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# Probable Distribution of Upper Jurassic and Lower Cretaceous Deposits on the Laptev Sea Shelf and Their Petroleum Resource Potential

**V. A. Zakharov[a], B. I. Kim[b], and M. A. Rogov[a]**

[a]*Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 119017 Russia*
*e-mail: mzarctic@gmail.com*

[b]*All-Russian Research Institute of Geology and Mineral Resources of the World Ocean (VNIIOkeanogeologiya), Angliiskii pr. 1, St. Petersburg, 190121 Russia*

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**Abstract**—The analysis of Upper Jurassic and Lower Cretaceous marine sections developed in surrounding structures of the Laptev Sea revealed that all of them are composed of terrigenous rocks, which enclose abundant concretions cemented by calcareous material. The Upper Jurassic portion of the section is the most variable in thickness and stratigraphic range of sediments usually including hiatuses. Its Lower Cretaceous part represented by the Boreal Berriasian (=Ryazanian) and lower Valanginian stages is most complete. The Upper Jurassic and Lower Cretaceous sections are usually composed of fine-grained rocks (clays and mudstones) in the west and coarser cemented varieties (siltstones and sandstones) with rare mudstone intercalations in the east. Practically all the investigated Upper Jurassic and Lower Cretaceous sections include readily recognizable age and facies analogs of the Bazhenovo Formation and Achimov sandstones, which are petroliferous in West Siberia. There are grounds to assume the occurrence of these formations also on the Laptev Sea shelf, which is confirmed by seismic records. Conditions favorable for the formation of potential hydrocarbon reservoirs could exist in the western part of the paleobasin along the Nordvik Peninsula coast and northeastern Tamyr Peninsula margin. Paleotectonic reconstructions presented in this work are well consistent with stratigraphic conclusions.

*Keywords:* Upper Jurassic, Lower Cretaceous, Laptev Sea, paleogeography, depositional environments, facies, hydrocarbon reservoirs, seismic records

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## INTRODUCTION

The discovery of large gas and gas condensate fields (Shtokmanovskoe, Ledovoe, Rusanovskoe, and Leningradskoe) on the Barents–Kara sea shelves provides grounds for assuming a significant petroleum resource potential of shelves in North Asian seas as well.

The Laptev Sea shelf, now well studied by seismic methods, is the most promising area for hydrocarbon prospecting in the northern part of East Siberia (Khutorskoi et al., 2011). This is evident from the significant thickness of its sedimentary cover (up to 13 km) and wide development of large troughs, swells, and riftogenic structures documented by seismic exploration investigations and a peculiar geothermal field, and, which is most important, direct indications of the petroleum resource potential. These are semicommercial oil accumulations discovered in the Anabar–Khatanga saddle area in the 1950s, bitumen occurrences observed in core samples from all the wells drilled in the coastal zone, and anomalous concentrations of hydrocarbon gases established immediately at 70 shelf stations during sediment degassing: three of these stations yielded hydrocarbon contents exceeding 1 $cm^3/kg$ (Yashin and Kim, 2007).

In this connection, the analysis of depositional environments of Upper Jurassic and Lower Cretaceous sediments, which enclose in their North Siberian sections one of the main regional oil-generating formations (Bazhenovo), is of both practical and theoretical significance since their presence in the sedimentary cover of the shelf (along with older rocks) sheds light on the important and debatable now problem of the possible offshore continuation of the Siberian Platform.

The recent investigation of Upper Jurassic and Lower Cretaceous rocks cropping out in the lower reaches of the Lena River and on Stolbovoi Island of the New Siberian Archipelago brought important stratigraphic data. In Soviet times, coeval marine sedimentary successions were thoroughly investigated in areas surrounding the Laptev Sea in the west: south of the Cape Tsvetkov (northeastern Taimyr), on Bol'shoi Begichev Island, along the Anabar River, and in the Anabar Inlet (Knyazev, 1975; Sanin, 1979; Zakharov et al., 1983; Bogomolov et al., 1983; Bogomolov, 1989). Less detailed data are available for sections cropping out along the Olenek River, in lower reaches of the Lena River, and on islands of the New Siberian Archipelago (Voronkov, 1958; Galabala and Leonov, 1967; Bidzhiev, 1973; Ivanov et al., 1974; Vinogradov and Yavshits, 1975; Zinchenko and Alekseev, 1981; Gol'bert et al., 1983). The detailed stratigraphic data on Upper Jurassic and Lower Cretaceous sections cropping out in eastern structures surrounding the Laptev Sea were obtained only in recent years (Zakharov and Kuz'michev, 2008; Kuz'michev et al., 2009; Rogov et al., 2011; Rogov and Zakharov, 2012). This work is dedicated to discussion of recent and previously obtained data on the geological structure of Upper Jurassic and Lower Cretaceous sections with new seismic data obtained for the Laptev Sea shelf taken into account.

## CURRENT VIEWS ON AGE OF THE SHELF SEDIMENTARY COVER AND SURROUNDING STRUCTURES

The geological structure of the Laptev Sea shelf is considered in many works, which reflect the views of investigation teams from the All-Russian Research Institute of Geology and Mineral Resources of the World Ocean (VNIIOkeangeologiya, St. Petersburg), Open Joint-Stock Company Marine Arctic Geological Expedition (OAO MAGE, Murmansk), Laboratory of Regional Geodynamics (LARGE, Moscow), Federal Institute for Geosciences and Natural Resources (BGR, Germany), and Rosneft Oil Company. The most complete characterization of sediment stratigraphy, structure of the sedimentary cover, and its petroleum resource potential is available in the monograph *Arctic Seas* (*Geologiya*..., 2004), which includes, among other materials, the schematic tectonic zoning of the folded shelf basement (Fig. 1) based on offshore extrapolations of lithotectonic complexes well investigated in onshore structures and on islands with consideration of patterns of potential fields and seismostratigraphy of the sedimentary cover.

Four points of view on the stratigraphic range of the sedimentary cover are currently discussed in the specialized literature. German researchers (Franke et al., 2001) consider it to be the Cenozoic in age. Russian geologists (Vinogradov and Drachev, 2004; Vinogradov et al., 2008) date it to the Aptian–Cenozoic believing that the shelf is universally underlain by the late Cimmerian basement. This standpoint is shared by most geophysicists of OAO MAGE. For substantiating late Cimmerian age of the basement in the western part of the shelf, some researchers frequently use the data on Jurassic and Cretaceous sections cropping out in the Cape Tsvetkov area (eastern Taimyr). For example, V.A. Vinogradov believes that these rocks take part in the structure of the Cape Tsvetkov anticline. At the same time, according to Yu.E. Pogrebitskii (*Gosudarstvennaya*..., 1998), "Jurassic and Cretaceous rocks in the northern limb of the Yenisei–Khatanga trough rest on the folded complex with the angular unconformity in the form of a platform cover, and the brachyform anticline of the Cape Tsvetkov represents simultaneously a near-slope inlier of the basement underlying the Yenisei–Khatanga trough." The geologists from OAO Rosneft assume the presence of the Late Paleozoic–Cenozoic cover (Hercynian basement) in the western and central parts of the shelf and Aptian–Cenozoic cover in its eastern segment (Malyshev et al., 2009, 2010). Judging from his last publications, S.S. Drachev now concedes development of Upper Jurassic–Cretaceous rocks on the shelf between the Lena River delta and Khatanga Bay (Drachev et al., 2010).

Many researchers (I.S. Gramberg, V.L. Ivanov, N.M. Ivanova, B.I. Kim, D.V. Lazurkin, S.B. Sekretov, and others) consider the sedimentary cover as being the Jurassic–Cenozoic in age in the westernmost part of the shelf, Late Riphean–Cenozoic in its western and central parts, and Aptian–Cenozoic in the east. This viewpoint reflects the conception that was popular for many years at NIIGA–VNIIOkeangeologiya, according to which the Siberian Platform framed by structures of the early Cimmerian Taimyr fold system in its westernmost part and by structures of the late Cimmerian fold systems (Verkhoyansk–Kolyma and New Siberian–Chukotka) in the east continues offshore to the Laptev Sea shelf. The western branch of the Verkhoyansk–Kolyma system (or the Olenek zone of dislocations) extending along the southern coast of the Laptev Sea is considered to represent an inverted aulacogen within the platform body reflected in the topography by a range which is typical of such structures. Degeneration of this structural branch is evident from several facts: (1) westward decrease in the contrast and complexity of folds (up to typical brachyforms); (2) its virgation first in front of the shelf (Buor Khaya Inlet) and then near the northeastern boundary of the Yenisei-Khatanga trough; (3) the lack of thrusts, which would be confirmed by geological mapping at a scale of 1 : 200000 (stored materials at VNIIOkeangeologiya); (4) significantly lower (by a factor of two to three) thickness of the Verkhoyansk Complex ($C_2$–$K_1h$) as compared with the Verkhoyansk region.

In conclusion, it should be noted that the western and central parts of the Laptev Sea shelf are interpreted in the *Tectonic Map of the Kara and Laptev Seas and Northern Siberia* (scale 1 : 2500000, Eds. N.A. Bogdanov and V.E. Khain) as representing the offshore continuation of the Siberian Platform.

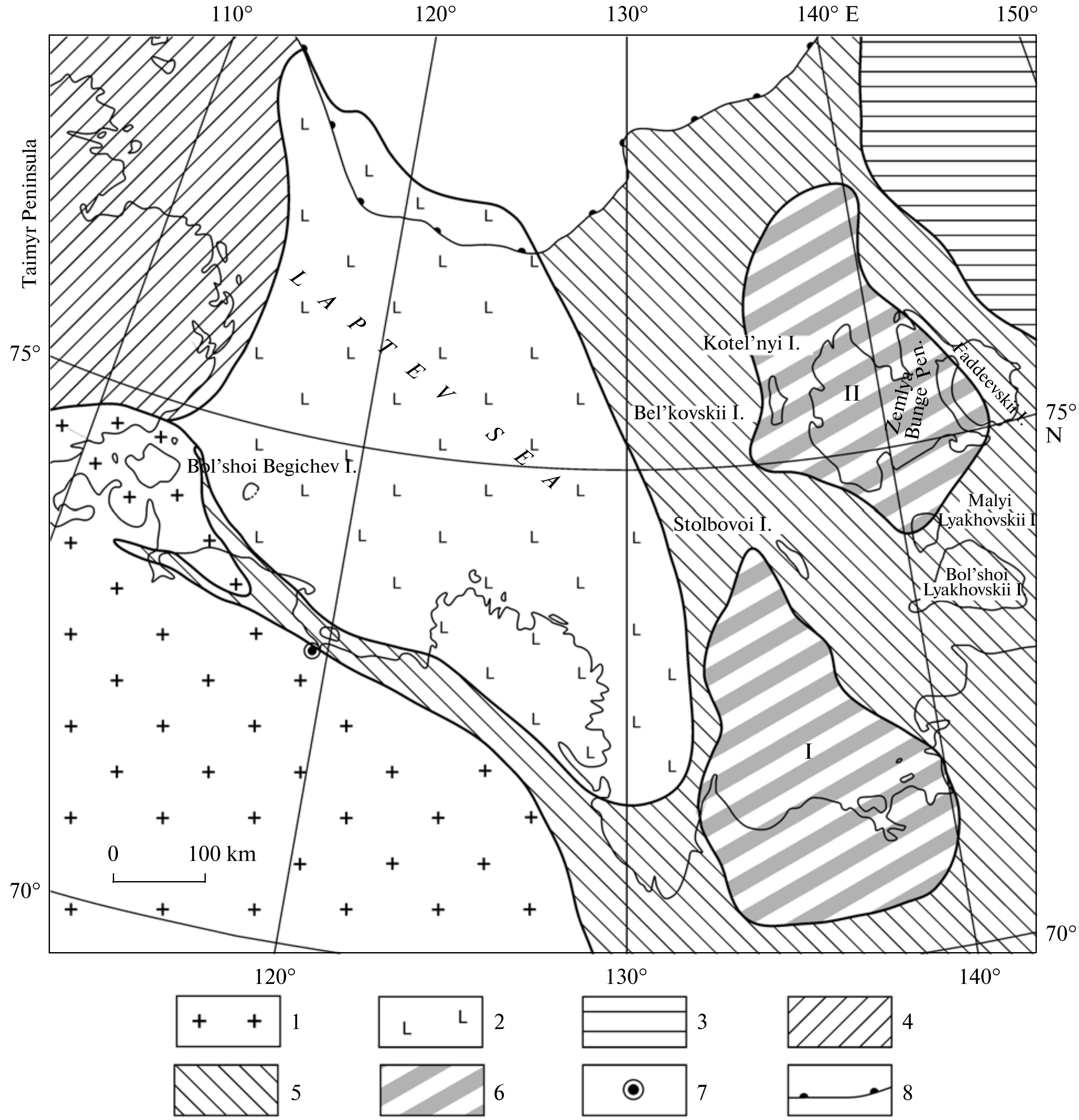


**Fig. 1.** Schematic zoning of the folded basement beneath the Laptev Sea shelf.
(1–5) Age of basement blocks: (1) Karelian, (2) Grenvillian, (3) Caledonian, (4) early Cimmerian, (5) late Cimmerian; (6) median massifs with the Precambrian basement: (I) Shelonskii, (II) Kotel'nyi; (7) Ust'-Olenekskaya Well; (8) shelf edge.

