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Arctic Zone of the Siberian Platform - Resource Base and Development Potential

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Abstract

The interest of oil and gas companies in the Arctic region of the Earth, despite the difficulties in the geological exploration, the development and the exploitation of discovered fields, in access to markets for the produced hydrocarbons is quite high. According to the US Geological survey, the subsoil of the Arctic zones of five coastal States – the United States, Canada, Russia, Denmark and Norway – contains at least 525 billion BBOE (barrels of oil equivalent) or 75 billion tons, including the subsoil of the Arctic zone of Russia – 315.4 billion BBOE (26). The Arctic zone of the Eastern Siberia is characterized by a harsh climate (in winter the temperature drops below −60 °C on land and to −40 °C at sea), the presence of the permafrost, the lack or remoteness of the infrastructure for the delivery of the necessary equipment and materials, the transportation of produced hydrocarbons, short periods of the field work from November to April on land, from July to September at sea (6, 7, 25). The basic concepts of the geological and tectonic structure and the oil and gas content of the land and the adjacent shelf of the Arctic zone of the Siberian platform are based on the seismic data, tied to the existing deep parametric and exploratory wells. To date, five regional seismostratigraphic complexes have been identified and described: the Mesozoic-Cenozoic, the Permian-Lower Triassic, the Upper-Middle Paleozoic, the Upper Proterozoic-Cambrian and the surface of the basement. The evaluation of the potential hydrocarbon resources was carried out in the Yenisei-Khatanga, the Anabaro-Khatanga, the Anabar-Lena and part on the Laptev Sea oil and gas regions.

Introduction

The formation of the Arctic Ocean basin occurred in the late Paleozoic-Mesozoic time – as in the fragmentation and the removal of the separate parts of the Laurasia macrocontinent by the mantle currents, and a result of the formation of the modern lithospheric plates. At the appropriate spreading rate, a rift zone separating the lithospheric plates is formed, with the formation of the oceanic crust. In the Arctic Ocean, the mid-oceanic Gakkel Ridge separates the North American and the Eurasian lithospheric plates, the tectonic

activation in the Cretaceous period led to the formation of the Laptev Sea Plate (Fig. 1). When the isostatic equilibrium is restored, depending on the rate of the spreading of the lithospheric plates during the descent of the chipping blocks of the mother lithospheric plate, an edge system is created along the fault system, which later transforms into a foredeep system (23). For foredeep systems, intensive sedimentation is typical with the formation of the sedimentary strata of high thickness, mainly due to the removal of the sedimentary material from the mother plate and the high heat flux, which creates the favorable conditions for the oil and gas formation. On the basis of the paleotectonic analysis, the Turukhan-Norilsk, the Yenisei-Khatang (Fig. 2), the Anabar-Lensky and the Verkhoyansk foredeep systems are distinguished in the north of the Siberian platform, formed at the pre-Paleozoic stage of the development of the Northern part of the Siberian platform (Fig. 3).

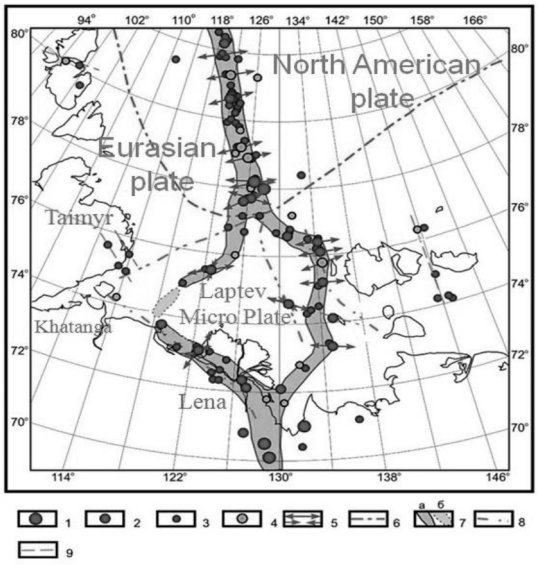

Figure 1—The system of rifts in the eastern part of the Arctic Ocean (1). 1-3 - earthquakes of different magnitude (M1> 6; M2 = 5-5.9; M3 = 4-4.9); 4 - earthquakes registered after 1991; 5 - tensile stress and compression stresses (the length of the arrow is proportional to the cosine of the angle of inclination to the horizon); 6-continental slope; 7 - plate boundaries (a - confident, b - assumed); 8 - the main fault zones; 9 - faults.

