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New insights into the Laptev Sea tectonics

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Abstract

While the Laptev Sea sedimentary basin belonging to the shelfal area of the Arctic Ocean is promising in terms of hydrocarbon discoveries, its geologic complexity hinders petroleum geologic studies and estimation of its hydrocarbon potential. Existing contradictory views about the tectonic framework and evolution of the Laptev Sea cause considerable uncertainties concerning its prospects. The current situation resulting by the fact that our basic understanding of the geology of the Laptev Sea margin was mostly established before 2000 and was based on a limited amount of seismic data, often of compromised quality. Still, recent years have seen the accumulation of a considerable amount of G&G data capable of improving our understanding of the Laptev offshore geology, although it has not been generalized and comprehensively reviewed to date. A unified dataset comprising both historical and newly acquired G&G data created in the course of this project enabled to revise the tectonic framework of the Laptev Sea. The comprehensive review of the information provided a consistent model for the tectonic evolution of the studied territory and clarified some controversial questions.

Key words

Laptev Sea, geology, tectonics, sedimentary basin, Arctic Ocean, hydrocarbon potential, seismic data.

Introduction

While the Laptev Sea is promising in terms of hydrocarbon discoveries among other Arctic offshore areas, its tectonic complexity is much greater, impeding the prediction and estimation of the territory's hydrocarbon potential. A salient feature of the Laptev shelf tectonic position is its location along the boundary between two major Eurasian and North American lithospheric plates that divides this offshore area roughly north to south. In the north the Laptev shelf borders the Nansen-Gakkel rift system. Researchers still have markedly different views about the tectonic nature of this boundary. According to one concept the Laptev Sea is the frontal closure of the rift system (Nikishin et al., 2018), whereas another concept maintains that the tectonic contact goes along the Yenisei-Khatanga transform fault (Shipilov, 2004, 2016; Dor´e et al.,2015), which crosses the offshore area diagonally from the Khatanga Bay in the southwest to the northeast. There is still debate about the location and the character of the boundary between the Laptev Sea Plate and the Siberian Platform (Zavarzina, Shkarubo, 2012; Vasilyeva, 2016). Also, since no deep drilling has taken place on the Laptev offshore, there is still no consensus on the age of the sedimentary cover units and its basement.

The lack of agreement on the key issues regarding the tectonic framework of the Laptev Sea gives rise to numerous and often contradictory hypotheses about its geologic evolution and consequently leads to considerable discrepancy in evaluation of hydrocarbon potential. The problem is the basic understanding of the Laptev Sea geological structure declared before 2000 was based on limited seismic data, often of compromised quality. However, in the past 15 years the Laptev Sea shelf has seen a considerable amount of geologic exploration and new large seismic datasets have been obtained (Fig. 1, 2). By early 2022, the density of seismic lines in the Laptev Sea raised up to 0.11 km/sq.km proving a completion of regional studies.

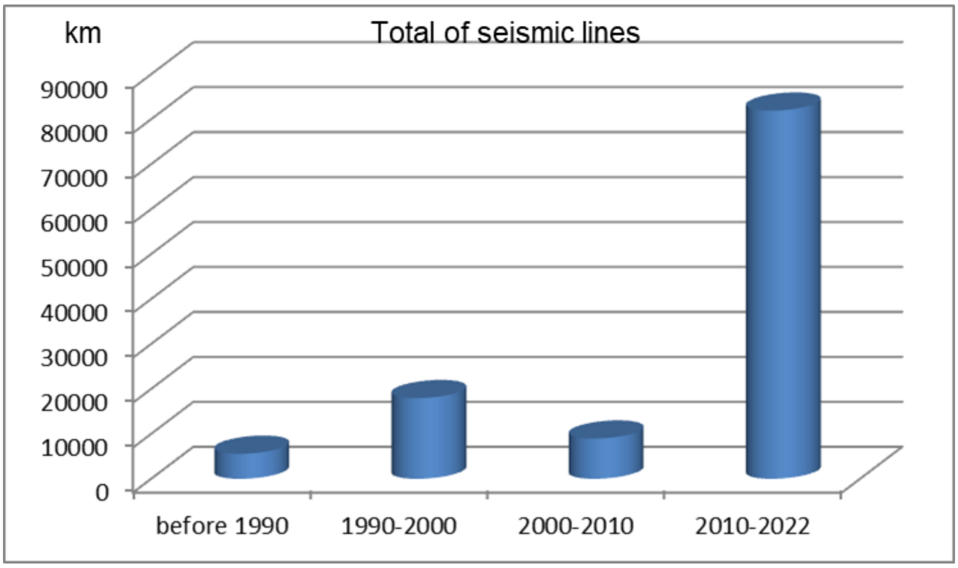

Figure 1 – The amount of seismic data acquired within the Laptev Sea showing of a substantial increase in information in the last years

Given these considerations, a comprehensive review of all new and historical geologic information is a task of significant interest. In our opinion, it can be helpful in shedding light on many unresolved questions about the Laptev Sea geology and making a critical review of the established hypotheses about its tectonic evolution. The goal of this study is to refine and substantiate the limits of the main tectonic elements within the Laptev Sea shelf as well as to review its tectonic evolution, which includes identifying the main tectonostratigraphic phases and furnishing the groundwork for further basin analysis and petroleum potential assessment.