## STRATIGRAPHY OF UPPER JURASSIC AND CRETACEOUS SECTIONS

### *General Characteristics*

The Upper Jurassic and Lower Cretaceous marine deposits are widespread around the Laptev Sea. They crop out on Nordvik Peninsula, along the Anabar River, in the Anabar Inlet, in the Olenek River basin, in the lower reaches of the Lena River, and on some islands of the New Siberian Archipelago (Figs. 2, 3).

On Nordvik Peninsula, the section cropping out in Laptev Sea cliffs comprises the upper Oxfordian Substage, Kimmeridgian Stage, middle and upper Volgian substages, complete Boreal Berriasian Stage, lower and upper (partly) Valanginian substages, and presumably basal Hauterivian Stage (along Nordvik Bay). The integral thickness of upper Oxfordian and Kimmeridgian silty clays is 34 m, the thickness of middle Volgian and Ryazanian mudstone-like $C_{org}$-enriched clays (Paksa Formation) is 51.3 m, and that of Valanginian

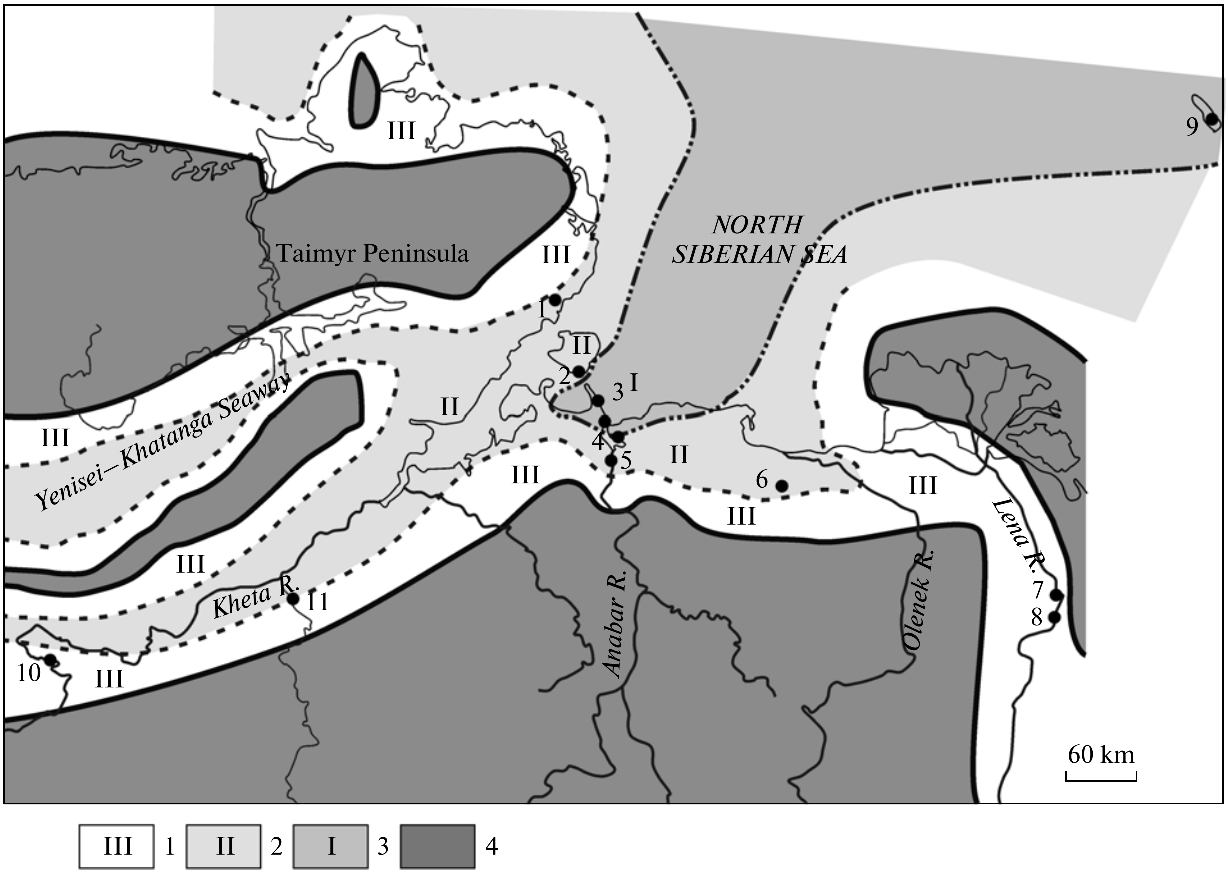


**Fig. 2.** Paleogeographic map of the Yenisei–Khatanga seaway and adjacent basins for the Ryzanian Age (Zakharov et al., in press). (1–3) Bionomic zones of the sea: (1) upper sublittoral (III), (2) middle sublittoral (II), (3) lower sublittoral (I); (4) land. Arabic numerals designate sections mentioned in the text: (1) Chernokhrebetnaya River, Osipa; (2) Bol'shoi Begichev Island; (3) Nordvik Peninsula; (4) Anabar Inlet; (5) Anabar River; (6) Buolkalakh River; (7) Cape Chekurovskii; (8) Cape Chucha; (9) Stolbovoi Island; (10) Kheta River; (11) Boyarka River.

silts and their clayey varieties is 86.2 m. Thus, the integral thickness of the black shale sequence exceeds 160 m. The apparent thickness of poorly sorted (in the lower 10-m-thick member) sand and medium- to fine-grained sandstone in upper members of the lower Hauterivian (?) section exceeds 41 m (Zakharov et al., 1983). The outcrops near the settlement of Uryung Khaya in the lower reaches of the Anabar River east of Nordvik Peninsula exhibit silts of the Bojarkia mesezhnikowi Zone with the apparent thickness of 30 m and mainly silts of the Lower Valanginian (the whole substage), overlying these beds with sedimentary unconformity, and upper Valanginian (?) clayey silts (Fig. 2; Sanin, 1979). The lower Valanginian silty clays grading upward along the section into silts, sandy silts, and crowning sands with calcareous sandstone intercalations crop out in coastal cliffs on the eastern shore of the Anabar Inlet (Bogomolov et al., 1983). The total thickness of these sediments is approximately 150 m. This section comprises all the ammonite zones, which are readily correlated with corresponding units in the Anabar River section (Bogomolov, 1989).

Further to the east, the most complete Upper Jurassic (Volgian Stage) and Lower Cretaceous (Boreal Berriasian and basal lower Valanginian) section is located in the upper reaches of the Buolkalakh River, a left tributary of the Olenek River near its mouth (Fig. 2). In this section, the Volgian Stage is represented by its middle and upper substages, while the Boreal Berriasian includes three zones: Hectoroceras kochi, Surites analogus, and Bojarkia mesezhnikowi. The lower Chetaites sibiricus Zone corresponds probably to the 25-m-wide gap in observations. The Valanginian Stage is represented by the lower Temnoptychites syzranicus Zone (corresponding to the interval spanning from the basal Valanginian approximately to the middle part of the Ramulicosta Zone (Bogomolov, 1989)). The Volgian and Boreal Berriasian stages are united into the Buolkalakh Formation (280 m thick in total) composed of silts and clays with subordinate members and intercalations of fine-grained sandstone. The Valanginian sediments are defined as the Iedes Formation represented by fine-grained compact sands and silts alternating frequently in some members with black clays. The apparent thickness of

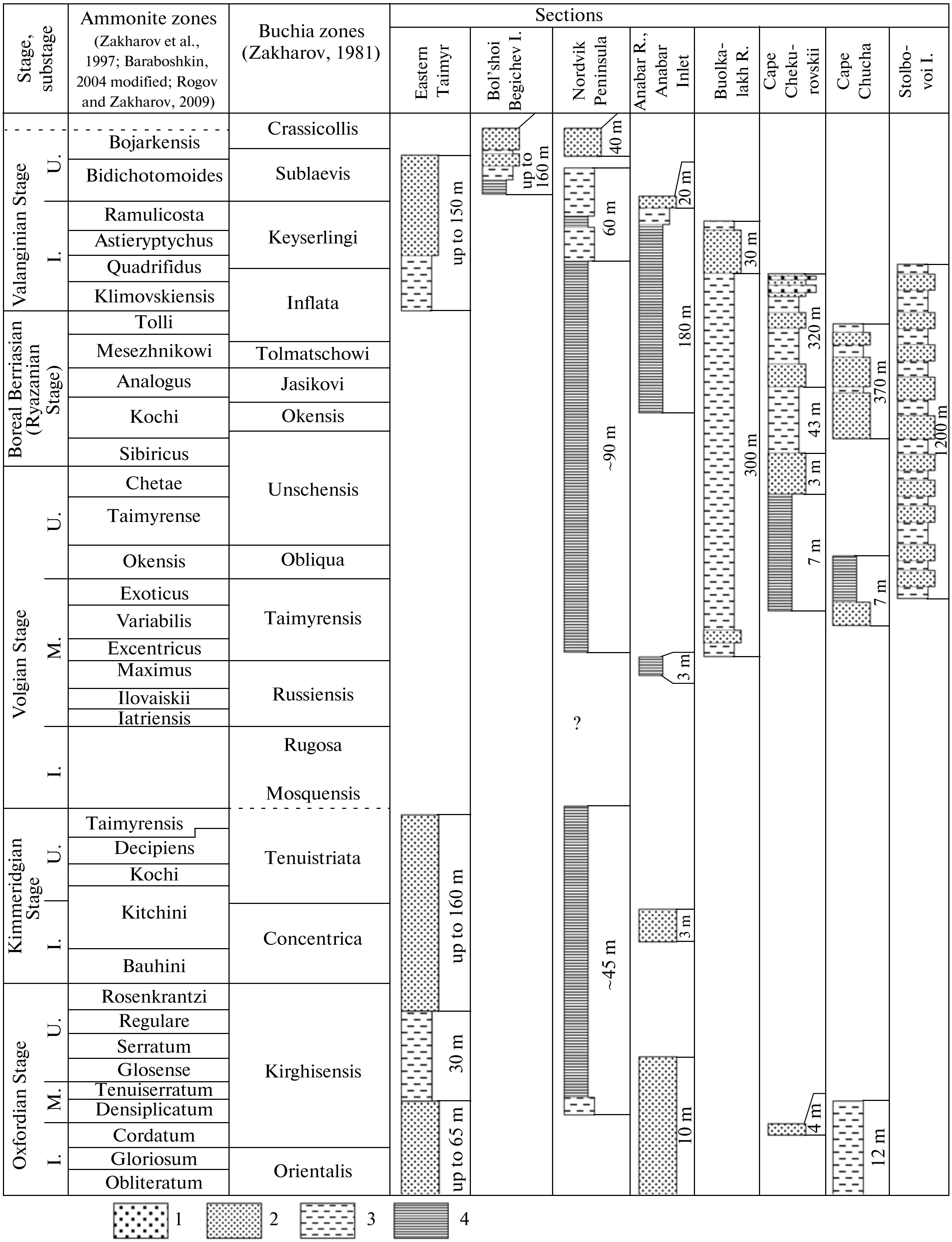


**Fig. 3.** Upper Jurassic–Hauterivian zonal stratigraphy based on ammonites and bivalves (buchiids) and structure of characteristic sections in geological structures surrounding the Laptev Sea.
(1) Gravelites; (2) sands and sandstones; (3) silts and siltstones; (4) clays and mudstones.