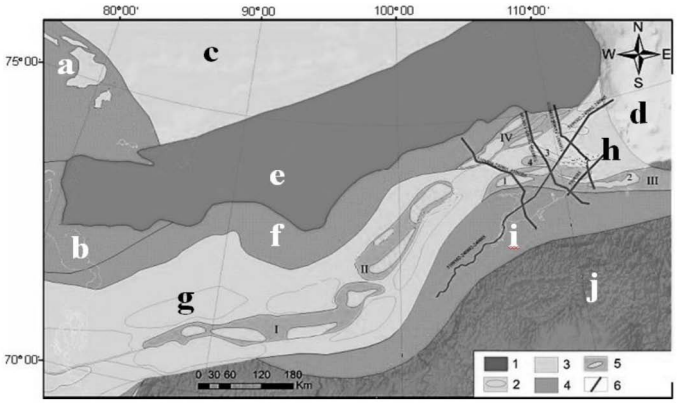

Figure 2—Tectonic scheme of the Yenisei-Khatanga trough (5). 1 - area of the Cimmerian folding; 2 - super deep depressions, with epicenters of immersion, 3 - platform massifs, 4 - slopes of the superdeep depressions (the step and monoclinic zones), 5 - inversion highlands / elevations within super deep depressions with local structures, 6 – lines of the seismic-geological sections; a - North-Siberian threshold (zone of steps); b - West Siberian stage; c– the North Kara plate; d - Laptev sea; e - Taimyr; f - Pre-Taimyr Monocline; g- Yenisei-Khatanga trough; h - Anabar-Khatanga depression; i – North-Anabar monocline; j - East-Siberian platform. Structures of the first order, inversion highlands: I - Rassokhin mega highland; II - Balakhnin highland; III - Belogor-Tigian zone of uplifts; IV - Kiryak-Tass zone of uplifts. The structures are of the second order: 1 - Sopochnoe uplift, 2 - Tigian-Anabar highland, 3 - Nordvik highland, 4 - Kharatumus depression.

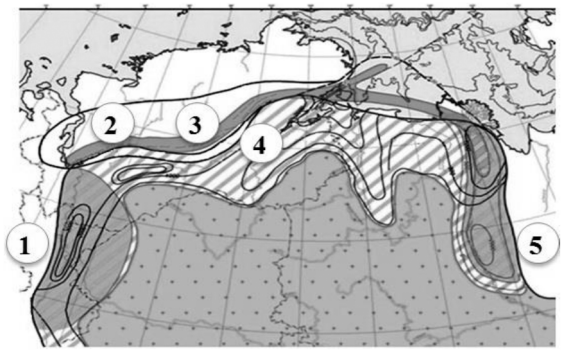

Figure 3—Foredeep systems of the north of the Siberian platform (13, 18), where 1 - Yenisei-Khatang trough; 2- Turukhan-Norilsk; 3-Yenisei-Khatang; 4-Anabar-Lensky and 5- Verkhoyansk foredeep systems.

North-Western border of the Siberian platform

In the Riphean-Precambrian time, the Yenisei-Khatanga and the Turukhano-Noril'sk foredeep systems are formed. In the Lower Paleozoic - Precambrian time from the northwestern part of the epiarchaean Siberian plate/platform, a large block breaks and descends along the Main Yenisei fault. According to the magnetometry data, the western boundary of the ancient epicarchian Siberian platform probably passes along the valley of the Taz River, at a distance of 250-300 km from the Yenisei River (12). The western and northern parts of this breakaway block of the ancient platform, having undergone a deep immersion in the Jurassic-Cretaceous time, became the part of the heterogeneous base of the epihercine West Siberian plate and the adjacent Yenisei-Khatanga trough. The rest of the epiarchaean plate/platform, located to the East of the Yenisei River, maintains a stable position and is called the Siberian Platform (3). Approximately in the same period from the northern part of the epiarchaean Siberian plate/platform the microplate of the mountain Taimyr/the Taimyr microcontinent is separated and moves in the northern direction. The formation of the Yenisei-Khatanga regional trough begins as an independent structure bordering the North-Western outskirts of the modern Siberian platform. In the slowly expanding trough, there is an intensive accumulation of Paleozoic-Mesozoic sediments with a thickness of 8 km in the East to 15 km in the West of the trough (27).

Yenisei-Khatanga Foredeep System

The Yenisei-Khatanga foredeep system is extended from the South-West to North-East in the Northern part of the Siberian platform. Its length is a little over 1000 km, the width on average is 250 km. The Yenisei-Khatanga foredeep system borders on the Yenisei paleo monocline, in the east - with the Anabar paleo trough.

Geological structure

The Yenisei-Khatanga Oil and Gas Region includes the territory of the Yenisei-Khatanga regional trough, the Yenisei Gulf, the Western part of the Anabaro-Khatanga saddle of the Northern edge of the modern Siberian platform, and the part of the Yenisei-Khatanga foredeep system. In the Jurassic time there was a transition from the filling of the grabens and the troughs to the formation of the continuous sedimentary cover. Sea basin of the Western part of the Yenisei-Khatanga regional trough occupies all the Southern and South-Eastern part of the modern area of the Laptev Sea and merges with the sea basin of the West Siberian plate to the West 60 km from the modern valley of the Yenisei river at the latitude of the Vankor area.