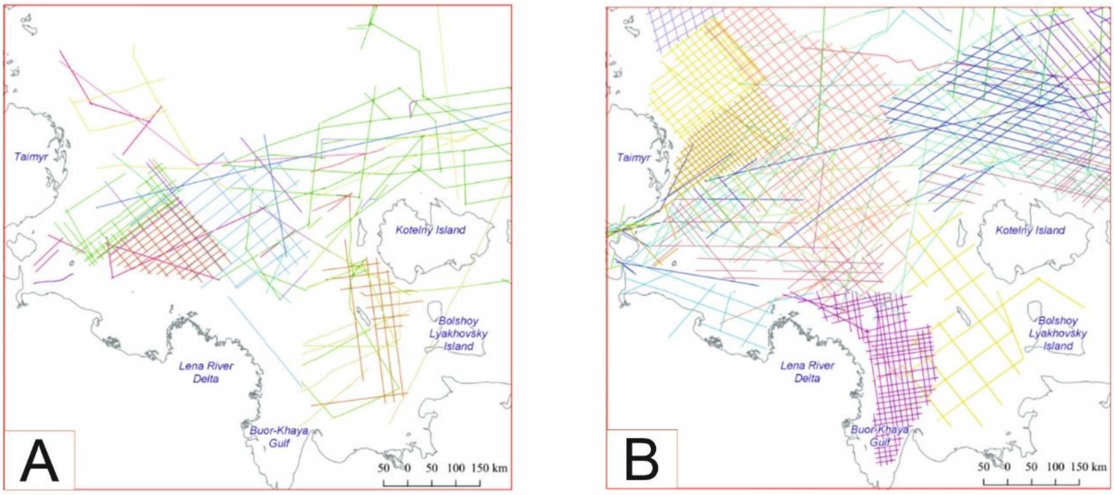

Figure 2 – Location of seismic lines in the Laptev Sea, a – researches accomplished before 2010 including surveys conducted by JSC "MAGE"1985-1986 yy., 1988 y., 1986-1990 yy., 2006-2008 yy., 2010 y.; JSC SMNG 1989, 1991 yy., JSC SMNG и BGR 1994 y., 1997 y.; LARGE 1989 y.; JSC «Yuzhmorgeologiya» 2010 y., b – researches accomplished before 2022 including surveys conducted by JSC "MAGE" 2013 y., 2014 y., 2015 y., 2016 y.; JSC SMNG 2015 y., 2019 y., 2020 y., 2021 y.; JSC «Yuzhmorgeologiya» 2014 y., 2016 y.)

Regional setting

The Laptev Sea relates to the shelf margin of the Arctic Ocean. The adjoining deepwater zone of the latter comprises the Eurasian Basin with the Nansen-Gakkel rift system which in turn includes the Nansen and Amundsen Basins and separates two major (Eurasian and North American) lithospheric plates. The Laptev Sea segment of the plate boundary crosses the offshore area roughly north to south, going farther south along the Verkhoyansk-Kolyma foldbelt. Since the North American Plate is moving counterclockwise and the Eurasian Plate is moving clockwise, shear and compressional deformations arise along the plate boundary (Earle, 2019). The existence of transpressional settings at the junction between the lithospheric plates is confirmed by the territory's high modern-day seismicity.

The regional tectonic framework of the offshore area in question (regarded as a separate Laptev Plate belonging to the marginal system of structures between the continent and the ocean) is dictated by its location at the junction of the following major tectonic features: the northern part of the ancient Siberian Platform as well as the Taimyr-Severozemelsk and Verkhoyansk-Kolyma fold system. The South Taimyr foldbelt and the Verkhoyansk-Kolyma fold system comprise sedimentary units of the passive continental margin of the Siberian Platform dating back to the Riphean (Khain, 2001) and are represented by SW- and S-vergent thrusts. Yenisei-Khatanga, Lena-Anabar and the Predverkhoyansk foredeeps are related to above-mentioned foldbelts.

During the early stages of studies on the Laptev Sea it was commonly accepted that western and central parts of the Laptev shelf, comprise a block of the Siberian Platform, which is separated from the platform by the Olenek inverted zone (Geological structure …, 1984; Ivanova, Sekretov, Shkarubo, 1989; Geology and natural resources …, 2004). According to this assumption, the sedimentary cover of the Laptev Plate hosts two structural levels, i.e. a paraplatform unit (Upper Riphean - Lower Cretaceous) and a basinal unit (Upper Cretaceous - Cenozoic). In the eastern part of the offshore area, the sedimentary cover consists of the upper unit only. Its thickness is within 2 kilometers in the western part, whilst it reaches 4 to 5 km in some grabens in the eastern part. The paraplatform deposits found in the west of the Laptev Sea shelf are much thicker, up to 7-11 km (Geologiya and poleznye…, 2004, Fig. 83, 84).

The beliefs about the geology of the Laptev Sea shelf changed dramatically once new seismic data was obtained. These new insights implied that the folded basement was created in the Late Mesozoic and had an almost ubiquitous presence within the offshore area, except the Khatanga Bay (Vinogradov, Drachev, 2000; Drachev, 2000; Khain, 2001). The supporters of this hypothesis still have very different views about the age of rocks making up the base of the sedimentary cover. Their age estimates vary from the Early Cretaceous (State geological map, 1999) to the Late Paleocene (K. Hinz et al., D.Franke et al., 2001). According to the interpretation by (Franke, Hinz, Oncken, 2001) the greater part of the shelf is a single sedimentary basin representing the frontal part of the Cenozoic rift with an intricate internal structure and widespread listric normal faults indicative of vigorous extension. The sedimentary section attains a thickness of more than 13 km in the deepest parts of this rift (called the Ust'-Lena rift by the authors). The majority of researchers currently regard the Laptev shelf as a single sedimentary basin formed during the Late Cretaceous - Cenozoic.

From a tectonic viewpoint, the Laptev rift system in this offshore area is regarded as a link between the Nansen-Gakkel mid-oceanic ridge and the Momsky continental rift. It is generally accepted that 'the structure of the Laptev Sea sedimentary basin comprises a system of linear rift-induced grabens with the Late Cretaceous to Miocene-aged sedimentary fill overlain by the Pliocene-Quaternary blanket complex' (Hinz et al., 2001; Andieva, 2008; Drachev, 2000, 2010, 2011; Shkarubo, Zavarzina, 2011; Zavarzina, 2012, 2013; Nikishin et al., 2017). Lying at the base of the sedimentary section over much of the offshore area are the structures of the Verkhoyansk-Kolyma fold system (Andieva, 2008; Vernikovsky, 2013; Nikishin et al., 2018). Although the hypothesis about the rift-induced origin of sedimentary basins underlying the Laptev Sea shelf has been widely accepted, it is still doubted by some authors (Gaina et al., 2002; Shephard et al., 2013; Dor´e et al, 2015; Alvey et al., 2008; Wienecke et al., 2011; Franke et al., 2001).

The majority of researchers agree that the contact between the Nansen-Gakkel rift system and the Laptev Plate can be traced along a shear zone (Yenisey-Khatanga, transform zone) (Shipilov, 2016; Vernikovsky, 2013; Andieva, 2008; Dor´e et al., 2015). However, by drawing on seismic interpretation results A.M. Nikishin points out the absence of the extensive Khatanga - Lomonosov transform fault and proposes a hypothesis suggesting that the Eurasian Basin opened in a wedge-like pattern, with the southward progradation towards the Laptev Sea (Nikishin et al., 2022).

Material and methods

This paper relies on data set that includes the interpreted results of seismic studies conducted over 1990-2021 from more than 20 surveys covering certain parts of the offshore area and the adjoining coast obtained with the permission by the Russian State Geological Depository.