the formation is approximately 50 m (Gol'bert et al., 1983). Another distribution area of Jurassic and Lower Cretaceous marine sediments is located in the lower reaches of the Lena River. The most complete section of Upper Jurassic and Lower Valanginian sedimentary successions is exposed on the left side of the river near Capes Chekurovskii and Chucha. In these sections, lower Oxfordian sandstones (Cape Chekurovskii) or lower–middle Oxfordian siltstones (Cape Chucha) are overlain with the erosional surface by a middle–upper Volgian 5-m-thick member of black siltstones. They are in turn overlain by siltstones and sandstones of the Boreal Berriasian Stage over 200 m thick in total and siltstones of the lower zone of the lower Valanginian Substage with the apparent thickness of approximately 160 m (Rogov et al., 2011). It should be noted that, despite the insignificant distance between the Chekurovskii and Chucha sections, the structures of their Cretaceous parts are notably different: in the Cape Chucha section, marine sediments of the Valanginian Stage are represented only by a single layer within the thick terrestrial sequence and underlying sediments of the Boreal Berriasian Stage dominated by sandstones are characterized by a notably higher thickness than in the Cape Chekurovskii section (almost 400 m; Rogov et al., 2012). A continuous section comprising the upper Volgian Substage, Boreal Berriasian Stage, and lower part of the lower Valanginian Substage was also described on Stolbovoi Island, located north of the Laptev Sea shelf. The upper Volgian Substage is largely composed of sandstones with rare members of clayey sandstones and black mudstones with the apparent thickness amounting to 700 m. The Boreal Berriasian Stage, which comprises all the Buchia zones known in the Arctic region, is represented by alternating light to dark gray clayey sandstones with rare black mudstone intercalations approximately 400 m thick. The lower Valanginian Substage is composed of light to dark gray sandstones with mudstone and siltstone intercalations; its apparent thickness is approximately 100 m (Kuz'michev et al., 2009).

Practically all the above-mentioned marine sedimentary sequences contain relatively abundant and diverse molluscan remains, including primarily representatives of the genus *Buchia* and Boreal ammonites from the Craspeditidae, Polyptychitidae, and Dorsoplanitidae families. The Volgian Stage and the lower part of the Lower Cretaceous section are characterized also by still insufficiently investigated Phylloceratids and Lithoceratids; the sections from the deepest part of the basin enclose heteromorph ammonites *Bochianites*. The analysis of molluscan assemblages makes it possible to define both the stages and biostratigraphic units of the bed and zone ranks characteristic of the Boreal realm. The successions of these ammonite- and *Buchia*-based biostratigraphic units are established in sections of the Nordvik Peninsula, the Anabar River, and the Anabar Inlet, in the Olenek River basin, in the lower reaches of the Lena River, and on Stolbovoi Island in the New Siberian Archipelago (Fig. 3).

The zone-by-zone correlation of Upper Jurassic–Lower Cretaceous sections in areas surrounding the Laptev Sea is beyond doubt. Despite the slight difference in lithology and thickness of stratigraphic units constituting Upper Jurassic and lower parts of the Lower Cretaceous sections in western and eastern areas surrounding the Laptev Sea reflected mainly in the stratigraphic range of marine sediments and their thicknesses, which increase in the eastern direction, their principal structure is rather similar in these areas except for Stolbovoi Island. It should be noted that Upper Jurassic and Lower Cretaceous turbidite sediments of Stolbovoi Island were subjected to late Cimmerian folding and constitute the linear syncline complicated by normal and reversed faults (Kuz'michev and Danukalova, 2010). The boundary between the folded Mesozoides and offshore continuation of the Siberian Platform coincides with the Lazarevskii fault, which is considered to be a main basin-forming disjunctive structure (*Geologiya...*, 2004). The area located east of this fault is marked by the disappearance of seismic complexes attributed to the "intermediate" structural stage of the sedimentary cover (Upper Riphean–Hauterivian). As a whole, the Upper Jurassic and basal Lower Cretaceous sections in the areas under consideration are usually composed of dominant clays and silts (or mudstones and siltstones), while the main Lower Cretaceous part of sections is dominated by sandstones. Such sedimentation patterns with dominant fine-grained sediments in the Volgian Stage and increased role of coarse-grained facies in the basal Lower Cretaceous are typical of most areas in the Russian Arctic region (Mesezhnikov et al., 1971).

The zone-by-zone and bed-by-bed correlation of sections provided grounds for the unambiguous conclusion concerning the presence of the upper Volgian Substage in all the above-mentioned sections and middle Volgian Substage in most of them. It is established that all the sections, except the Anabar area, include the complete Boreal Berriasian Stage (equivalent of the Ryazanian Stage). It is also shown that lower Valanginian sediments are universally distributed through the region under consideration.

### *Characteristics of Stages*

The sections in surrounding structures of the Laptev Sea include all the stages of the Upper Jurassic and lower part of the Lower Cretaceous series. Judging from incomplete successions of ammonite- or *Buchia*-based zones, some intervals are missing from some particular sections. Such local lacunae are most frequently explained by erosion of older rocks. At the same time, regional stratigraphic hiatuses in composite sections are extremely rare. The most significant regional hiatus is documented in the lower Volgian

Substage. Inasmuch as high-resolution molluscan biostratigraphy made it possible to date for the first time some narrow intervals of the section, we believe it reasonable to present these materials on the Upper Jurassic and Lower Cretaceous stages. They should be taken into consideration when planning offshore drilling works. Therefore, when characterizing stages, we voluntarily used some information from the section "General Characteristics."

### *Upper Jurassic*

The *Oxfordian Stage* is the most completely represented in sections along the Chernokhrebetnaya River, which contain all zones. The lower, lowermost middle, and upper parts of the upper Oxfordian Substage are largely composed of sands approximately 80 m thick; the uppermost middle substage and largest part of the upper substage consist mostly of silty sediments. A similar structure is characteristic of the Oxfordian Stage in the section cropping out along the Anabar River, where it is largely represented by sands up to 50 m thick and includes all the zones of the lower to middle and, at least partly, upper substages (Knyazev, 1975; *Stratigrafiya*..., 1976). In sections of the Anabar Inlet and Cape Urdyuk Khaya, the Oxfordian Stage is composed of finer rocks (mudstones in the upper middle and basal upper substages grading up and down into sandy siltstones) up to 10 m in total. The lower Oxfordian Substage is missing from this section (its outcrops are located slightly further south) and the latter begins with the middle Oxfordian Substage overlain by the complete upper substage. The Cape Urdyuk Khaya area hosts the only section in the region under consideration with the gradual transition between the Oxfordian and Kimmeridgian stages (Rogov and Wierzbowski, 2009). Further east, the upper Oxfordian Substage pinches out (locally, the middle substage as well). The section located near Cape Chekurovskii in the Lena River basin includes only the Bukowskii Subzone of the lower Oxfordian Cordatum Zone represented by a thin (from 1 to 3 m) sandstone or limestone layer. Further north, near Cape Chucha, the lower Oxfordian Substage up to 6–7 m thick largely composed of siltstones with intercalations of carbonate concretions is characterized by its complete stratigraphic range being overlain by the middle Oxfordian Substage represented by the Densiplicatum Zone (Rogov et al., 2011).

The *Kimmeridgian Stage* in most Upper Jurassic sections around the Laptev Sea is characterized, dissimilar to the Oxfordian one, by a reduced range or is missing completely. The only exception is the Cape Urdyuk Khaya section, where the Kimmeridgian Stage is represented by all zones except, probably, for the terminal Taimyrensis Zone, which cannot be unambiguously recognized, since ammonites from the genus *Suboxidiscites*, close to *S. taimyrensis*, occur in this section beginning from the lower Kimmeridgian Substage (Rogov and Wierzbowski, 2009). In the Cape Urdyuk Khaya section, the Kimmeridgian Stage is largely composed of mudstones up to 10 m thick. The relatively complete Kimmerdgian Stage section is observed further north at the Chernokhrebetnaya River, where the thick (approximately 160 m) sequence of sands and sandstones contains ammonites characteristic of the lower Kimmeridgian Bauhini and Kitchini zones and the upper Kimmeridgian Eudoxus Zone (Basov et al., 1963; Mesezhnikov, 1984). In the lower courses of the Anabar River, lower Kimmeridgian ammonites are found only in talus. They originate most likely from a thin (<3 m) glauconite sand layer with carbonate concretions (*Stratigrafiya*..., 1976). Further east, in the Lena River basin, Kimmeridgian fossils occur only in pebbles at the base of lower Volgian sediments. No Kimmeridgian outcrops are known in this area.

The *Volgian Stage* is characterized in the region under consideration by a wider distribution as compared with the Kimmeridgian one, although its sections are frequently incomplete. At the Anabar River, only the upper part of the middle Volgian Substage is established. In this area, it is represented by a 3-m-thick member of clays and silts (*Stratigrafiya*..., 1976). In the Cape Urdyuk Khaya section, the oldest levels of the Volgian Stage are attributable, on the basis of ammonites, to the Variabilis Zone or, probably, uppermost part of the Excentricus Zone. The underlying sediments contain only belemnites, which allow its boundary with the Kimmeridgian Stage to be established, although they provide no grounds for attributing them to the particular part of the Volgian Stage. The higher layers of the Volgian Stage represented by an approximately 20-m-thick member of mudstones with abundant phosphate and carbonate concretions contain diverse ammonite, belemnite, and bivalve fossils, which imply that the section under consideration comprises only the upper part of the middle substage and complete upper substage (Zakharov and Rogov, 2008). A similar stratigraphic range is characteristic of Volgian clays and siltstones approximately 10 m thick cropping out along the Buolkalakh River in northern Yakutia (Gol'bert et al., 1983) and an 8-m-thick member of Volgian mudstones near Capes Chekurovskii and Chucha in the lower reaches of the Lena River. In sections located further south along the Lena River and its tributaries, the thickness of alternating mudstones, siltstones, and sands of the Volgian Stage increases considerably, up to 300 m (Bidzhiev, 1973). The maximum thickness of the Volgian Stage is observed on Stolbovoi Island, where upper Volgian turbidites represented by alternating sandstones, siltstones, and mudstones are up to 700 m thick (Kuz'michev et al., 2009). They are practically barren of ammonites (only a single *Boreophylloceras* fragment is found), and the presence of the upper Volgian Substage in this area is evident from the characteristic Buchia assemblage (Zakharov and Kuz'michev, 2008).