On these deposits lies the clay-silt layer of the Upper Jurassic sediments. The surface of the crystalline basement in the Western part of the Yenisei-Khatanga regional trough is immersed in 14-16 km from the ocean level. The depression is filled with sediments of Jurassic and Cretaceous times with a capacity of up to 6-7 km, which quietly lying on the surface of the Paleozoic-Triassic folded complex with a capacity of

more than 6 km, which, in turn, is located on the Precambrian folded basement. At the beginning of the Late Jurassic era, the West Siberian plate acquired a modern shape. In the East of the West Siberian plate, a common marine sedimentation basin was formed in the Yenisei-Khatanga regional trough and the modern Yenisei Bay. The sedimentary complex is composed of sediments of marine and coastal-marine facies and includes sedimentary deposits of the Upper Jurassic, Lower and Upper Cretaceous times (Fig. 4). The depth of the crystalline basement in the Central part of the depression exceeds 12 km (Fig. 5, 6). Deposits of Valangin-Cenomanian time are characterized by a strong predominantly sandy thickness (27). There was an intense deflection in the Triassic time in the Eastern part of the Yenisei-Khatanga regional trough. The capacity of Triassic deposits is 1.5-2.5 km. Triassic deposits are an independent structural floor above the basement which is composed of the dislocated rocks of the Middle and Upper Paleozoic times. Structural plan of the Mesozoic complex of the Yenisei-Khatanga regional trough inherits the structural plan of the Upper Paleozoic - Lower Mesozoic complex, but becomes more plicative character. The total capacity of the Jurassic and the Cretaceous sediments is about 2.5-3.5 km. Deposits of the Jurassic and the Cretaceous times lay horizontally, but in some areas they are dislocated. Cretaceous deposits in the Western part of the Yenisei-Khatanga regional trough (Eastern part of the PUR-Taz Oil and Gas Region) are oil-bearing. Permian sediments in the Eastern part of the Yenisei-Khatanga regional trough (Yenisei-Khatanga Oil and Gas Region) and the Western part of the Anabaro-Khatanga saddle are oil-rich. Nine seismostratigraphic complexes in the Yenisei Gulf are confidently traced.

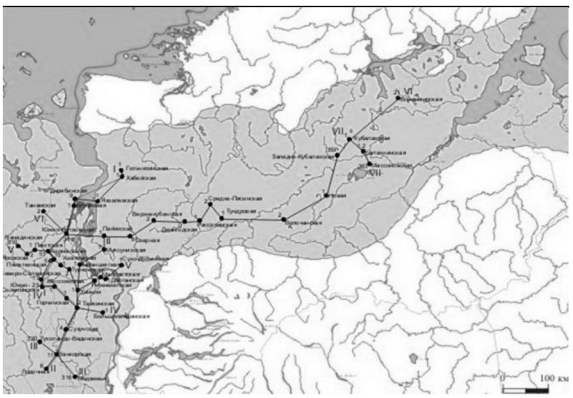

Figure 4—Scheme of distribution of Jurassic-Cretaceous deposits in the Yenisei-Khatanga regional trough (11).

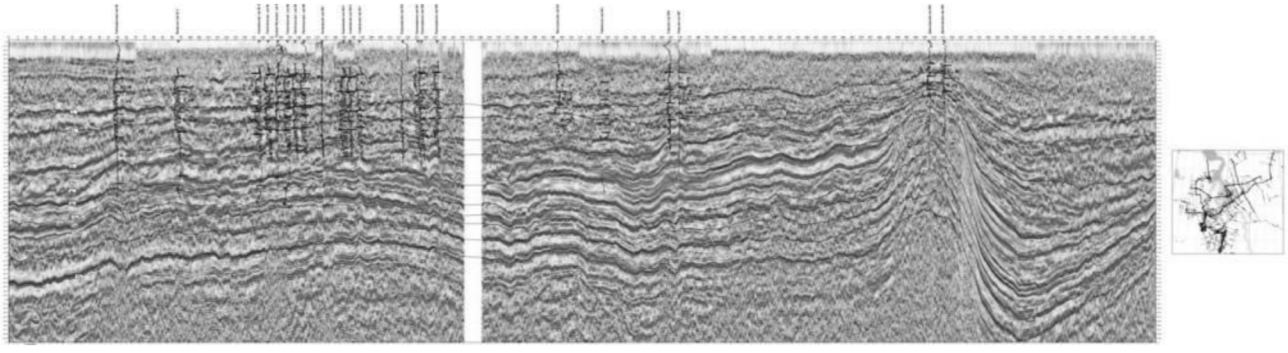

Figure 5—Stratified sublatitudinal regional framework profile Region 1 (11).