Given the absence of deep wells in this offshore area, the main unconformities were dated with consideration to regional tectonic events of importance to the examined territory. These events were established from the published literature including the results of plate tectonic and paleogeographic reconstructions of the formation and evolution undergone by the Arctic Ocean, studies on hiatuses and unconformities in outcrops, fission track and radiometric dating of rock samples recovered from the ocean floor and outcrops on the adjoining mainland. The following four main unconformities have been identified in the sedimentary section of the Laptev Sea as a result of this review: the pre-Aptian unconformity (A) associated with the collision between the Siberian platform and the Alaska-Chukotka microcontinent (ACMC); along the Cretaceous-Paleogene boundary (mBU) caused by rifting in the Makarov-Podvodnikov Basin; along the Eocene-Oligocene boundary (UB) caused by spreading in the Eurasian Basin; and along the Oligocene-Miocene boundary (RU) marking the onset of post-rift subsidence in the southern part of the Nansen-Gakkel rift zone.

While constructing unconformities spanning the entire study area (Fig.3), we reconciled the results of structural imaging from individual surveys. The quality of final maps was checked against stacked seismic sections.

Tectonic zonation along the base of the sedimentary cover was done using the structural imaging of the A reflector while also taking into consideration gravity/magnetic data, schematic tectonic maps supplementing the State geologic map at a scale of 1:1000 000 (State geological map of the Russian Federation, Sheet S-50, 2010; Sheet S-51-52, 2011; Sheet S-53-54, 2014, Proskurnin et al., 2017), and thickness maps of the main structural-formational complexes.

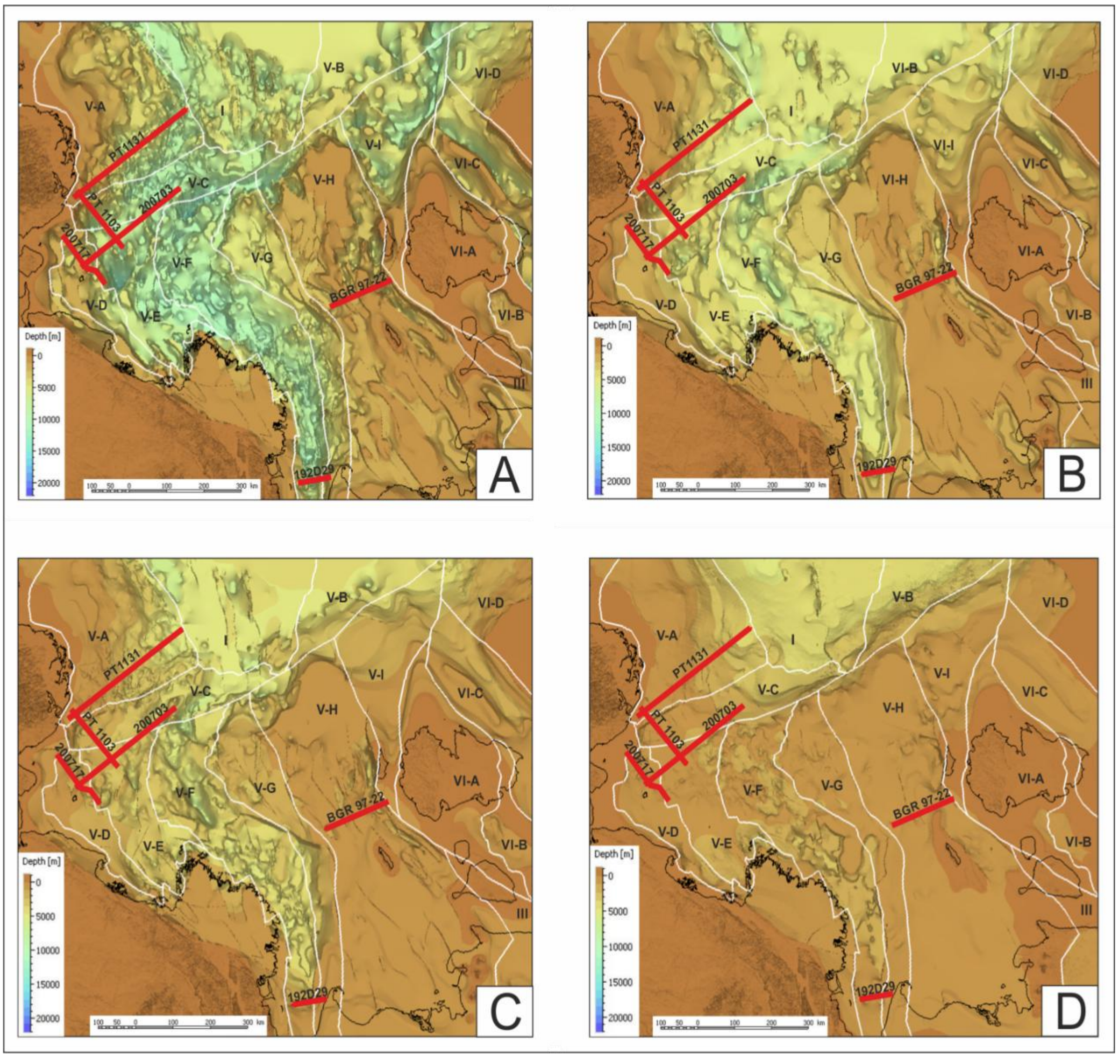

Figure 3 – Depth maps showing the structural pattern of the main unconformities as well as the first order tectonic elements and their indexes resulted from performed zonation. For details see Fig.4. Red lines depict location of seismic sections illustrated inner structure of the tectonic elements at Fig. 5-10 and discussed in the text

Results

Our in-depth review of G&G information has resulted in the tectonic zonation of the Laptev Sea (Fig.4). The Khatanga shear zone is confined to the NE trending Yenisei-Khatanga transform fault regarded as a key element in the general tectonic framework of the studied territory. Lying south of this fault is a series of NW trending tectonic structures (i.e. the predominant trending within the examined territory), such as the Lena-Taimyr zone of boundary uplifts, South Laptev structural zone, Ust'-Lena graben, Omoloy shear zone, and East Laptev compressional zone. They are readily discernible in the thicknesses of the sedimentary section and in the structure of the anomalous gravity field. The north-trending Bel'kov-Svyatonos shear zone separates the Laptev Plate from the East Siberian Plate (located outside the studied territory). Lying north of the Yenisei-Khatanga fault are the NW trending Pritaimyr structural area, Lomonosov trough, and a superorder structure, i.e. the north-trending Nansen-Gakkel rift zone.