### *Lower Cretaceous*

The *Ryazanian Stage (Boreal Berriasian)* rests conformably on the upper Volgian Substage in sections, where they form a continuous succession. The distribution of the Ryazanian Sage through the region under consideration is wider and it is usually thicker as compared with the Volgian Stage. On Nordvik Peninsula, the Ryazanian Stage is present in its complete range. It is largely composed of clays and subordinate silts with abundant carbonate concretions. The thickness of the stage is approximately 50 m. On the eastern shore of the Anabar Inlet, the exposed section includes only the upper part of the stage (Tolli Zone) represented by mudstones with the apparent thickness of 5 m. The section along the Anabar River comprises lower layers of the stage, at least beginning from the Kochi Zone. In this area, the thickness of Ryazanian clays with carbonate concretions exceeds 30 m (Saks et al., 1972). East of the Anabar River, the thickness of coeval Boreal Berriasian layers increases substantially. At the Buolkalakh River (left tributary of the Olenek River), the Boreal Berriasian Stage is composed of clays and silts with carbonate concretions up to 280 m thick in total (Gol'bert et al., 1983). A similar or greater thickness is characteristic of the Ryazanian Stage in the lower reaches of the Lena River (Capes Chucha and Chekurovskii) and on Stolbovoi Island. In the Cape Chekurovskii section, the stage is represented by alternating thick members of siltstones and sandstones with ammonites indicating the presence of all zones (Rogov et al., 2011). In the neighboring Cape Chucha section, the thickness of the Ryazanian Stage with a substantially higher share of sandstones increases approximately to 400 m. The fossils are rare with ammonites characterizing only the Mesezhnikowi Zone. At the same time, the finds of *Buchia unschensis* and *B. fischeriana* in underlying sediments implies the presence of the lower part of the stage in this section (Rogov et al., 2012). On Stolbovoi Island, the approximately 600-m-thick Boreal Berriasian sequence is composed, similar to the Volgian Stage, of turbidites, which contain only *Buchia* remains (Kuz'michev et al., 2009).

The *Valanginian Stage* (particularly its upper part) is largely represented by coarser rock varieties as compared with the Ryazanian Stage. The distribution of lower Valanginian marine sediments is universal through the region under consideration. The upper Valanginian Substage is entirely or partly represented by terrestrial facies. In eastern Taimyr, the 150-m-thick sequence of alternating clays, silts, and sands with concretions of clayey limestone and siderite corresponds to the Valanginian Stage (*Stratigrafiya*..., 1987). In Nordvik Peninsula, the stage is composed of siltstones up to 100 m thick. The terminal part of the section attributed to the Homolsomites bojarkensis Zone is observable on the western coast of Nordvik Peninsula and on Bol'shoi Begichev Island. It is composed of sands and sandstones with the apparent thickness of approximately 30 m. The section at the Anabar River includes the Klimovskiensis and Quadrifidus zones largely composed of clay 55 m thick. The more complete section of the Valanginian Stage is documented in the Anabar Inlet, where its lower substage is complete, being formed by clays approximately 150 m thick. The terminal part of the lower Valanginian Substage is composed of sands and sandstones approximately 20 m thick (Bogomolov, 1989). Its higher layers are exposed on the opposite side of the Anabar Inlet, where they are represented by terrestrial facies. The section at the Buolkalakh River includes silts and sands approximately 50 m thick corresponding only to the lower part of the lower Valanginian Substage (Gol'bert et al., 1983). The marine Valanginian facies in the Cape Chekurovskii section characterizes only the lower substage. The apparent thickness of siltstones, sandstones, and conglomerates exceeds in this section 100 m (Rogov et al., 2011). In the Cape Chucha section, the lower Valanginian Substage is mostly composed of terrestrial facies except for a thin sandstone layer with *Buchia keyserlingi*. As follows from many *Buchia inflata* finds, the Stolbovoi section also includes only the lower part of the Valanginian Stage approximately 100 m thick (Zakharov and Kuz'michev, 2008).

## FACIES AND PALEOGEOGRAPHY

Only indirect interpretation of Late Jurassic and Early Cretaceous depositional environments in the Laptev Sea is possible on the basis of evidence derived from corresponding sections in its surrounding structures and seismic records. In the Late Jurassic–Early Cretaceous, the Yenisei–Khatanga trough was occupied by a seaway that connected the eastern part of the Arctic basin with the West Siberian Sea. According to (Saks, 1961), this sea included three facies zones extending parallel to the Taimyr land block in the north and Middle Siberian land in the south. The extensive investigation of the geological structure in northern Siberia carried out by geological teams from the Research Institute of Arctic Geology, All-Russia Petroleum Research Exploration Institute, and Institute of Geology and Geophysics (Siberian Branch of the USSR Academy of Sciences of the USSR) in the 1960s–1970s contributed much to the detailed paleogeographic and facies reconstructions of the Late Jurassic and Early Cretaceous North Siberian Sea. The integrate analysis of litho- and biofacies for the Volgian, Boreal Berriasian, Valanginian, and early Hauterivian ages made it possible to reconstruct bathymetric zones for all these epochs and describe complexes of particular lagoonal, lagoonal–marine, shallow-marine, moderately deep marine, and relatively deep marine facies (Zakharov and Yudovnyi, 1974). The taphonomic and lithological–sedimentological field observations combined with the paleoecological, mineralogical, and geochemical investigations in laboratories provided grounds for characterizing the main factors of depositional environments (hydrodynamics, gas regime in bottom water layer, substrate types, salinity, and temperature) and estimating depths of the basin. The extensive data on Upper Jurassic deposits on continental blocks surrounding the Laptev Sea were summarized by lithologists and paleontologists at the beginning of the 1980s in the monograph *Paleogeografiya*... (1983). In broad terms, the following succession of depositional events may be reconstructed.

At the beginning of the Oxfordian Age, the Khatanga Sea inherited late Callovian depositional environments. These settings of the middle sublittoral zone were, however, replaced soon both in the north (eastern Taimyr, Chernokhrebetnaya River) and in the south (Anabar River) by relatively shallow-water conditions with development of dominant sandy facies in response to the regression onset. No deepwater sediments are recorded in the Yenisei–Lena interfluve. They are probably missing in the Laptev Sea as well. The bay of the early Oxfordian Sea reached the lower courses of the Lena River (Bulkur River, Cape Chekurovskii), where it accumulated thin clayey–silty sediments with remains of the stenohaline ammonite, belemnite, and bivalve fauna. In the late Oxfordian, the central part of the basin became deeper, which resulted in the leveled bottom equilibrium profile on the Taimyr side and in the south near the Middle Siberian land. Upper Oxfordian clays on Nordvik Peninsula (Cape Urdyuk Khaya) may be considered as middle sublittoral facies, which could extend in the eastern direction from the Nordvik coast toward the present-day New Siberian Islands. Nevertheless, no upper Oxfordian sediments are established in the Lena River basin, located in the eastern part of the region under consideration.

The Kimmeridgian relief of northern East Siberia was in general inherited from the Oxfordian Age: configurations of sea basins in the Yenisei–Khatanga interfluve remained practically unchanged as compared with the latter. At the onset of the Kimmeridgian Age, Oxfordian shallow-water settings in the Khatanga Sea were replaced by deeper environments with a stable depositional regime. The areas near the northern and southern coasts in the Kimmeridgian mostly were characterized by sandy sediments: glauconitic–ferruginous–chloritic sands up to 25 m thick with concretions and nodules of calcareous sandstone (Boyarka River) and sands over 40 m thick with siltstone intercalations, concretions of sandy limestone, and coquina lenses (eastern Taimyr, Chernokhrebetnaya River). The central part of the basin (Nordvik Peninsula) was occupied by the middle littoral zone with stable deposition of clays and clayey silts up to 18 m thick. Similar to the late Oxfordian, the transverse bathymetric profile in the early Kimmeridgian was asymmetrical: gentle on the Middle Siberia land side and relatively steep on the Taimyr side (*Paleogeografiya*..., 1983, fig. 28). In the late Kimmeridgian, the central part of the Khatanga basin (at least its eastern half) subsided to form a relatively deep (lower sublittoral) zone. Through the entire Kimmeridgian Age, northern East Siberia was occupied by a sea basin populated by highly diverse and abundant invertebrates. The average annual temperatures of its waters were as high as 14.5 and 14.7°C in the early and late Kimmeridgian, respectively. In the lower reaches of the Lena River, reworked Kimmeridgian ammonites are registered in basal layers of the Volgian Stage. It is conceivable that this region was partially drainaged in the late Kimmeridgian (Bidzhiev, 1965).

In the Volgian Age, most regions of North Eurasia experienced substantial paleogeographic reorganizations. A brief regression in the mid-early Volgian is reflected in erosional surfaces and stratigraphic hiatuses within corresponding sections. The middle and late Volgian time was characterized by the maximal Jurassic transgression. The enhanced tectonic movements were accompanied by orogenesis and differentiation of the land and sea bottom relief (*Paleogeografiya*..., 1983, p. 131). In the Khatanga Sea, the middle littoral zone approached the Middle Siberian land and Taimyr in the late Volgian time in response to transgression and subsidence of its central part. Silty–clayey facies formed in relatively and moderately deep settings became widespread throughout the basin. Material for them was provided by the peneplaned Siberian land, which was subjected to intense weathering under the influence of the humid moderately warm climate (Gol'bert et al., 1968). In the Khatanga Sea, three distinct depositional and bionomic zones located parallel to paleoshores differentiated at that time: coastal-shallow, moderately deep offshore, and relatively deep located further away from the shoreline. The deepest marine environments existed in the axial part of the basin (Nordvik Peninsula). The remarkable feature of its sediments is rhythmical alternation of clayey rock types with different lithological–geochemical and paleoecological characteristics (Basov et al., 1970). Of particular interest are brownish dark gray bituminous platy mudstones with layers 0.2–0.3 m thick. The $C_{org}$ content in middle–upper Volgian and lower Berriasian mudstones (Paksa Formation) varies from 2 to 3%, locally amounting to 4% (Zakharov and Yudovnyi, 1974). Dispersed organic matter is dominated by sapropelic material and remains of benthic plants similar to brown algae in coeval sections of West Siberia (Kaplan et al., 1973). The analysis of clay minerals and elemental composition of the black-shale sequence through its entire distribution area from the Laptev Sea to northern Greenland allowed the conclusion that depositional (and, probably, tectonic) processes in the eastern and western segments of the Arctic basin were stable during the terminal Jurassic–initial Cretaceous period (Dypvik and Zakharov, 2010, 2012). It is quite conceivable that such rocks are widespread also in the Laptev Sea. The

Volgian sediments contain remains of diverse marine stenohaline invertebrate (ammonites, belemnites, bivalves, gastropods, brachiopods, foraminifers, crustaceans, Echinodermata) and vertebrate (ichthyosaurs, Teleostei) organisms and marine phytoplankton, which indicate the normal marine regime. Paleothermometric investigations reveal that the basin was characterized by moderately warm waters with the average annual temperatures of 14–15°C. The paleoecological analysis of the deepest benthic communities indicates intermittent oxygen deficiency at the sediment–water interface during accumulation of bituminous platy mudstones (Zakharov et al., in press). The sedimentological analysis of middle and upper Volgian clayey silts and clays with phosphate and carbonate concretions enclosing ammonites and bivalves from sections cropping out along the right bank of the Anabar River and in the Anabar–Olenek interfluve shows that these sediments were deposited in the middle sublittoral zone. The presence of conglomerates, gravelites, and coarse-grained sandstones at the base and top of succession implies unstable depositional environments (*Stratigrafiya*..., 1976). During the Volgian Age, the Taimyr and Middle Siberia land blocks (source areas) were higher as compared with the Kimmeridgian Age and clastic material transported to margins of the paleobasin was coarser. The seaway that was formed in the northeastern part of the Middle Siberia land separated Olenek Island from it. The lower reaches of the Lena River were occupied by a bay, which ran deep into the lacustrine–fluvial valley and had free water exchange with western and eastern basins (*Paleogeografiya*..., 1983, fig. 29). During the Volgian Age, the bay accumulated a thin sequence of fine-grained sediments.