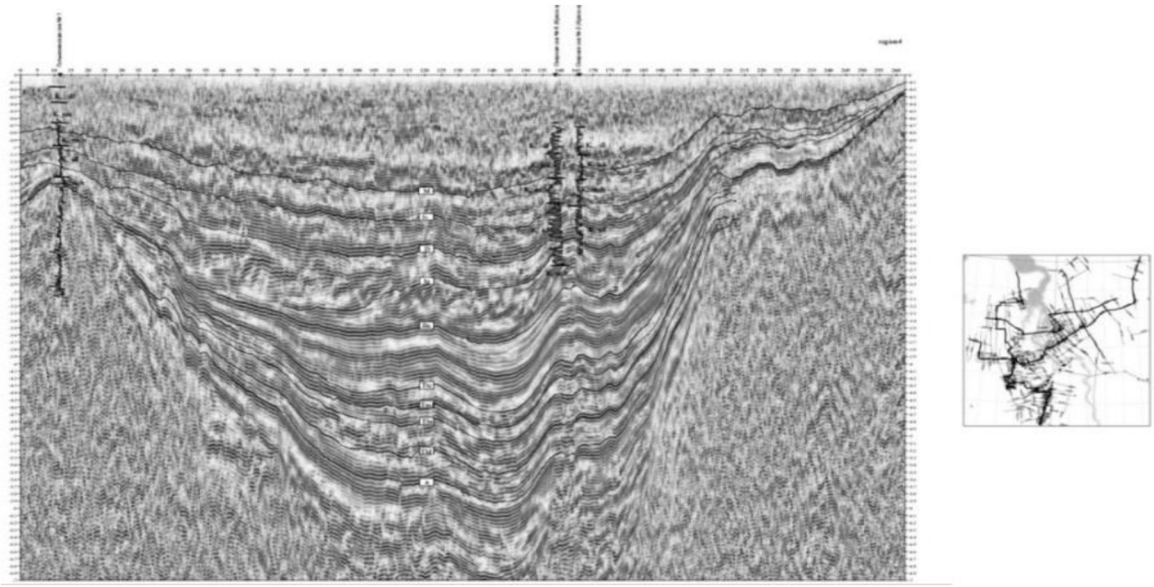

Figure 6—Stratified submeridional framework profile Region 4 (11).

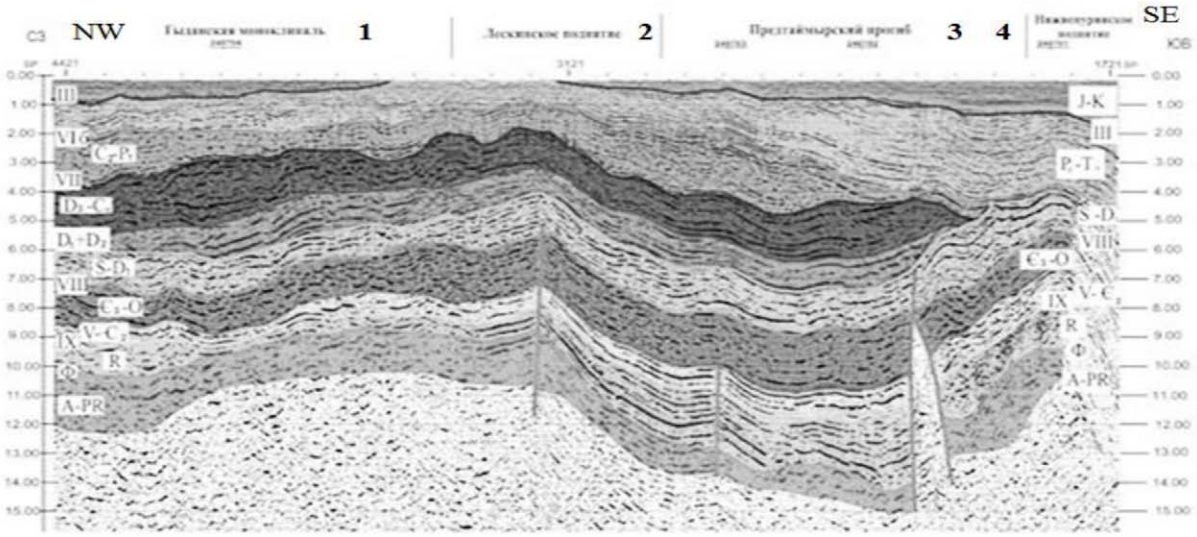

Figure 7a—The Yenisei Bay. Seismic stratigraphic complexes and reflecting horizons, seismic profile 240706 (12), where 1 - Gydan monoclinal; 2 - Leskin uplift; 3 – Pre Taymyr deflection and 4 - Lower Turanian uplift.