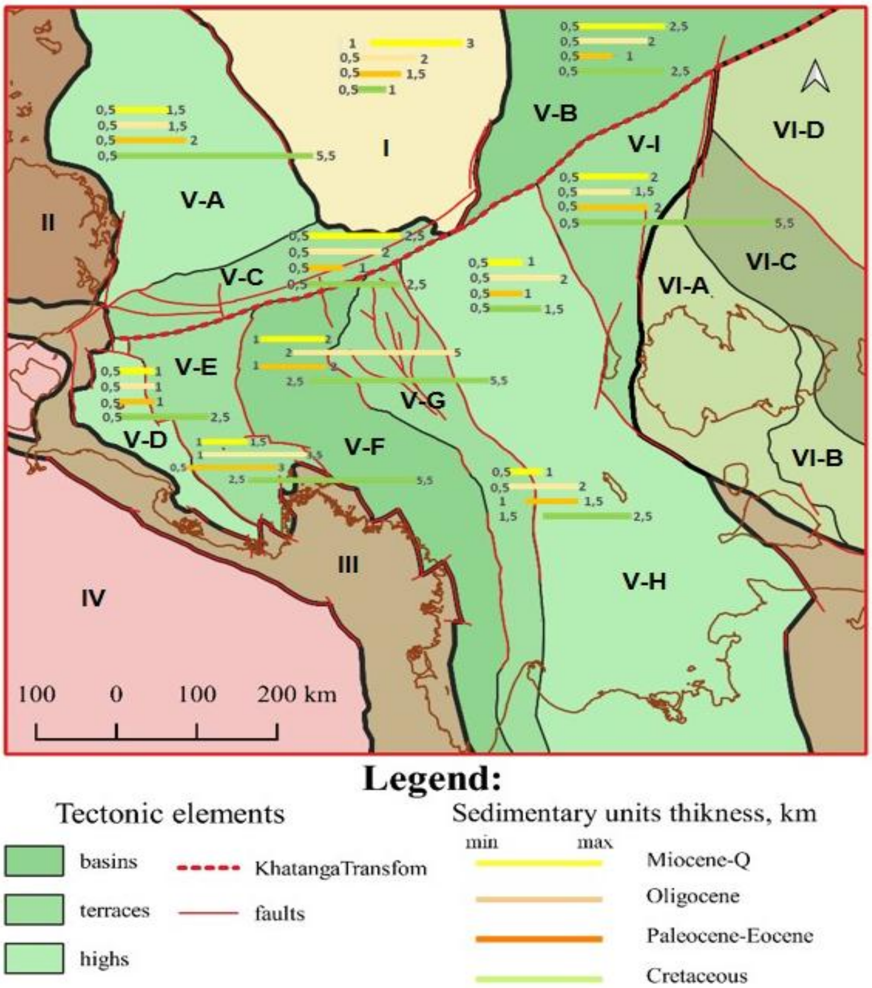

Figure 4 – Tectonic map of the Laptev Sea shelf: I Nansen-Gakkel rift zone, II Taimyr-Severozemelsk foldbelt, III Verkhoyansk-Kolyma fold system, IV Siberian platform, V Laptev Plate, including V-A Pritaimyr structural area, V-B Prilomonosov trough abuts, V-C Khatanga shear zone, V-D Lena-Taimyr zone of boundary uplifts, V-E South Laptev structural zone, V-F Ust'-Lena graben, V-G Omoloy shear zone, V-H East Laptev compressional zone, V-I Bel'kovsky-Svyatonos shear zone, VI East Siberian Plate, including VI-A Novosibirsk structural region, VI-B Kotelnicheskoe raising, VI-C Anisin graben zone VI-D DeLong Raise

The Lena-Taimyr zone of boundary uplifts extends from the Lena River Delta along the northern boundary of the Verkhoyansk-Kolyma fold area to the Khatanga transform. It was first identified in 1979-1983 by V.A. Vinogradov, E.K.

Zatsepin and others as a zone of 'buried uplifts' of the Laptev Plate manifested as strong and contrasting high-gradient gravity anomalies. As new seismic data is obtained, many researchers view it as a marginal structure between the Siberian Platform and the Laptev Plate (Geology …, 2004; Andieva, 2008; State geological map of the Russian Federation, Sheet S-51-52, 2014; Vasilyeva, 2016). The Tumat basement high that exhibits a contrasting gravity maximum of up to 55 mGal is assigned to the Lena-Taimyr zone in line with GGK S-50, S-51, 52. This is the most uplifted block of crystalline rocks of the pre-Riphean basement and Early Proterozoic rocks (rheomorphozed in the Riphean) overlain by a thin cover of Pliocene and Quaternary deposits (Zavarzina, Shkarubo, 2012). However, if we consider that outcropping volcanic and carbonate-terrigenous complexes of the Devonian to Middle Carboniferous formations are inferred on the basement high's limbs and that its southern limb is cut by reverse faults and reverse thrust faults, with fault planes dipping in the northeastern direction (State geological map of the Russian Federation, Sheet S-51-52, 2014), it is more logical to view this block as part of the Verkhoyansk-Kolyma fold system brought about by the collision between the Siberian Platform and the ACMC. The sedimentary cover in the Lena-Taymyr zone of boundary uplifts contains Aptian- to Upper Cretaceous-aged deposits (up to 2.5 km thick) and Cenozoic sedimentary formations (up to 1.5-3 km thick). In grabens the base of the sedimentary cover subsides to a depth of as much as 5.0 km. Over the uplifts, Aptian, Upper Cretaceous and Paleocene rocks pinch out successively against the surface of the folded basement, whereas Oligocene and Miocene rocks are truncated by the pre-Pliocene unconformity. The folded basement is inferred to contain disturbed Upper Paleozoic, Triassic, and Jurassic-Lower Cretaceous (pre-Aptian) strata. Time sections show faults with complex kinematics within the Lena-Taimyr zone, i.e. strike-slips with a normal fault component and strike-slips with a reverse fault component trending northwestward and affecting the entire sedimentary section (Fig. 5).