In the first half of the Boreal Berriasian Age, the paleogeographic situation resembled that of the terminal Volgian Age: land–sea proportions, depositional environments, climate, water salinity, and temperature remained similar to those parameters in the late Volgian basin (Zakharov and Yudovnyi, 1974, fig. 9). This period corresponded to a single late Volgian–early Ryazanian depositional and ecological stage. Nevertheless, sedimentation patterns in western areas of the Khatanga Sea changed in the early Ryazanian time: upper Volgian silts in the Kheta River section (Bukatyi Creek) were replaced by fine-grained sands of the Chetaites sibiricus Zone corresponding to the basal Boreal Berriasian Stage. This event coincided with the onset of the regression, which culminated in the Hauterivian in the disappearance of the sea basin in almost all of northern Eurasia. In the Nordvik Peninsula area, lower Ryazanian clayey sediments were replaced by clayey–muddy facies with admixture of ferruginous chlorites in the late Boreal Berriasian Age. Bituminous mudstones of the second type disappeared gradually from the section. By the end of the Boreal Berriasian Age, the relatively deep marine settings were preserved only in the eastern axial part of the Khatanga trough. Average annual temperatures gradually decreased by 2–3°C as compared with their late Volgian values. Similar to the Volgian Age, trappes served as a main source of terrigenous material. In the terminal Boreal Berriasian Age, shallow-water settings in the eastern part of the Khatanga basin were displaced to the areas of the Popigai and Anabar rivers, which accumulated gravelly and sandy sediments with cephalopod remains and relatively diverse benthic organisms, among which *Buchia* representatives were dominant. In the Ryazanian Age, sedimentation rates in the lower reaches of the Lena River became substantially higher and sediments coarser.

The early Valanginian time was marked by further degradation and shallowing of the Khatanga basin (Zakharov and Yudovnyi, 1974, figs. 11, 12). The coarse-grained sediments represented by various sands locally with gravel admixture were distributed practically throughout the entire region under consideration: Taimyr Peninsula, Begichev Island, Nordvik Peninsula, Anabar Bay, Olenek River, and lower reaches of the Lena River. Abundant features indicating shallow-water conditions such as ripple marks, synsedimentary hiatuses, rapid changes in sedimentation rates, cross-bedded structures, coquinas, and *Scolithos*-type ichnofossils imply unstable depositional environments. The most stable depositional settings were characteristic of the axial part of the Khatanga Sea. They are reflected in the Nordvik Peninsula section, which is composed of siltstones with members of sandy–limy concretions containing *Buchia* remains and rare ammonite shells. Against the background of the general Early Cretaceous regression, the shoreline displacement was variably oriented: it either retreated inland or migrated seaward. This resulted in frequent changes of sedimentation settings and ecological conditions. The climate was warm and humid at that time. Development of coeval analogs of the Achimov (Berriasian–lower Valanginian) deposits and their significant thicknesses throughout the entire southern continental margin of the Laptev Sea provide grounds for an assumption that they are distributed in the basin proper.

## INTERPRETATION OF SEISMIC RECORDS

Of importance for the objective solution of the debatable problem concerning the stratigraphic range of the sedimentary cover on the Laptev Sea shelf (in absence of drill holes) is the correlation of seismic sections obtained by geophysicists at their intersections with simultaneous comparison between occurrence depths (or travel times) of defined reflectors and their stratigraphic control. In this connection, the extended (325 km) German BGR 97-01 profile crossing the western and eastern parts of the shelf and two Russian MAGE 86709 and 86707-II profiles were selected for the analysis. The first and second of them cross the German profile in the central and eastern part of the shelf, respectively. For our purposes, it is important that the BGR 97-01 profile crossing the western and central parts of the shelf reaches also its eastern part, where Aptian–Cenozoic age of the sedimentary cover is widely accepted by Russian researchers. It should be remembered that Aptian strata (Balyktakh Formation) in the Kotel'nyi Island section rests upon underlying rocks with the erosional surface and angular unconformity, and data on the geological structure of the island (where Upper Jurassic and Lower Cretaceous rocks constitute the synclinal fold) and southeastern Laptev Sea coast allow the unambiguous conclusion that its basement in the eastern part of the shelf was formed by the late Cimmerides.

When interpreting the time section along the BGR 97-01 profile (*Cruise...,* 1997; *End Bericht...*, 1999), the German researchers defined three regional reflectors (from the base upward): (LS1) confined to the unconformity between the lower and upper Paleocene at the base of the sedimentary cover (65–56 Ma); (LS2) corresponding to the unconformity in the lower part of the Oligocene section (35 Ma); (LS3) coinciding with the unconformity in the lower part of the upper Miocene section (9–10 Ma). The analysis of the deep part of this record revealed that the thickness of the sedimentary cover through most of its length amounts to 10–13 km, gradually decreasing in the eastern direction to 5–6 km and becoming 2.5 km behind the Lazarev fault in the eastern part of the shelf (Franke et al., 2001). This, unnamed fault was first defined in (Ivanova et al., 1989) using seismic materials obtained by MAGE in 1986–1990. The fault is distinctly expressed by a step in the gravity field. In the schematic map of tectonic zoning of the folded basement beneath the shelf, it marks the eastern boundary of the Grenville block, which is identified with the offshore continuation of the Siberian Platform. Correspondingly, west of this boundary, the thickness of the sedimentary cover increases significantly on account of its "intermediate" (Riphean–Lower Cretaceous) stage. According to the alternative model, the shelf is the Cenozoic (*End Bericht...*, 1999) or Aptian–Cenozoic (Vinogradov and Drachev, 2000) in age. In the fault zone, it is displaced with the amplitude ranging from 2.5 to 5–7 km. The analysis of seismic records obtained along two crossing profiles helps in solving this problem. One of these profiles (German BGR 97-01) is transverse relative to the strike of structures and another (Russian MAGE 86707-II) is oriented along their strike (Fig. 4). Their intersection point is located in the junction zone between the Omoloi trough and horst-shaped uplift of the late Cimmerian basement (Central Laptev). The cover thickness in the first and second structures is up to 10 and 1.3–3.0 km, respectively.

The interpretation of the BGR profile (Fig. 5a) reveals that the section along the line of intersection with the MAGE profile, east of the Lazarev fault (after K. Hinz), exhibits several additional regional reflectors (indicated in records along the Russian profile as reflectors III–VI, Fig. 5b) below reflector LS1 (identified with the acoustic basement surface and corresponding to reflector II in the Russian profile). Four main reflectors in sections of these profiles are defined at the same times (depths): LS1 (1.7 s)–II (1.7 s); III (2.6 and 2.6 s); IV (2.8 and 2.8 s); VI (3.5 and 3.45 s). In the central part of the shelf, reflector VI is identified with the acoustic basement, i.e., Grenville folded basement; reflector IV with the unconformity at the base of Upper Devonian; reflector III with the unconformity and contrasting interface between Middle Paleozoic carbonate and Upper Paleozoic terrigenous rocks; and reflector II with the unconformity at the base of the Aptian sequence.

In both profiles, reflector VI is traceable, similar to reflectors IV and III, only for approximately 10 km away from their intersection point and is truncated by faults, which occupy the easternmost positions in both of them. In fact, it represents a single fault crossed at two points and corresponding in this area to the boundary between the "platformal" and "folded" zones of the shelf. East of this fault, reflector II (LS1 in the German profile) is traceable.

Thus, the following two conclusions may be made:

(1) The boundary between the "platformal" and "folded" zones of the shelf extends 30 km from the Lazarev fault, i.e., within its zone, not strictly along the fault (Fig. 5a).

(2) West of this boundary, the reflector LS1 (the top of the basement, according to German researchers) is underlain by a thick section belonging to the paraplatformal ("intermediate") structural stage of the sedimentary cover (Figs. 6a, 6b) resting upon the Grenville basement.[1]

The comparative analysis of interpreted seismic records obtained along the BGR 97-01, MAGE 86707-II, and MAGE 86709 profiles (Figs. 3, 4) shows that main (reference) reflectors in the sedimentary cover section (VI, V', V, IV, II, $II_1$, and L) are best recognizable within large negative structures in the central part of the shelf: Ust'-Lena graben and Omoloi trough located west of the profile fragments considered in this work. Near the Lazarev fault zone, some lower reflectors enclosed in the sedimentary cover (V', V) demonstrate a tendency for pinching out in sections (Fig. 5a). All the reflectors are confined to unconformities in sections of surrounding islands and coastal areas and in well sections drilled in the Lena–Anabar trough. For example, the LS1 (II), LS2 ($II_1$), and LS3 (I) reflectors correspond to unconformities at the bases of the Aptian, Paleocene, and Miocene sequences, respectively. In the eastern part of the shelf, reflector II (LS1) represents the last correlative reflection and is identified with the top of the late Cimme-

[1] Upper Riphean deposits recovered on the coast by the Ust'-Olenekskaya well are consistent with Grenvillian age.

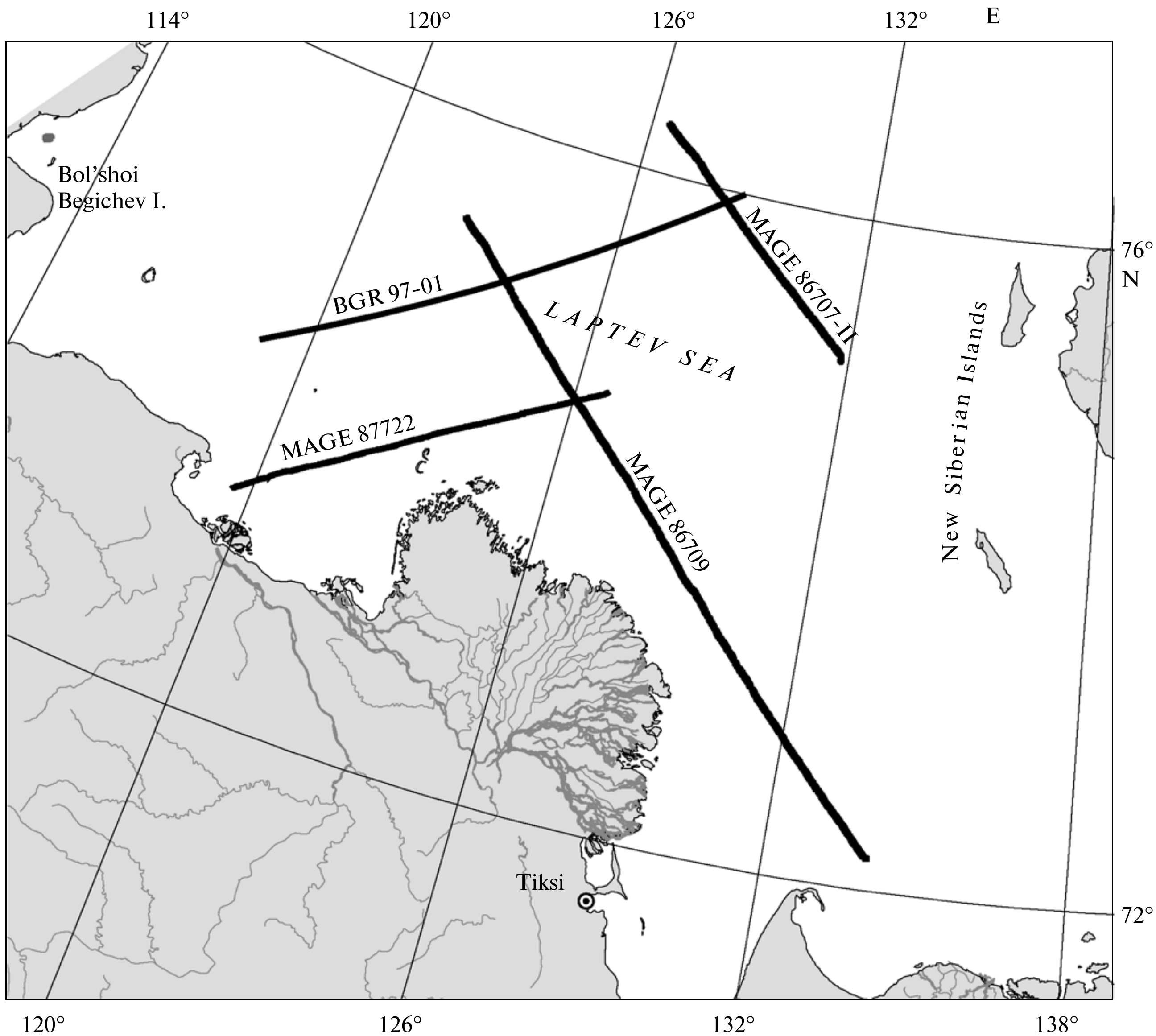


**Fig. 4.** Location of seismic profiles across the Laptev Sea shelf.

rian folded basement. The Laptev continental marginal plate as a single geostructure corresponds to the Aptian–Cenozoic structural stage. For the eastern part of the plate, this is the first and only stage reflected in its sedimentary cover. Figure 7 demonstrates the correlation of reflectors and age of seismostratigraphic units in the section of the sedimentary cover on the Laptev Sea shelf.