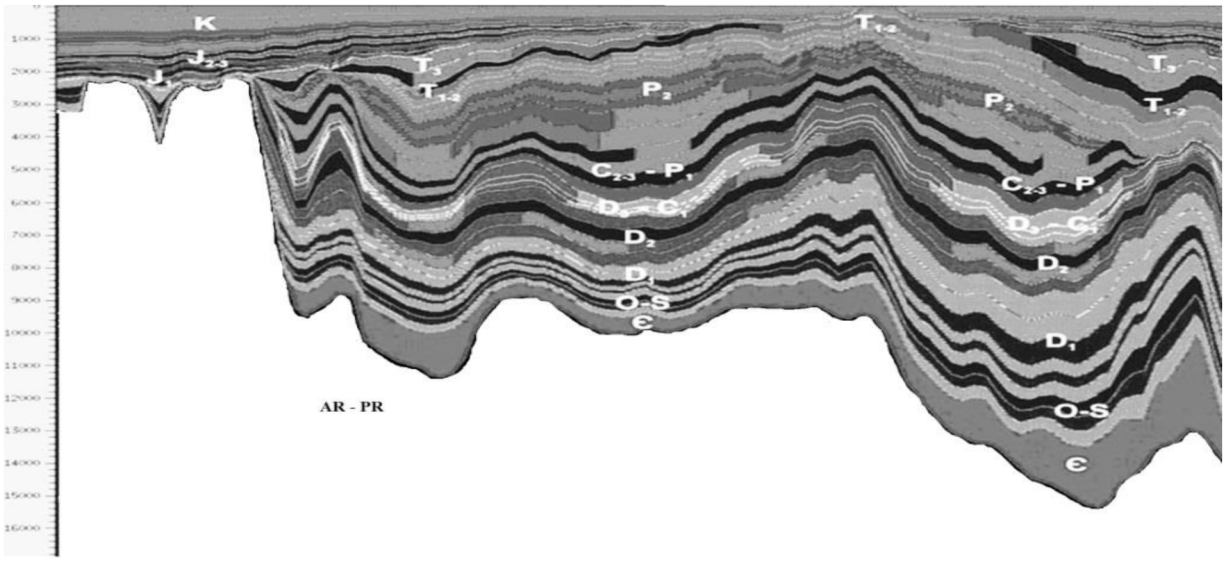

Figure 7b—Geological section of the Yenisei Gulf by seismic profile 240706 (12).

The Anabar-Lena foredeep system

The Anabaro-Lena foredeep system covers the North and East of the Anabar shield. It includes allocated the Anabar-Khatanga saddle on the Mesozoic deposits or the Khatanga megadepression on the Riphean deposits, and the Anabar trough, the northern boundary of which is in the waters of the Laptev Sea. The sedimentary cover is represented by the Lower Riphean - Middle Paleozoic terrigenous-carbonate and Upper Paleozoic-Mesozoic terrigenous deposits. Within its boundaries allocate the Anabaro-Khatanga Oil and Gas Region and Anabaro-Lena Oil and Gas Region.

Anabar-Khatanga Oil and Gas Region includes the territory of the Mesozoic Anabar-Khatanga saddle or the Khatanga depression along the Riphean-Paleozoic sediments and the Khatang Bay included in the Anabar-Lena foredeep system. The territory of the Khatanga megadepression is a peripheral area of the saline accumulation in the Anabaro-Lena trough and the modern waters of the Laptev Sea (1, 5, 17). In the West of the Anabar-Khatanga saddle (AHS) developed saline stocks of the Middle Devonian. The Central part is composed of the Permian-Mesozoic-Cenozoic mainly terrigenous complex with a capacity of up to 10 km. Deposits of the Lower-Middle Paleozoic and the Precambrian times, characteristic of the Northern slope of the Anabar massif of the Siberian platform, are revealed on the sides of the deflections at the base of the section. Sedimentary strata of these complexes are represented by various limestones, dolomites and marls with layers of shale, mudstone and intrusive rocks (7). The oil content of the Permian terrigenous strata, distributed over Anabar-Khatanga area of 4500 km^2, was reliably established. The porosity of Permian deposits in some areas reaches 20%, the permeability - up to 500 mD. The oils of this region have different composition and properties. Their specific weight is in the range from 0.760 to 0.985 g / cm^3. The explored structures are at depths till 2000 m.

In the course of the oil exploration activities conducted in 1934-1953 years in Anabaro-Khatanga area, were open six small fields/reservoirs. Numerous oil occurrences are recorded throughout the open section interval from the Precambrian to the Lower Cretaceous inclusive (25). In the Khatanga Bay, the most interesting deposits are the rocks of the subsalt complex, as well as the Lower *Cretaceous* carbonate and Lower Permian terrigenous deposits (1).

The exploratory well was drilled in 2017-2018 years from the coast of the Hara-Tumus Peninsula, revealed the presence of oil in the range of 2305-2363 m in the Khatanga Bay (Fig. 8).

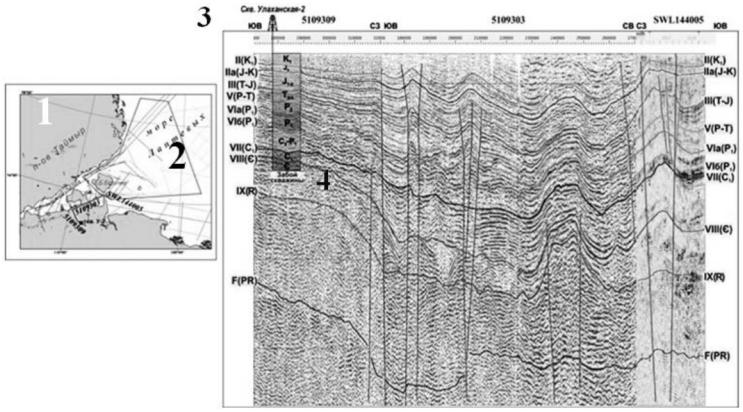

Figure 8—The eastern shore of the Khatanga Bay. Stratigraphic binding of reflecting horizons to the well Ulakhanska 2 (1), where 1 - Taimyr; 2 – Laptev sea; 3 - Ulakhanska 2 and 4 - downhole.

