct geological data. The lower age limit of the formation of the folded basement of the shelf area, corresponding to the Early Aptian, is specified. The resulting data indicate the completion of the final phase of collision processes in the Novosibirsk–Chukotka fold and thrust belt at the beginning of the Aptian, which is well-correlated with the Aptian–Albian age of the post-deformational granites of this belt [Katkov et al., 2007; Luchitskaya and Sokolov, 2021].

Thirdly, the results of the stratigraphic tie to horizons and interpretation results of 2D seismic survey are applied to date the extension phases by direct biostratigraphic methods. As a result, the synrift seismic-stratigraphic sequence of the first, earliest rifting phase is dated to the Paleocene. The post-rift sequence characterized by extension attenuation is dated to the Eocene. Both seismic sections and outcrops on the Kotelny, Novaya Sibir, and Belkovsky islands provide abundant evidence of the second recent phase of extension within the eastern branch of the Laptev Sea rift system. The second intense extension phase is dated to the Messinian – Pliocene interval.

Fourthly, the core of well SSDAN-1 represents two significant depositional gaps corresponding to the most of the Early Eocene to the lowermost Middle Eocene and the uppermost Late Oligocene to the lowermost Early Miocene. It is noteworthy that the absence of angular unconformities in the Paleogene section indicates that the identified depositional gaps are not associated with deformations. Their presence is apparently due to the high position of the studied sections relative to the sedimentation depocenters in the grabens and is also associated with eustatic fluctuations in the sea level.

Finally, the stratigraphic drilling does not reveal presence of sedimentary rocks older than the Upper Barremian – Lower Aptian in the section, which is obviously due to the depth limitation of the shallow drilling technique used [Kolyubakin et al., 2023] and the absence of structures composed of older strata accessible for drilling in the region. The earlier sedimentary formations investigated here for reconstructing the geological history of the region, such as the Late Jurassic–Berriasian turbidites of the Stolbovoy Island, as well as the “deep strata” of the Kotelny Island, have not yet found their seismostratigraphic expression. It is possible that the Volgian–Hauterivian sediments conformably underlie the Barremian–Aptian sediments because no angular unconformities older than the Paleocene base are recorded in the seismic sections. At the same time, regional 2D seismic data do not exclude the possibility of identifying older post-deformational sedimentary successions in the deeper western parts of the Laptev Sea shelf (Aptian–Albian and/or Upper Cretaceous?) than those dated in stratigraphic wells as Early Paleocene. This key issue of regional geology is to be the subject of a separate comprehensive study taking into account the resulting drilling data and detailed seismostratigraphic subdivision of the sedimentary cover of the Laptev Sea shelf.

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