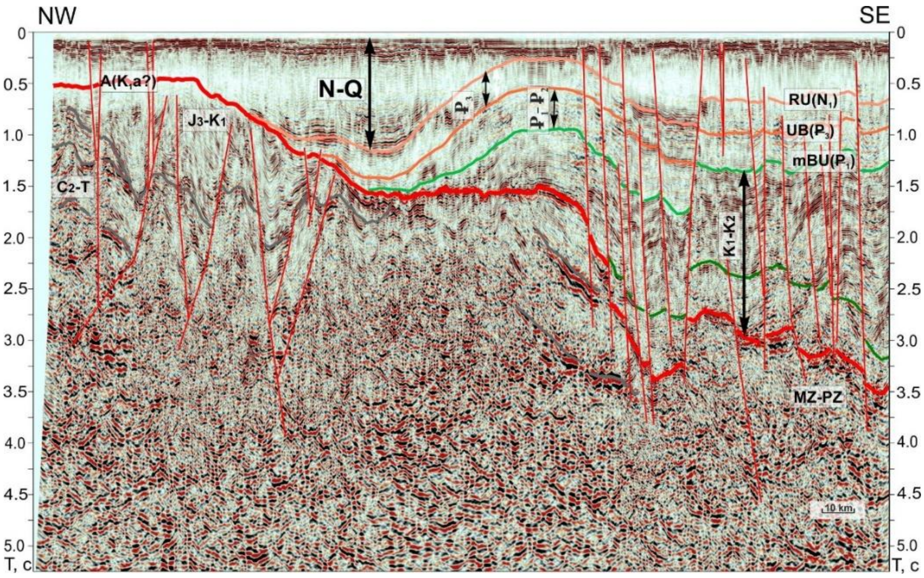

Figure 5 – Tectonic map of the Laptev Sea shelf: I Nansen-Gakkel rift zone

In the Cretaceous interval there are one-sided half-grabens complicated by strike-slips with a normal fault component. The zone probably formed through the manifestation of compressional processes and tectonic shearing during the pre-Aptian. As the Laptev Sea Basin began to take shape during the Aptian - Late Cretaceous, compressional settings alternated with extensional and shear settings. The Lena-Taimyr zone levels out in the structural geometry of upperlying deposits (mBU and UB).

The South Laptev structural zone stretches from the Lena River Delta to the Khatanga shear zone. Here the folded basement has a varied and highly rugged topography, with depths ranging from 3 to 14 km. The South Laptev zone is generally marked by alternating narrow, linear, multi-oriented horsts and grabens at depths between 7 and 10 km. Also, Aptian-Upper Cretaceous deposits attain a considerable thickness of 5.5 km. The northwestern part of the zone along the Khatanga fault hosts the deepest grabens complicated by N-NW trending normal faults and strike-slips with a normal fault component. In the Aptian-Upper Cretaceous complex, fan-like or flower-like faults as well as inverted structures (indicative of shear dislocations) are discernible on time sections. As for the Cenozoic complex, shear dislocations inherited from the Aptian - Late Cretaceous and manifested as flower structures can also be seen on time sections (Fig.6).

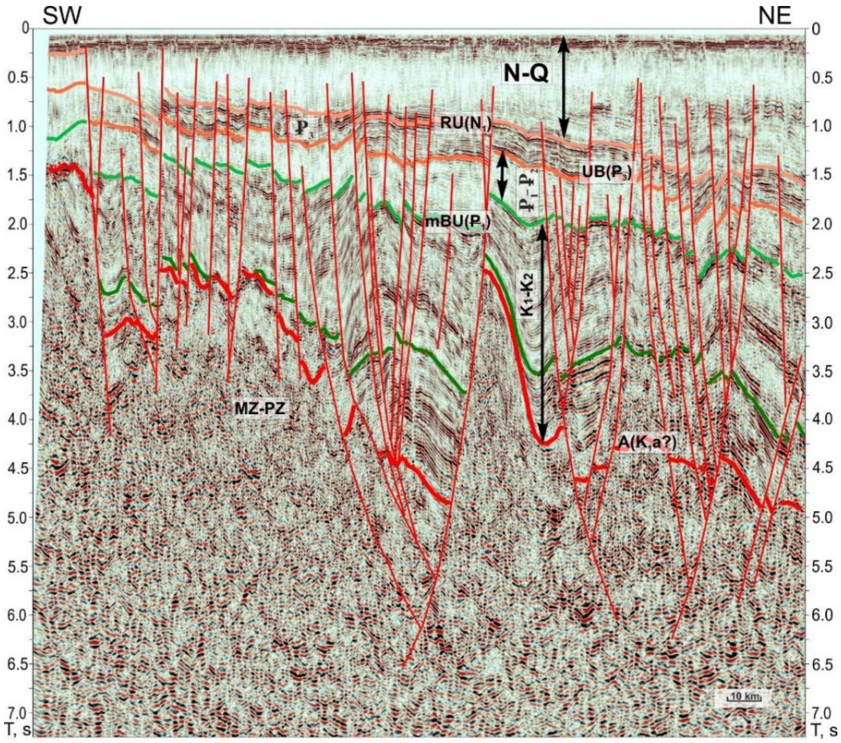

Figure 6 – Time section along the line 200703illustrating the geology of the South Laptev structural zone revised after Shlykova V.V., et al., 2013 (JSC "MAGE” technical report)

The pattern of faulting, structural geometries and vertical distribution of sedimentary complex thickness within the South Laptev zone are generally not representative of extension. The grabens level out to the depths of 6-7 km along the top of Cretaceous rocks (mBU). Paleogene (Paleocene-Eocene and Oligocene) deposits attain a total thickness of 5-5.5 km, whereas the total thickness of Miocene - Quaternary strata is within 1.5 km. The Ust'-Lena graben - the axial structure in the Laptev Sea basin, extends northwestward from the Buor-Khaya Bay along the Lena River Delta and is bounded in the north by the Khatanga tranform, shifting along the latter in the eastern direction. The intricate Ust'-Lena graben is controlled by the mutual arrangement of two fault systems and the location of rigid blocks of the Siberian craton, i.e. the Taimyr orogen in the west and a fragment of the Verkhoyansk orogen emerging in the Lena River Delta. This depressional area is intensely broken up by faults and comprises numerous minor depressions of varied shape and orientation. The base of the sedimentary cover within the depression occurs at depths between 8 and 15 km. The sedimentary cover encompasses the deposits of the following four sedimentary complexes: Aptian-Upper Cretaceous, Paleocene-Eocene, Oligocene, and Miocene-Quaternary. The Aptian-Upper Cretaceous strata do not exceed 5.5 km in thickness. The Cenozoic succession is dominated by Oligocene rocks. Although the structural geometry of the deposits is generally inherited from the (A) horizon, the complexes become less broken up (upsection). The tectonic zone hosts two main fault systems: the first one includes faults cutting the sedimentary cover and reaching deep into the folded basement, whereas the second system is representative of a later (Cenozoic) tectonic activity. One-sided half-grabens affected by strike-slips with a normal fault component are observed on time sections in the Aptian-Upper Cretaceous complex within the Ust'-Lena graben (Fig.7). The intricate kinematics of faults and the fact that the Cenozoic complex is broken by multiple faults suggest that the Ust'-Lena graben formed in the settings of shear tectonics both during the Late Mesozoic and Cenozoic stages of its evolution (Fig.7).