Of interest is also geological interpretation of the MAGE 87722 profile (Fig. 8). The profile begins at one of the uplifts of the Lena–Taimyr boundary zone in Olenek Bay, which separates structures of the shelf from the onshore coastal Olenek zone of dislocations. The thickness of the sedimentary cover in the Lena–Taimyr zone never exceeds 1.8 km, while in most subsided areas of the South Laptev trough, where the section comprises up to eight seismic units, it amounts to 8 km. The stratigraphic positions of seismic units of the basinal ($K_1a$–KZ) and Upper Paleozoic–Mesozoic complexes of the cover are established most reliably in contrast with Lower–Middle Paleozoic complexes constituting the lower part of the intermediate structural stage.

According to alternative interpretation of the record obtained along this profile, the section includes seven seismostratigraphic units and the age of the basement is accepted as being the late Cimmerian. In the opinion of some authors (Vinogradov et al., 2008), the upper seismostratigraphic unit is the Cenozoic in age, while underlying units are dated back to the Aptian–Late Cretaceous. If two large transgressions that happened during the Apian–Albian and Late

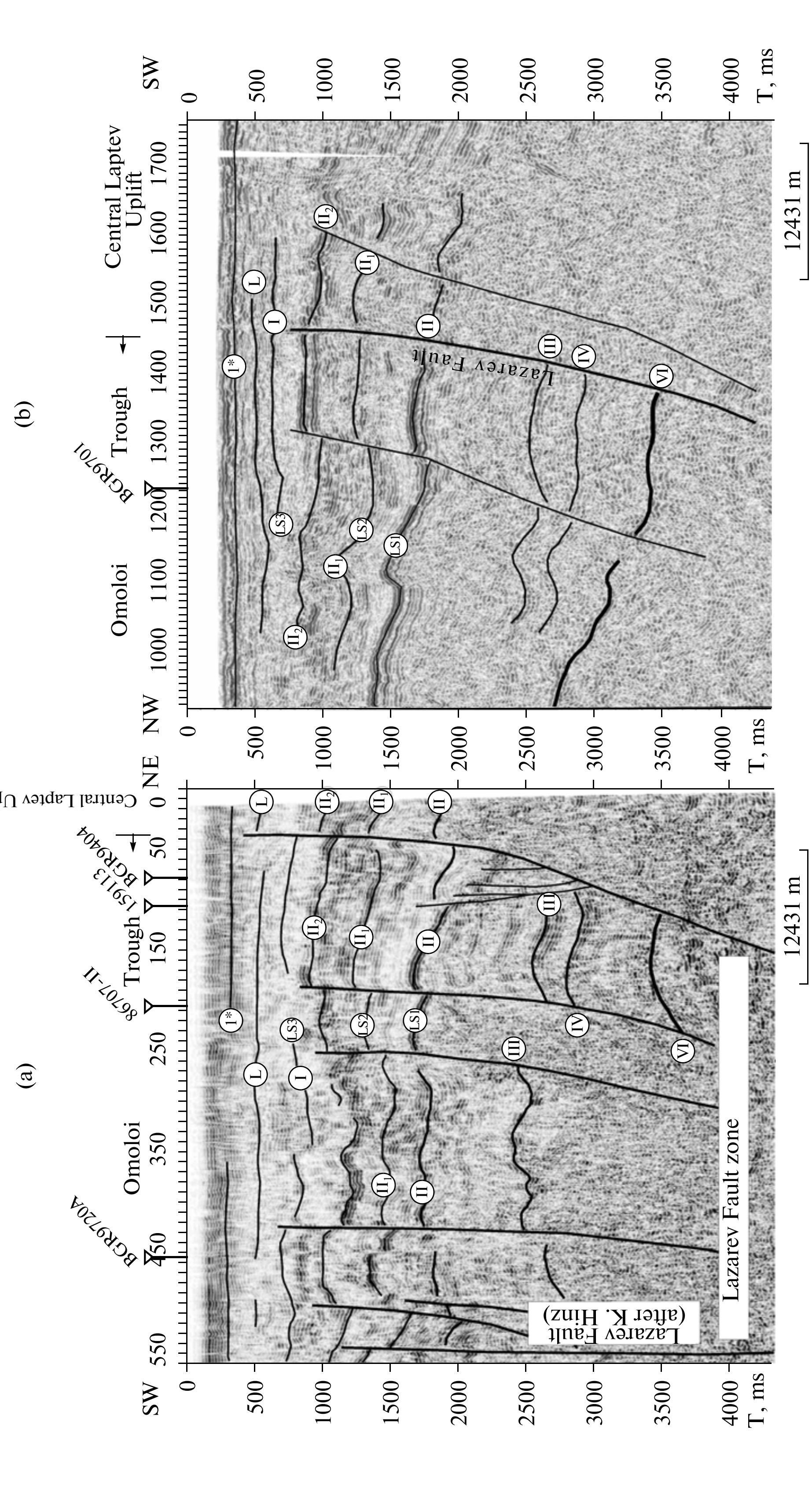


**Fig. 5.** Fragments of seismic time sections along the BGR 97-01 profile intersecting with the MAGE 86707-II profile (a) and the MAGE 86707-II profile intersecting with the BGR 97-01 profile (b).

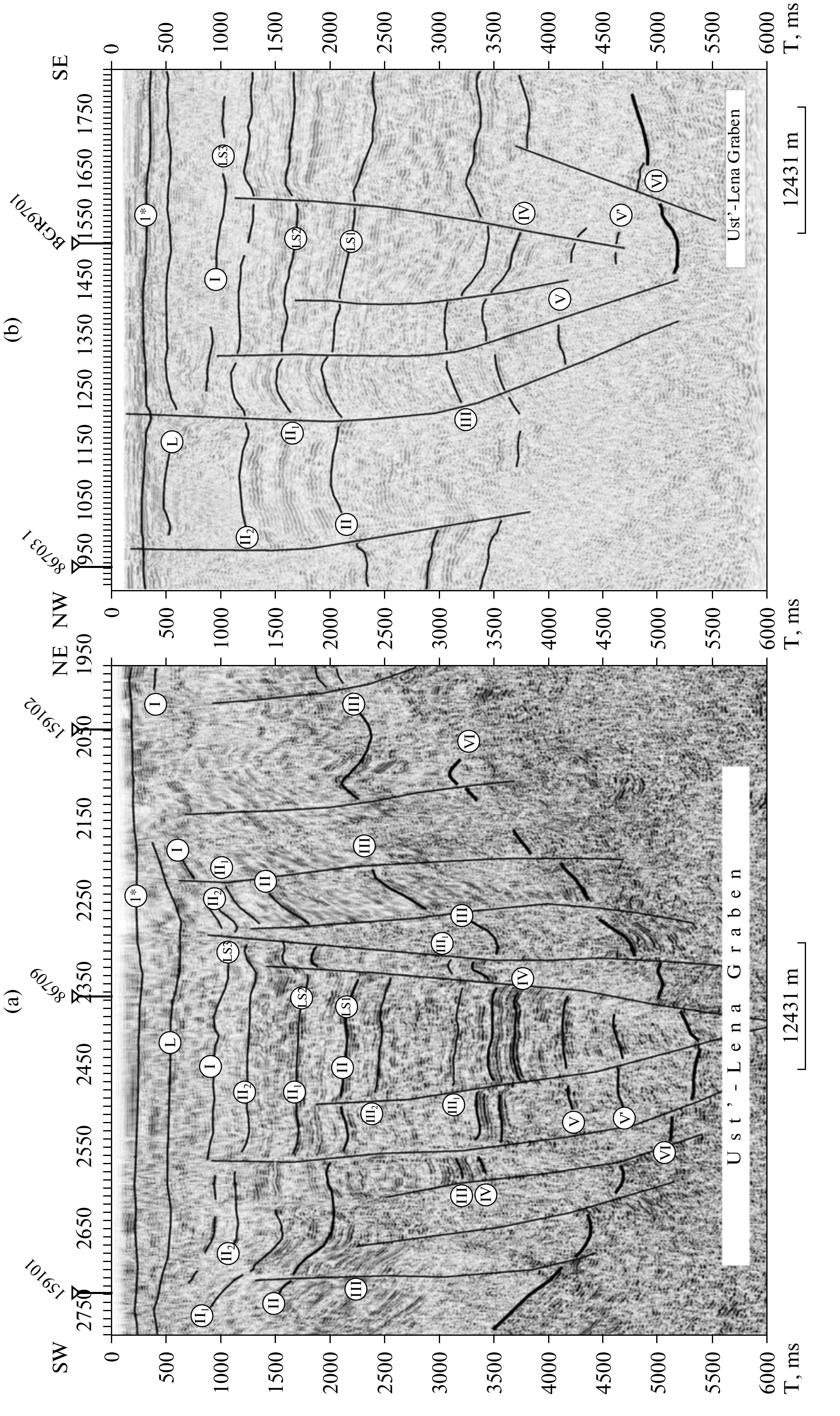


**Fig. 6.** Fragments of seismic time sections along the BGR 97-01 profile intersecting with the MAGE 86709 profile (a) and the MAGE 86709 profile intersecting with the BGR 97-01 profile (b).

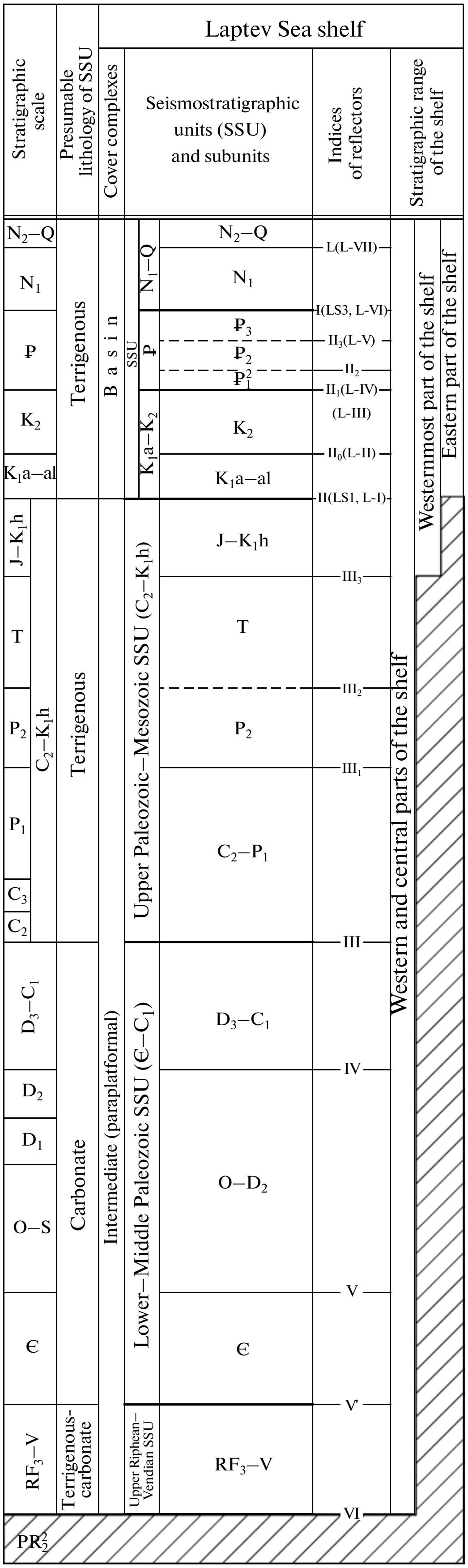


**Fig. 7.** Correlation of reflectors and age of seismostratigraphic units in the section of the sedimentary cover on the Laptev Sea shelf.