Anabar-Lensky Oil and Gas Region covers the territory of Anabar-Lensky trough and the adjacent shelf of the Laptev Sea. Anabar-Lensky trough continues to the East of the southern strip of troughs of the Yenisei-Khatanga foredeep zone. From the North it is limited to the damped West Olenek folded system extending from the Lena Delta to the Khatanga Bay along the coast of the Laptev sea (Fig. 9). The sediments of the basic structural-facies complex reach more than 1000 m. There is a significant thickness of the Riphean - Upper Paleozoic sediments, and the possible presence of the Paleozoic saline strata. In 2012, new and reinterpreted previous seismic data were linked with updated stratigraphic breakdowns by the parametric wells (Ust-Olenek 2370, Charchyk 1, Khastakh 930, Burskaya 3410), as well as with available the geological and the geophysical information on these deep wells.

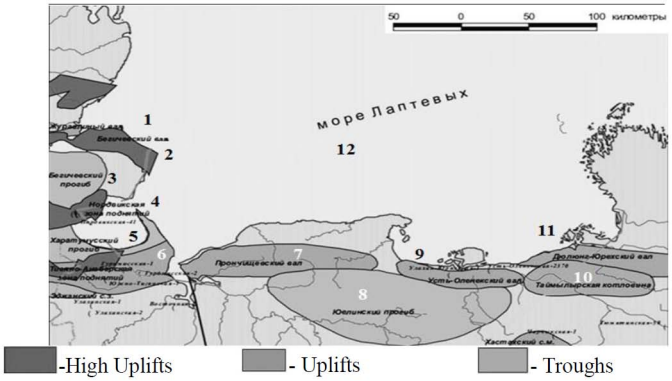

Figure 9—Tectonic scheme of the Anabar-Lena megaflex (17), where 1 - Zhuravlinyy; 2 - Begichev; 3 - Begichev trough; 4 - Nordvik; 5 – Haratamus trough; 6 - Tigian - Anabar; 7 - Pronchishchev; 8 - Yuslin; 9 - Ust - Olenek; 10 - Taymylyr; 11 - Dyulyung - Yureh and 12 – Laptev sea.

As a result, the reference reflecting horizons in the Paleozoic and the Proterozoic sediments were more reliably identified on time sections and the Mesozoic, the Permian, the Cambrian, the Vendian and the Riphean seismogeological complexes were determined (Fig. 10). The thickness of the Riphean deposits exceeds the thickness of the entire overlying the Vendian-Mesozoic strata of rocks. The Riphean complex is composed of five independent complexes controlled by the reflecting horizons and having different areas of the distribution. The thickness of Mesozoic deposits varies in the range from 0 to 1645 m, increasing regionally in the North direction. A sharp reduction in the thickness of the Mesozoic deposits is observed over the Pronchishchev, the Allah and the Ust-Olenek structures, and in the South of the territory under consideration the complex is completely absent in the time sections. Fields of the natural bitumen on many areas of the Anabar-Lena foredeep system are reliably established (Fig. 11).

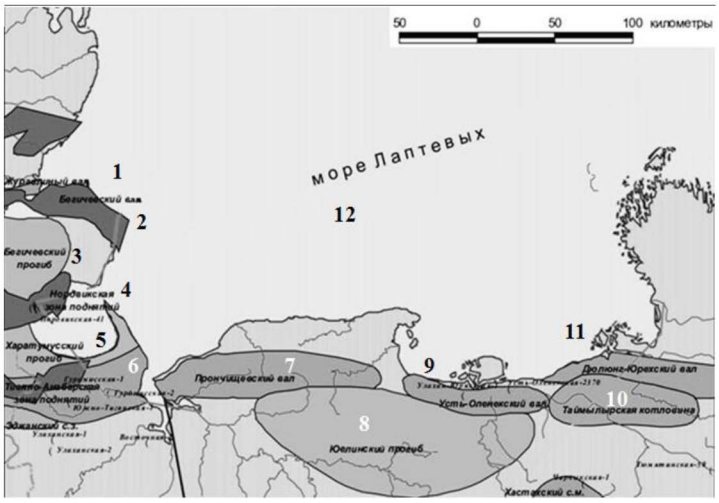

Figure 10—Seismogeological characteristics of the Riphean-Mesozoic deposits (24), where 1 – Charchik −1 well and 2 - Ust – Olenek uplift.

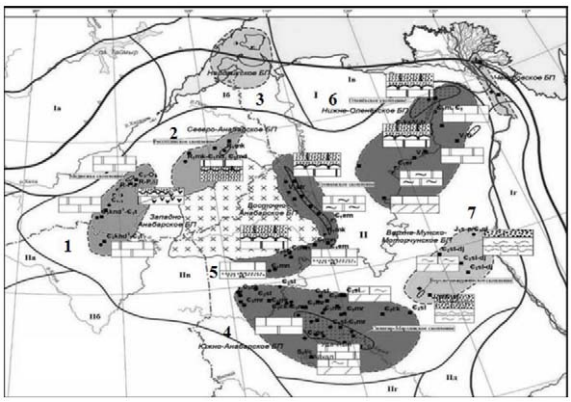

Figure 11—Location of fields of natural bitumen on the Siberian platform (17), where 1 - West Anabar; 2 – North Anabar; 3 - Nordvik; 4 – South Anabar, 5 – East Anabar; 6 - Lower - Olenek and 7 - Upper-Mun-Motochun.