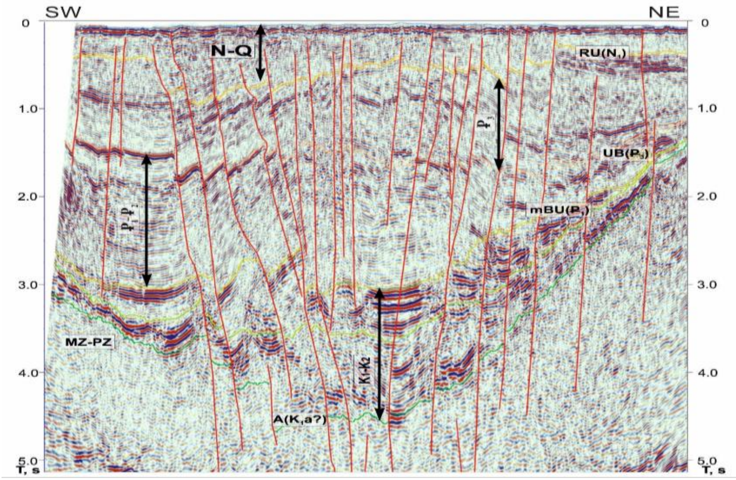

Figure 7 – Time section along the line 192D29 illustrating the geology of the Ust'-Lena graben revised after Vasilyeva E.A. et al., 2021 (JSC "Rosgeo" technical report)

In the Omoloy shear zone to the east of the Ust'-Lena graben, the folded basement is buried at relatively modest depths (4 to 6 km) and subsides in a stepwise manner toward the adjacent graben. All sedimentary complexes are reduced in thickness. The zone is cut by roughly north-south trending normal faults and strike-slips with a normal fault component that form a series of NW trending parallel en echelons.

The East Laptev compressional zone is a predominantly uplifted area with minor narrow depressions controlled by a system of strike-slips. The base of the sedimentary cover within this zone does not occur deeper than 3-4 km, except its northern part abutting on the Khatanga transfom, where the folded basement is buried at depths between 6 and 8 km. The sedimentary cover is generally reduced in thickness within this territory. The thickness of Aptian-Upper Cretaceous strata does not exceed 1.5 km, whereas the thickness of Cenozoic deposits varies in a broad range from 0.5 to 4.0 km. The boundary between the East Laptev compressional zone and the Omoloy shear zone is traceable as an abrupt stepwise subsidence of the folded basement along the system of the N-NW trending strike-slips with a normal fault component. The pattern of disturbance of the sedimentary fill within the East Laptev zone suggests its formation in compressional settings manifested as reverse faults and strike-slips with a reverse fault component.

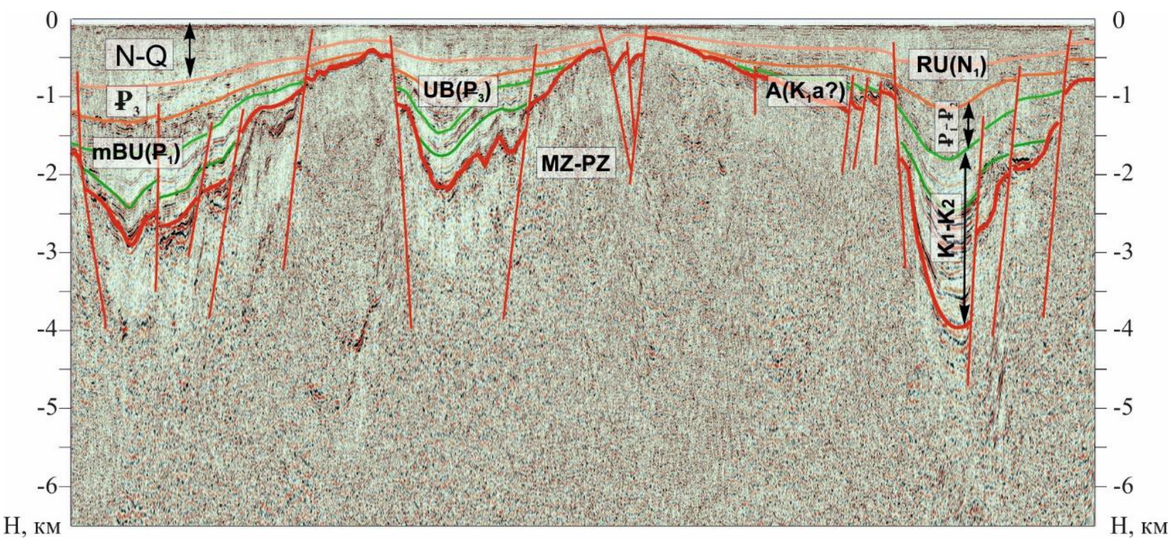

Figure 8 – Depths section along the line BGR 97-22 illustrating the geology of the East Laptev compressional zone revised after Burguto A.G. et al., 2015 (JSC "MAGE" technical report)

The Bel'kovsky-Svyatonos shear zone lies between the East Laptev compressional zone and the Kotel'nyy-Svyatonos axial structural zone. In the north it is bounded by the Khatanga fault. The folded basement occurs at depths between 5.0 and 9.0 km in this area. This shear zone hosts N-NE trending linear grabens, where Aptian-Upper Cretaceous deposits reach a thickness of 5.5 km. The thickness of the Cenozoic section is evenly distributed among the main complexes

(Paleocene-Eocene, Oligocene and Miocene-Quaternary) and varies in a range from 1.5 km to 5.5 km. The zone is complicated by normal faults and strike-slips with a normal fault component trending northward and northwestward.