Indices of reflectors (L, I–VI) are given after (Ivanova et al., 1989; Sekretov, 1993); in brackets: indices of reflectors LS1–LS3 in the record along the BGR 97-01 profile correspond to reflectors L-I–L-VII after (Vinogradov et al., 2005) in the record along the crossing MAGE 86707-II profile (*Geologiya...*, 2004).

Cretaceous (Vail et al., 1977) are taken into consideration, there are still four lower seismostratigraphic units with ages which fall outside of the stratigraphic interval accepted by these researchers. According to R.O. Galabala (*Gosudarstvennaya...*, 2001), "judging from the seismic materials and logging available for the Charchykskaya Well, the average stratal velocities are 3.6, 4.18, and 5.44 km/s in Permian terrigenous, Cambrian carbonate, and Upper Proterozoic terrigenous–carbonate deposits, respectively. By their density parameters, they are close to sequences reflected in seismic records along Profile 87722."

Thus, interpretation and analysis of seismic records under consideration indicate in our opinion that the Siberian Platform continues to the shelf.

## DISCUSSION AND CONCLUSIONS

The high-resolution stratigraphy of Jurassic and Cretaceous sections in structures surrounding the Laptev Sea (Cape Tsvetkov area, Nordvik Peninsula, Anabar River, Anabar Inlet, Olenek River, lower reaches of the Lena River, and islands of the New Siberian Archipelago) and analysis of seismic records allow an assumption that the sedimentary cover of the Laptev Sea comprises Upper Jurassic and Lower Cretaceous sequences, including coeval analogs of the highly carbonaceous Bazhenovo Formation (Volgian Stage) and reservoir Achimov Formation (Boreal Berriasian and lower Valanginian) of West Siberia.

Interpretation of seismic records implies that, in the eastern part of the shelf, these formations represent elements of the late Cimmerian folded basement and cannot be considered as potential hydrocarbon source rocks. At the same time, significant thicknesses of the sedimentary cover documented by seismic exploration works west of the Lazarev fault (or fault zone) and approximately equal number of reflectors corresponding to unconformities in sections (including sections of onshore wells) indicate development of older (in addition to Jurassic and Cretaceous) formations in the sedimentary cover of the western and central parts of the shelf. This observation justifies construction of a structural map for the cover base with subsequent specific recommendations for drilling parametric wells which would be able to solve also prospecting tasks.

In this connection, we should draw attention to the report by B. Mouly and D. Franke on the Laptev Sea

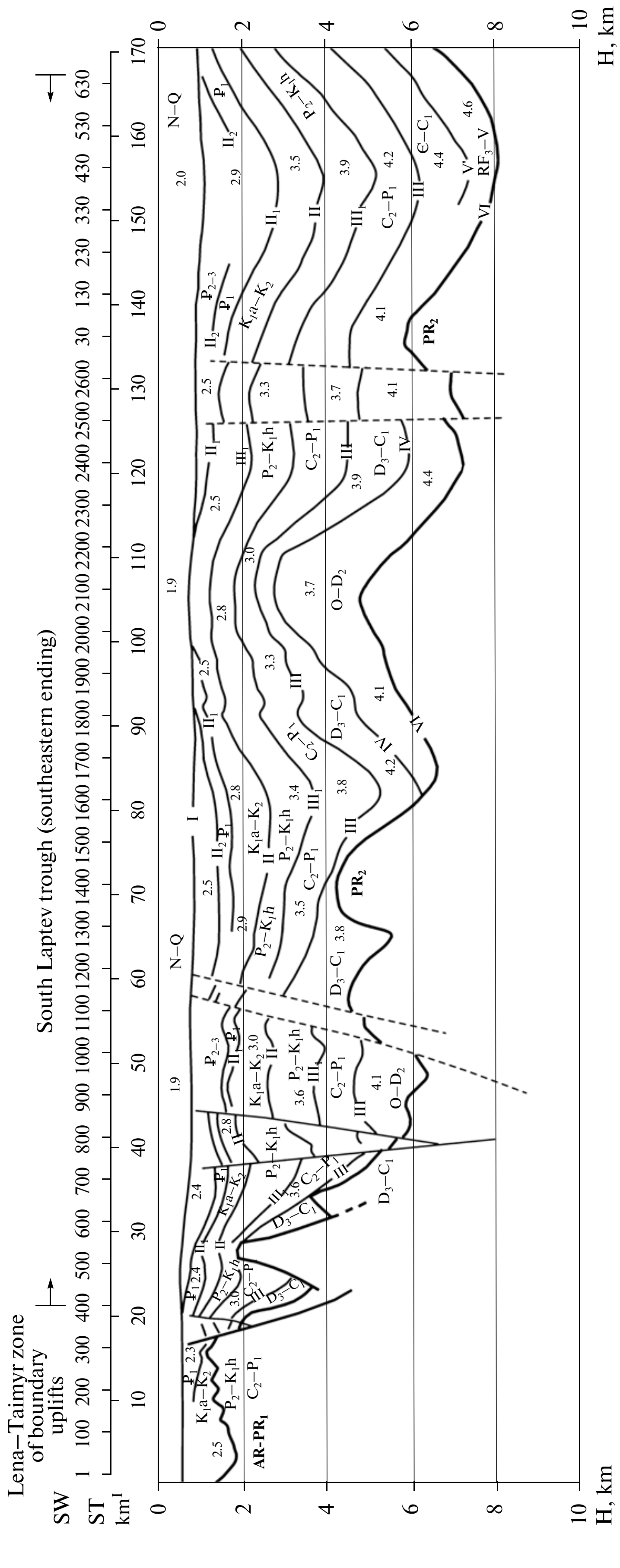


**Fig. 8.** Deep seismic geological section along the MAGE 87722 profile.

shelf presented at the conference "Geosciences: Making the Most of the Earth's Resources" held in St. Petersburg in 2012. These authors noted that Profile 87722 remains the only one which allows correlation of the offshore data with onshore Profile 85275 (Yakutskgeofizika trust, Khastakh team 27/85/86) and drilling data derived from the Ust'-Olenekskaya well. In their opinion, despite the significant distance between these profiles (approximately 45 km), the unconformity surfaces defined in the off- and onshore records exhibit an identical set of features, which allow them to be preliminarily interpreted as reflecting the replacement of carbonate sedimentation by terrigenous sedimentation at the beginning of the Middle Carboniferous. This, in turn, offers the opportunity to specify the structure of Paleozoic and Mesozoic sections (Permian–Triassic) in the transitional land–sea zone of Olenek Bay.

The conditions most favorable for accumulation of analogs of the Bazhenovo and Achimov formations could exist in the western part of the paleobasin approximately 100–150 km from the Nordvik Peninsula coast and northeastern margin of Taimyr Peninsula. The stratigraphic evidence allows us to back the opinion of those geologists who consider the South Laptev and Omoloi troughs, Ust'-Lena graben, and Minin Swell as structures most promising with respect to hydrocarbon prospecting on the Laptev Sea shelf. The complex analysis of seismic and geological data and considerations presented in this work favoring continuation of the sedimentary cover and structures of the Siberian Platform to the western and central parts of the shelf provide grounds for the inference that the presence of Upper Jurassic and Lower Cretaceous formations in the sedimentary cover section increases the petroleum resource potential of the region under consideration.

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## REFERENCES

Baraboshkin, E.Yu., The Lower Cretaceous ammonite zonal standard of the Boreal Belt, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 2004, vol. 79, no. 3, pp. 44–68.

Basov, V.A., Zakharov, V.A., Mesezhnikov, M.S., and Yudovnyi, E.G., New data on Stratigraphy of the Jurassic deposits of the Eastern Taimyr Peninsula, *Uch. Zap. NIIGA. Regional. Geol.*, 1963, no. 1, pp. 157–164.

Basov, V.A., Zakharov, V.A., Ivanova, E.F., et al., Zonal subdivision of Upper Jurassic and Lower Cretaceous deposits of the Urdjuck-Khaya Cape (Paksa Peninsula, Anabar Bay), *Uch. Zap. NIIGA. Paleontol. Biostratigr.*, 1970, no. 29, pp. 14–31.

Bidzhiev, R.A., Zonal subdivision of Jurassic deposits of the north of the Priverkhoyansk foreland basin, *Geol. Geofiz.,* 1965, no. 4, pp. 49–57.

Bidzhiev, R.A., Volgian Stage on the north of the Priverkhoyansk foredeep (inner zone), *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.,* 1973, vol. 48, no. 2, pp. 61–71.

Bogomolov, Yu.I., Polyptichitidae (ammonoids) and biostratigraphy of the Boreal Valanginian, *Tr. IGiG SO AN SSSR*, 1989, no. 696.

Bogomolov, Yu.I., Zakharov, V.A., and Plotnikov, Yu.I., The Valanginian Section in the Eastern Coast of the Anabar Gulf (Northern Siberia), *Tr. IGiG SO AN SSSR*, 1983, no. 528, pp. 99–113.

*Cruise Report: Marine seismic measurements and geoscientific studies on the shelf and slope of the Laptev Sea and East Siberian Sea/Arctic. Part II: Preliminary scientific results*, Bundesanstalt fur Geowissenschaffen und Rohstoffe. 1997.

Drachev, S.S., Malyshev, N.A., and Nikishin, A.M., Tectonic history and petroleum geology of the Russian arctic shelves: an overview, in *Proc. 7th Petrol. Geol. Conf. "Petroleum Geology: from mature basins to new frontiers,"* Geol. Soc. London, 2010, pp. 591–619.

Dypvik, H. and Zakharov, V., Late Jurassic/Early Cretaceous phosphates of Nordvik, North Siberian basin, *Polar Res.*, 2010, vol. 29, pp. 235–249.

Dypvik, H. and Zakharov, V., Late Jurassic–Early Cretaceous fine-grained epicontinental arctic sedimentation—mineralogy and geochemistry of shales from the Late Jurassic-Early Cretaceous transition, *Norwegian J. Geol.*, 2012, vol. 92, pp. 65–87.

*End Bericht uber die arbeiten der BGR zum project Lapseis: Untersuchungen zur Neotektonik in der Laptev—See, Ostsibiriscen See und auf dem angrezenden NE—Sibirischen Festland mit seismologischen Beitbanddaten. Projekt—Nr. 03GO 529 A*, Hannover: BGR, 1999.

Franke, D., Hinz, K., and Onchen, O., The Laptev Sea Rift, *Marine Petrol. Geol.*, 2001, vol. 18, no. 10, pp. 1083–1127.

Galabala, R.O. and Leonov, B.N., Stratigraphy of the Cretaceous Deposits in the Priverkhoyansk foreland basin, in *Stratigrafiya mezozoya i kainozoya Srednei Sibiri* (Stratigraphy of the Mesozoic and Cenozoic of Middle Siberia), Novosibirsk: Nauka, 1967, pp. 121–127.

*Geologiya i poleznye iskopaemye Rossii. T. 5. Kn. 1. Arkticheskie morya* (Geology and mineral resources of Russia. Vol. 5. Book 1. Arctic Seas), St. Petersburg: VSEGEI, 2004 [in Russian].

Gol'bert, A.V., Markova, L.G., Polyakova, I.D., et al., Paleolandscapes of West Siberia in the Jurassic, Cretaceous, and Paleogene, *Tr. IGiG SO AN SSSR*, 1968, no. 573, p. 152.

Gol'bert, A.V., Klimova, I.G., Bulynnikova, S.P., et al., Volgian and Neocomian marine deposits Buolkalakh River basin (Arctic Yakutia), *Tr. IGiG SO AN SSSR*, 1983, no. 532, pp. 48–58.

*Gosudarstvennaya geologicheskaya karta RF. Masshtab 1 : 1000000 (novaya seriya). List S-50-52—Bykovskii. Ob"yasnitel'naya zapiska* (The 1 : 1000000 State geological map of the Russian Federation. New Series. Sheet S-50-52:

Bykovskii. Explanatory note), St. Petersburg: VSEGEI, 2001 [in Russian].