Figure 11 shows the boundaries of oil and gas provinces (OGP): I – Khatanga-Vilyuy province, II – Leno-Tungus province; boundaries of the petroleum regions (Oil and Gas Region): $I_а$ – Yenisei-Khatanga Oil and Gas region, $I_б$ – Khatanga perspective region, $I_В$ – Anabar-Lena perspective region, $I_г$ – Lena-Vilyui Oil and Gas region, $II_а$ – Anam perspective region, $II_б$ – Evenki perspective region, $II_В$ – Anabar perspective region, $II_г$ – Sukdjer perspective region, $II_д$ – West of the Vilyui Oil and Gas Region. Olenek field was discovered in the zone of Permian sediments wedging on the Northern slope of Olenek uplift (19). The marine part of the Anabar-Lena Oil and Gas Region is quite promising for the discovering of hydrocarbon fields (Fig. 12, Fig. 13).

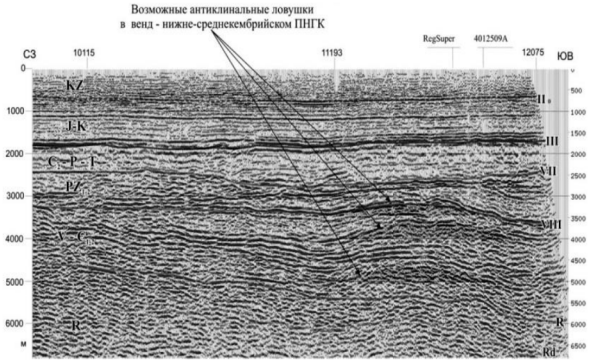

Figure 12—Fragment of the deep seismogeological section along profile 4012501, illustrating possible anticlinal traps in the Vendian-Lower Cambrian prospective oil and gas complex in the offshore part of the Anabar-Lena oil and gas region (17).

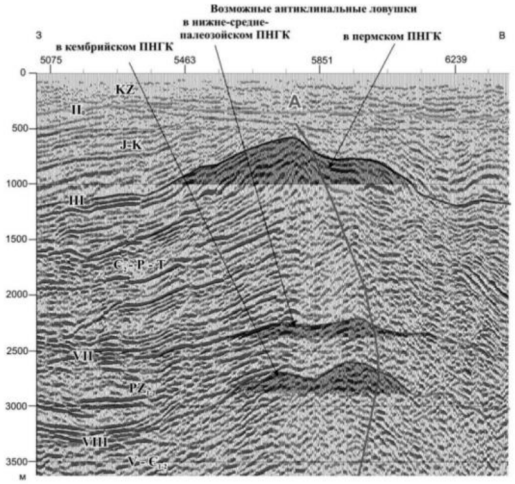

Figure 13—Fragment of the deep seismogeological section along profile 4012504, illustrating possible anticlinal traps in the Permian, Lower Middle Paleozoic and Cambrian prospective oil and gas complexes in the marine part of Anabar-Lena oil and gas region (17).

Oil and gas potential

Currently, the Siberian platform is the third region of Russia after the Western Siberia and the Ural-Volga regions with a large concentration of the oil and gas resources on the land. The study area is located in the Western Siberia, the Khatanga-Vilyuy and the Lena-Tungus oil and gas provinces (27). Most of the considered territory is located in the North of the Lena-Tungus oil and gas province (NGP). The total area of oil-prospective lands of the considered territory is over 700 thousand square kilometers (4, 11, 25). Estimates of hydrocarbon resources (hydrocarbon) in the Arctic zone of Eastern Siberia were carried out in various years by the organizations of the Ministry of geology of USSR and the Ministry of natural resources and ecology of Russia, mainly by analogy, volumetric-genetic method, 2D and 3D basin modeling. In the southern and Central parts of the Lena-Tungus oil and gas province oil source strata confined to the Riphean, Vendian, Lower - Middle Cambrian deposits. The generation of hydrocarbons took a long time. The intensive phase of the realization of the scattered organic matter can be attributed to the Late Riphean (2, 21, 22). Riphean-Mesozoic deposits are widely developed in the regional parts of the North and the North-East of the Siberian platform.

Dynamics of assessment and development of potential resources of the Arctic zone of the Siberian platform and the adjacent shelf

The total area of the petroleum potential of the onshore part of the Yenisei-Khatanga, Anabar-Khatanga and Anabar-Lena Oil and Gas Region, covering the Yenisei-Khatanga and Anabar-Lena regional system provided 700 thousand square km (4, 18, 25). In tables 1 and 2 presents the distribution of hydrocarbon resources (geological)/categories and Oil and Gas Region in the North of the Siberian platform on 01.2017 year.

Table 1—Initial total resources in the Yenisei-Khatang foredeep system, localized by the oil and gas complexes, million tones (MMT) in units of oil equivalent/conditional fuel – oe/cf (7, 12, 17, 19, 25).