The Khatanga shear zone extends in the northeastern direction from Taimyr along the continental slope and forms a junction between the Laptev Sea continental margin and the structures of the Eurasian Basin. On time sections it characteristically exhibits the severely broken up sedimentary cover and abrupt thickness variations of Aptian-Upper Cretaceous and Cenozoic deposits (Fig.9). There is a discrepancy in the thickness of coeval rocks on different sides of faults probably due to a change from the kinematics of normal faults to the kinematics of reverse faults as a result of horizontal shearing in the basement. Most faults in the Khatanga shear zone trend northeastward in contrast to the other tectonic elements of the Laptev Plate dominated by NW trending faults. The faults can be divided into the following three groups: the first one affects the entire sedimentary section, with its roots reaching the folded basement. This system of strike-slips formed during the Aptian-Late Cretaceous and was reactivated in the Cenozoic (Fig.9). The second and third groups control faults inside Cretaceous and Cenozoic deposits, respectively. On time sections there are many faults with complex kinematics, i.e. fan-like or flower-like faults typically associated with shear dislocations (Fig.9).

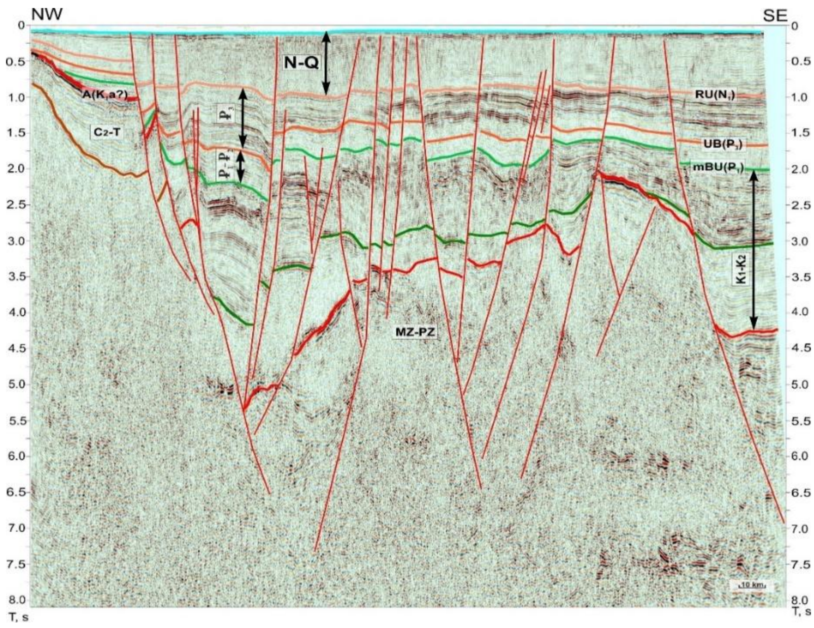

Figure 9 – Time section along the line PT1103 illustrating the geology of the Khatanga shear zone revised after Shlykova V.V., et al., 2013 (JSC "MAGE" technical report)

The Pritaimyr structural area extends in the northwestern direction (north of the Khatanga shear zone). It is marked by the block structure of the folded basement, with the surface buried at depths between 1.0 and 6.0 km. Some blocks contain a mildly metamorphosed layered series compatible with Permian-Carboniferous? and Jurassic-Lower Cretaceous deposits (Fig.10). The Aptian-

Upper Cretaceous strata and Cenozoic deposits vary in thickness from 0.5 to 5.5 km and from 1.5 to 4.5 km, respectively. The sedimentary cover is broken by predominantly NW and roughly NS trending faults (normal faults and strike-slips with a normal fault component) (Fig.10), some of which affect the entire sedimentary section, while some fade away in Cretaceous deposits and less commonly in Paleogene deposits. Time sections show one-sided half-grabens filled with Aptian-Upper Cretaceous deposits cut by flower structures indicative of shear dislocations.

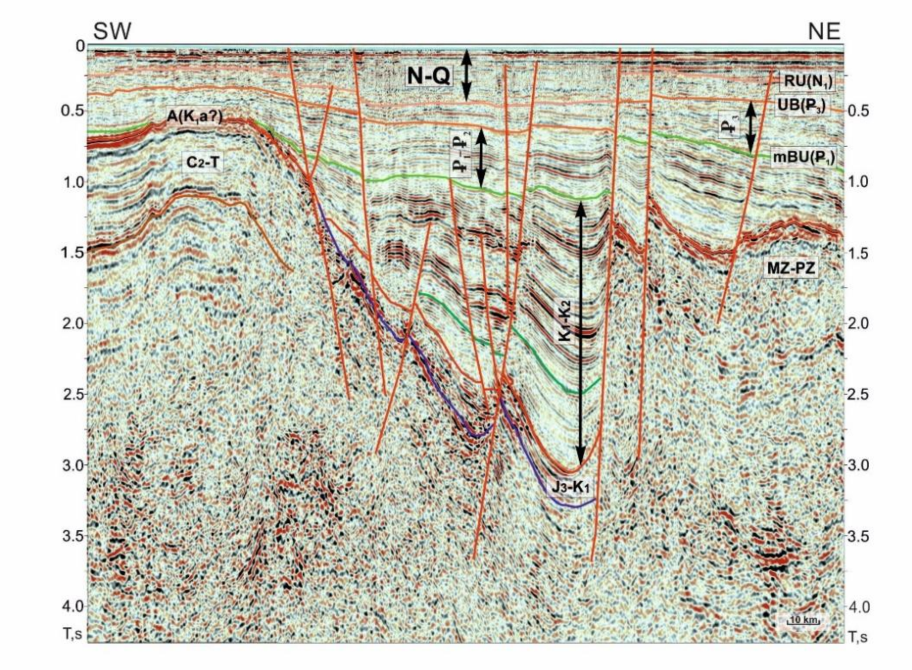

Figure 10 – Time section along the line PT1131 illustrating the geology of the Pritaimyr structural area revised after Shlykova V.V., et al., 2013 (JSC "MAGE" technical report)

The Prilomonosov trough abuts on the Eurasian Basin and constitutes a negative structure with the base of the sedimentary cover buried at depths between 4 and 7 km.

The Aptian - Upper Cretaceous deposits range in thickness from 0.5 to 2.5 km. In the Cenozoic interval there is a successive increase in Cenozoic deposits (upsection) from 1.5 to 5.5 km, which suggests extensional processes (along with normal-fault tectonics).

Established patterns in the thickness distribution of Aptian-Upper Cretaceous and Cenozoic complexes as well as the kinematics of the main faults indicate that the main negative structures in the central part of the Laptev Sea area identified in the modern-day structural geometry and associated, in our opinion, with the shear tectonics (as the ACMC attached to the Siberian Platform) formed at the end of the Cretaceous and some of them experienced vigorous evolution also during the Cenozoic.