*Gosudarstvennaya geologicheskaya karta RF. Masshtab 1 : 1000000. List S-47-49—oz. Taimyr. Ob"yasnitel'naya zapiska* (The 1 : 1000000 State Geological Map of the Russian Federation. Sheet S-47-49: Taimyr Lake. Explanatory note), St. Petersburg: VSEGEI, 1998 [in Russian].

Ivanov, V.V., Klubov, B.A., and Pokhilainen, V.P., New data on the geology of Stolbovoi Island (Novosibirsk Archipelago), *Dokl. Akad. Nauk SSSR*, 1974, vol. 216, no. 4, pp. 879–880.

Ivanova, N.M., Sekretov, S.B., and Shkarubo, S.I., Data on geological structure of Laptev Sea shelf based on seismic research materials, *Okeanologiya*, 1989, vol. 29, no. 5, pp. 789–795.

Kaplan, M.E., Yudovnyi, E.G., Zakharov, V.A., et al., Depositional environment of marine sediments of Paksa Peninsula transitional between Jurassic and Cretaceous (Anabar Bay), *Dokl. Akad. Nauk SSSR*, 1973, vol. 209, no. 3, pp. 691–694.

Khutorskoi, M.D., Podgornykh, L.V., Suprunenko, O.I., et al., Thermotomographic model and oil-and-gas forecasting for the sedimentary cover of the Laptev Sea shelf, *Dokl. Earth Sciences*, 2011, vol. 440, no. 2, pp. 1381–1386.

Knyazev, V.G., Ammonites and zonal stratigraphy of the Lower Oxfordian of North Siberia, *Tr. IGiG SO AN SSSR*, 1975, no. 275.

Kuz'michev, A.B. and Danukalova, M.K., Paleozoic and Mesozoic sedimentary basins in the shelf of Laptev Sea: results of fieldworks of the Geological institute on the Novosibirsk Islands in 2007–2008, in *Stroenie i istoriya razvitiya litosfery* (Structure and Evolution History of Lithosphere), M.–SPb.: Izd. Paulsen, 2010, pp. 228–242.

Kuz'michev, A.B., Zakharov, V.A., and Danukalova, M.K., New data on the stratigraphy and depositional environment for Upper Jurassic and Lower Cretaceous deposits of the Stolbovoi Island (New Siberian Islands), *Stratigr. Geol. Correlation*, 2009, vol. 17, no. 4, pp. 396–414.

Malyshev, N.A., Obmetko, V.V., Borodulin, A.A., et al., New data on structure and formation of sedimentary cover of Laptev Sea, in *Mat. XLII Tekton. Sovesh. T. II* (Proc. XLII Tectonic. Conf. Vol. II), Moscow: GEOS, 2009, pp. 32–37.

Malyshev, N.A., Nikishin, A.M., and Drachev, S.S., Tectonic history of sedimentary basins of Russian arctic shelves and adjacent land, in *Mat. XLIII Tekton. Sovesh. "Tektonika i geodinamika skladchatykh poyasov i platform fanerozoya". T. II* (Proc. XLIII Tecton. Conf. Tectonics and geodynamics of folded belts and Phanerozoic platforms. Vol. II), Moscow: GEOS, 2010, pp. 10–23.

Mesezhnikov, M.S., *Kimeridzhskii i volzhskii yarusy severa SSSR* (Kimmeridgian and Volgian Stages of north of the USSR), Leningrad: Nedra, 1984 [in Russian].

Mesezhnikov, M.S., Balabanova, T.F., Vereninova, T.A., et al., Paleogeography of the northern USSR in the Jurassic and Cretaceous, *Tr. VNIGRI*, 1971, no. 304, pp. 3–132.

Paleogeography of the north of USSR in the Jurassic, *Tr. IGiG SO AN SSSR*, 1983, Iss. 573.

Rogov, M. and Wierzbowski, A., The succession of ammonites of the Genus *Amoeboceras* in the Upper Oxfordian–Kimmeridgian of the Nordvik Section in Northern Siberia, *Volumina Jurassica*, 2009, vol. II, pp. 147–156.

Rogov, M.A. and Zakharov, V.A., Ammonite- and bivalve-based biostratigraphy and Panboreal correlation of the Volgian Stage, *Science in China Series D, Earth Sci.*, 2009, vol. 52, no. 12, pp. 1890–1909.

Rogov, M.A., Zakharov, V.A., and Ershova, V.B., Detailed stratigraphy of the Jurassic-Cretaceous Boundary Beds of the Lena River Lower Reaches Based on Ammonites and Buchiids, *Stratigr. Geol. Correlation*, 2011, vol. 19, no. 6, pp. 641–662.

Rogov, M.A., Shchepetova, E.V., Pokrovskii, B.G., et al., Oldest records of the Cretaceous glendonites in the Ryazanian of Northern Yakutia and their significance for palaeoclimatic reconstructions, in *Melovaya sistema Rossii i blizhnego zarubezh'ya: problemy stratigrafii i paleogeografii* (Cretaceous System of Russia and CIS countries: problems of stratigraphy and palaeogeography), Baraboshkin, E.Yu., Bondarenko, N.A., Baraboshkin, K.E., Eds., Krasnodar: Izd. Kuban' Gos. Univ., 2012, pp. 252–255.

Rogov, M.A. and Zakharov, V.A., Stratigraphy of Late Jurassic–Valanginian deposits of the Laptev sea border, in *Melovaya sistema Rossii i blizhnego zarubezh'ya: problemy stratigrafii i paleogeografii* (Cretaceous System of Russia and CIS countries: problems of stratigraphy and palaeogeography), Baraboshkin, E.Yu., Bondarenko, N.A., Baraboshkin, K.E., Eds., Krasnodar: Izd. Kuban' Gos. Univ., 2012, pp. 256–261.

Saks, V.N., Paleogeography of the Arctic during Jurassic and Cretaceous Periods, in *Doklady na ezhegodnykh chteniyakh pamyati V.A. Obrucheva* (Proc. Obruchev Annual Conf.), Moscow: Izd. AN SSSR, 1961, pp. 20–48.

Saks, V.N., Basov, V.A., Zakharov, V.A., et al., *Granitsa yury i mela i berriasskii yarus v boreal'nom poyase* (Jurassic–Cretaceous boundary and the Berriasian stage in the Boreal Realm), Novosibirsk: Nauka, 1972 [in Russian].

Sanin, V.Ya., Paleoecology and conditions of fauna existence in Early Cretaceous sea in the Anabar area (northern Siberia), *Tr. IGiG SO AN SSSR,* 1979, no. 411, pp. 91–109.

Sekretov, S.B., Geological structure of the Laptev Sea shelf according to seismic studies MOV OGT, *Extended Abstract of Cand. Sci. (Geol.–Min.) Dissertation*, SPB, 1993.

*Stratigrafiya yurskoi sistemy severa SSSR* (Stratigraphy of Jurassic System in the north of the USSR), Moscow: Nauka, 1976 [in Russian].

*Stratigrafiya SSSR. Melovaya sistema. Polutom 2* (Stratigraphy of the USSR. Cretaceous System. Semivolume 2), Moscow: Nedra, 1987, vol. 2.

*Tektonicheskaya karta morei Karskogo i Laptevykh i severa Sibiri* (Tectonic map of the Kara and Laptev Seas and Northern Siberia), Bogdanov, N.A. and Khain, V.E., Eds., Moscow: Inst. Litosfery RAN, 1998 [in Russian].

Vail, P.R., Mitchum, R.M., and Thompson, S., Seismic stratigraphy and global changes of sea level. Part 4. Global cycles of relative changes of sea level, *Mem. Am. Assoc. Petrol. Geol.,* 1977, vol. 26, pp. 83–89.

Vinogradov, V.A. and Yavshits, G.P., Stratigraphy of Upper Jurassic and Lower Cretaceous deposits of the northern part of Stolbovoi Island, in *Geologiya i poleznye iskopaemye Novosibirskikh ostrovov i ostrova Vrangelya* (Geology and mineral resources of the Novosibirsk Islands and Wrangel Island), Leningrad: NIIGA, 1975, pp. 38–42.

Vinogradov, V.A. and Drachev, S.S., On the tectonic nature of the basement of the southwestern part of the Laptev shelf, *Dokl. Akad. Nauk*, 2000, vol. 372, no. 1, pp. 72–74.

Vinogradov, V.A., Lopatin, B., Burskii, F.Z., et al., Major results of 1 : 1000000 geological mapping of the Arctic shelf of Russia, *Razved. Okhr. Nedr*, 2005, no. 6, pp. 45–52.

Vinogradov, V.A., Goryachev, Yu.V., Gusev, E.A., and Suprunenko, O.I., Sedimentary cover age and structure on the East Arctic Shelf of Russia and conditions of its formation in the continent–ocean system, in *60 let v Arktike, Antarktike i Mirovom okeane* (60 years in Arctic, Antarctic and the Ocean), St. Petersburg: VNIIOkeangeologiya, 2008, pp. 63–78.

Voronkov, A.V., Geological Structure of the Stolbovoi Island, New Siberian Archipelago, in *Sbornik Statei po geologii Sovetskoi Arktiki* (Collection of scientific articles on geology of Soviet Arctic), 1958, no. 9, pp. 37–43.

Yashin, D.S. and Kim, B.I., Geochemical indications of hydrocarbons presence in the eastern part of Russia's Arctic shelf, *Geol. Nefti Gaza*, 2007, no. 4, pp. 25–29.

Zakharov, V.A., Buchiids and biostratigraphy of the boreal Upper Jurassic and Neocomian, *Tr. IGiG SO AN SSSR*, 1981, no. 458.

Zakharov V.A., Rogov M.A., Dzyuba O.S., et al., Palaeoenvironments and palaeoceanography changes across the Jurassic/Cretaceous boundary in the Arctic Realm: case study of the Nordvik section (North Siberia, Russia), *Polar Res.* (in press).

Zakharov, V.A. and Yudovnyi, E.G., Conditions of sediment deposition and fauna existence in the Early Cretaceous sea of Khatanga depression, in *Paleobiogeografiya severa Evrazii v mezozoe* (Paleobiogeography of north of Eurasia in Mesozoic), Dagis, A.S. and Zakharov, V.A., Eds., Moscow: Nauka, 1974 [in Russian].

Zakharov, V.A., Nal'nyaeva, T.I., and Shul'gina, N.I., New data on the biostratigraphy of the Upper Jurassic and Lower Cretaceous deposits on Paksa peninsula, Anabar embayment (north of the Middle Siberia), *Tr. IGiG SO AN SSSR*, 1983, no. 528, pp. 56–99.

Zakharov, V.A., Bogomolov, Yu.I., Il'ina, V.I., et al., Boreal zonal standard biostratigraphy of the Siberian Mesozoic, *Geol. Geofiz.*, 1997, vol. 38, no. 5, pp. 927–956.

Zakharov, V.A. and Kuz'michev, A.B., Biostratigraphy of Upper Jurassic and Lower Cretaceous of Stolbovoy Island (Novosibirsk Archipelago) by buchias, in *Melovaya sistema Rossii i blizhnego zarubezh'ya: problemy stratigrafii i paleogeografii. Mat. 4-go Vseross. Sovesh.* (Cretaceous System of Russia and adjacent countries: problems of stratigraphy and paleogeography. Proc. 4th All-Russ. Meet.), Shurygin, B.N., Ed., Novosibirsk: GEO, 2008, pp. 74–83.

Zakharov, V.A. and Rogov, M.A., The Upper Volgian Substage in Northeast Siberia (Nordvik Peninsula) and its Panboreal correlation based on ammonites, *Stratigr. Geol. Correlation*, 2008, vol. 16, no. 4, pp. 423–436.

Zinchenko, V.N. and Alekseev, S.N., On position of the Jurassic–Cretaceous boundary in the Lena lower reaches, *Dokl. Akad. Nauk SSSR*, 1981, vol. 258, no. 5, pp. 1170–1172.

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