Oil and gas bearing areas	Mesozoic Oil and Gas Complex / Category, MMT in units oe/cf	MMT in units oe/cf
Yenisei-Khatanga - onshore	13560,3/C_1+D	13560,3
Yenisei-Khatanga - offshore	1318/D	1318
Total		**14878,3**

Table 2—Total initial resources in Anabaro-Lena foredeep system, localized by the oil and gas compelexes, MMT (million tones) in units of oil equivalent/conditional fuel – oe/cf (1, 4, 12, 17, 18, 22).

Oil and Gas Complex / Oil and gas bearing areas	Riphean / Category, MMT in units oe/cf	Vendian / Category, MMT in units oe/cf	Vend-Middle Paleozoic/ Category, MMT in units oe/cf	Upper Paleozoic / Category, MMT in units oe/cf	Mesozoic / Category, MMT in units oe/cf	Total, MMT in units oe/cf
Anabar-Khatanga - onshore	1001/ $D_{2\ loc.}$		968/ $D_{2\ loc.}$	5807/ $D_{1\ loc.}$		7776
Anabar-Khatanga - offshore				2117/D		2117 *
Anabar-Lena - onshore	216/ $D_{2\ loc.}$	420/ $D_{2\ loc.}$		1570/ $D_{1\ loc.}$	231/ $D_{1\ loc.}$	2437
Anabar-Lena - offshore				293/ $D_{2\ loc.}$	3207 $D_{2\ loc.}$	3500 *
Total	**1217**	**420**	**968**	**9787**	**3438**	**15830**

In General, the initial total resources in the Anabar-Lena regional system 15830, subsequently, onshore 10213 and offshore 5617 million tones.

Table 3 shows the distribution of hydrocarbon resources (geological)/categories and Oil and Gas foredeep regions of the Siberian platform on 01.2017 year. In general, the localized resources are 41017,3, subsequently, 27582,3 - onshore and offshore – 13435 MMT (million tones) of oil equivalent. Oil manifestations in the stratigraphic interval from the Riphean to Lower Cretaceous on the right bank Yenisei in the Yenisei-Khatanga Oil and Gas Region are installed. Ordovician and Silurian deposits in Norilsk region are oil and gas bearing (3). The Payaha, the North Payaha, the Baykalov, the Habei and the Ozernyi fields are opened, explored and partially developed at north part of the area. Total OOIP of which amount to at 1.2016.425.3 MMT (million tones) of oil equivalent/ conditional fuel in the categories C_1+C_2 (25). By 2018 year, issued operational licenses for four sites in the Yenisei-Khatanga Oil and Gas Region. Licenses for one ares of land and several offshore sections in the Khatanga Gulf at the Anabar-Khatanga Oil and Gas region are issued.

Table 3—Localized hydrocarbon resources by category in the North of Eastern Siberia according to (1, 6, 12, 14, 15, 17, 18, 20, 22, 24, 25), in units of oil equivalent.

Oil and gas bearing areas	Reserves	Resources				
	ABC_1+C_2, MMT in units oe	D_1, MMT in units oe	D_2, MMT in units oe	D_1+D_2, MMT in units oe	The category is ambiguous, MMT in units oe	Bcero, MMT in units oe
Yenisei-Khatanga - onshore	425,3	5538	7597	13135		13560,3
Yenisei-Khatanga - offshore					1318	1318
Anabar-Khatanga - onshore		5807	1969	7776		7776
Anabar-Khatanga - offshore				2117		2117
Anabar-Lena - onshore		1801	636	2437		2437
Anabar-Lena - offshore			384	384	3116	3500
Laptev Sea perspective					6500	6500
Pre-Verkhoyn	1		952			953
Vilyuy	471	1216	1169	2385		2856
Total	**881,6**	**14362**	**12707**	**28643**	**10934**	**41017,3**

Conclusion

Work in this direction was carried out from 2012 to 2018 years in the Analytical center of scientific and technical forecasting in the oil and gas industry of the OGRI RAS in the framework of research work "Integrated development and conservation of the earth's interior, innovative processes of the development of the mineral deposits and the deep processing of the mineral raw materials." The initial data used in the collections records of the industrial organizations of the Northern sea route of the USSR, the Ministry of Geology of the USSR, Academy of Sciences of the USSR, the Ministry of Natural Resources and Ecology of the Russian Federation, the Russian Academy of Sciences during the period from 1927 to 2017 years. The report uses the illustrations from the original reports in order to pay tribute to the specialists who performed the geological exploration in the Arctic. The results of the analysis show high prospects for the finding oil and gas on the territory of the Anabar-Khatanga and the Anabar-Lena Oil and Gas Region in the Anabar-Lena foredeep system. A great deal of the research interest is the unopened drilling deep-lying the Riphean - Middle Paleozoic sediments. Along with this very interesting halogen deposits are exposed on the Anabar-Khatanga saddle and in the shallow shelf of the Anabaro-Lena Oil and Gas Region. Drilling on the identified seismic prospecting structures on the shelf due to limited technical capabilities of Russian oil and gas companies in the near future is possible only from the shore.

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