Discussion

The integration and a comprehensive review of G&G information completed under this project have enabled us to clarify some controversial questions concerning the tectonic evolution of the Laptev Sea shelf such as the stratigraphic range of sedimentary cover units, the presence of the Siberian Platform elements in the make-up of the folded basement, the rift-induced origin of grabens as well as the character of junction between the Nansen-Gakkel rift system and the Laptev Plate. The analysis of unconformities identified throughout the sedimentary cover in the context of regional tectonic events suggests that it is Late Cretaceous to Cenozoic in age. This follows from the results of plate tectonic reconstructions performed by Somme et al. (Sømme et al., 2018). According to them a basin in the Laptev Sea was formed after the Alaska-Chukotka microcontinent attached itself to the Siberian Platform (against the background of the opening of the Canada Basin during 125-80 mya). A coeval tectonic event was documented by (Prokopiev et al., 2013) using structural observations and low-temperature thermochronology data. This event corresponds to the second stage of tectonic evolution undergone by the northern flank of the Verkhoyansk fold-and-thrust belt. This stage of predominantly compressional deformations manifested itself from 93 to 132 mya. This being said, the beginning of the Late Cretaceous saw short-lived extension accompanied by the intrusion of dolerite dykes aged 86–89 mya (Prokopiev et al., 2013). This tectonic event was also responsible for the unconformity established in the outcrops on the New Siberian Islands, which separates Jurassic-Barremian and Aptian-Upper Cretaceous rocks (Kos’ko, 2013).

Judging from the plate tectonic model for the region's evolution, a large part of the folded basement of the Laptev Plate is made up of rocks that formed as part of the microcontinent before its attachment to the Siberian Platform. However, A.M. Nikishin and co-authors assign the territory of the Yenisei-Khatanga Bay and the adjoining southern part of the offshore area to the Siberian Platform. In our interpretation it belongs to the Lena-Taimyr zone of boundary uplifts. We believe that assigning this territory to the platform is not sufficiently grounded, as it has experienced several stages of folding, some of which were accompanied by severe erosion (of up to several km) (Pavlovskaya, 2022; Prokopyev, 2013). The proposed model assumes that the northern flank of the Verkhoyansk fold-and-thrust belt front is an independent tectonic structure separating the Siberian Platform from the Laptev Plate. The folded basement of the Lena-Taimyr zone of boundary uplifts hosts deformed Late Paleozoic - Early to Middle Mesozoic rocks formed in the setting of the continental margin of the Siberian Platform before the onset of folded deformations caused by the closure of the South Anyui Ocean. They became part of the flexural trough conjugated with the Verkhoyansk orogen. A portion of this trough probably continues into the South Laptev structural zone, where it also belongs to the folded basement.

The results of our studies do not support the commonly accepted hypothesis about the rift-driven origin of the system of NW trending linear grabens that form the structure of the Laptev Plate. It is contradicted by the following specific aspects of the Laptev Sea shelf geology established in the course of the study: 1) the simultaneous presence of two perpendicular (NW and SE) axes of extension responsible for the formation of minor depressions of varied trend in the lower interval of the sedimentary section; 2) the lack of one common trend of depocenter shifting and the lack of successive upsection thickening of sedimentary complexes (typically associated with rifting) due to the stages of synrift and postrift subsidence. These particular aspects attest to the fact that the sedimentary cover underlying the Laptev Sea formed in the setting of shear tectonics with local extensional settings, which is consistent with the patterns of faults imaged on seismic sections.

The patterns in the thickness distribution of sedimentary complexes suggest that there were two phases of extension (in the second half of the Cretaceous and in the Oligocene), which had a profound effect on the formation of the sedimentary cover of the Laptev Plate and led to the accumulation of sizeable volumes of sediment. However, extensional processes within the studied territory proceeded with a varying degree of intensity. The Late Cretaceous stage manifested itself over much of the study area, except the East Laptev compressional zone. The Upper Cretaceous deposits exhibit a higher than average thickness compared to the other sedimentary complexes. The extension in the Oligocene was associated with the opening of the Eurasian Basin and manifested itself in the central Laptev Sea, including the Khatanga shear zone, South Laptev structural zone, Ust'-Lena graben, Omoloy shear zone, and East Laptev compressional zone, where sediments of considerable thickness were deposited, in some cases comparable with the Upper Cretaceous ones.

The completed studies have confirmed the existence of the Yenisei-Khatanga right-lateral transform fault separating the Eurasian Basin from the Laptev Plate. This zone is clearly identifiable on depth structure maps and thickness maps. Its southwestern segment represented by the Khatanga shear zone formed as early as the Late Cretaceous, as the ACMC attached itself to the Siberian Platform as a result of counterclockwise rotation. The rejuvenation of tectonic activity was brought about by the opening of the Eurasian Basin and culminated in the formation of the transform zone.

Conclusions

Specific aspects of the tectonic evolution undergone by the Laptev Sea basin determine the present-day architecture of its sedimentary section as well as a predictable change in the structural geometry of the main unconformities. In the proposed model for the tectonic evolution of the Laptev Sea shelf the results of seismic studies are in agreement with global plate tectonic imaging and the results of studies into regional tectonic events on the adjoining landmass that had a significant impact on the evolution of the Laptev Plate. The produced schematic map of tectonic zonation illustrates a conceptual understanding of the shear-driven nature of its tectonic elements and refutes the well-established hypothesis about the rift-driven origin of the system of grabens controlling the internal structure of the sedimentary section. It has been shown that a common basin was formed within the modern-day shelf of the Laptev Sea after the Alaska-Chukotka microcontinent attached itself to the Siberian Platform. This defines the lower age limit of rocks making up the sedimentary cover as Aptian-Albian. We have identified the following major tectonostratigraphic phases in the formation of the Laptev Plate sedimentary section: Aptian-Albian-Late Cretaceous, Paleocene-Eocene, Oligocene, and Miocene-Quaternary. They are associated with the key stages in the evolution of the Arctic Ocean. We have updated the location of the transform fault separating the Eurasian Basin from the Laptev Plate. It has been shown that the southwestern segment of this shear zone began forming during the Cretaceous (long before the opening of the Eurasian Basin) against the background of the collision between the Alaska-Chukotka microcontinent and the Siberian Platform.

These findings lay the groundwork for further basin analysis and will be used to study potential hydrocarbon systems.

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