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Oil and Gas Bearing Complexes of the Sedimentary Cover of the Arctic Zone of the Siberian Platform Marginal Zones of the North of the Siberian Platform?

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Abstract

The report discusses issues related to the assessment of the resource base and the development potential of the Arctic zone of the Siberian platform along the Northern sea route, the region of Russia with a high concentration of oil and gas resources. The basic concepts on the geological structure and the oil and gas potential of the Arctic zone of the Siberian platform are based on seismic data tied to existing deep exploratory wells. To date, five petroliferous complexes have been described in the Yenissei-Khatanga (the Yenisei Bay, the Yenisei-Khatanga regional trough) Anabar-Khatanga (Anabar-Khatanga saddle, Khatanga bay) Anabar-Lena oil and gas regions (Anabar-Lena trough and adjacent shallow shelf of the Laptev Sea) and the South Laptev sea promising oil and gas region for the main oil and gas complexes: Riphean, Vendian, Vendian-Middle Paleozoic, Upper Paleozoic and Mesozoic.

The report considers the results of the analysis of estimates of the filtration-capacitive properties of the sedimentary cover rocks in the marginal zones of the north of the Siberian platform available on 01/01/2019. Open fields are briefly described. The obtained results allow for the adjustment of state programs for the development of the Arctic zone of the Siberian Platform (Yenisei-Khatanga, Anabar-Khatanga and Anabar-Lena oil and gas regions, South-Laptev Sea promising oil and gas region).

The interest of oil and gas companies to the Arctic region of the Earth has increased dramatically due to the intensification of work on the development of the Northern Sea Route (Fig. 1). The development of oil and gas fields in the Arctic zone along the Northern Sea Route is the key to economic stability and energy security of Russia (Action, 2016). In Russia, more than 300 offshore wells have been drilled, of which less than 90 are in the Arctic region. The Federal project for the development of the Northern sea route until 2024 is expected to invest 734.9 billion rubles. The project will be financed mainly by oil and gas companies and PJSC Rosatom, which are interested in transporting liquefied natural gas, gas condensate and oil along the Northern Sea Route to world markets. The Decree of the President of the Russian Federation dated

07.05.2018 № 204 "On national goals and strategic objectives of the development of the Russian Federation for the period up to 2024" aims to increase cargo traffic on the Northern sea route to 80 million tons by 2024. The total volume of hydrocarbon shipments will reach 48.8 million tons, which will make up 81.3% of the total cargo traffic. The volume of cargo to ensure the search, exploration and development of oil and gas fields along the Northern Sea Route until 2024 is estimated at several million tons.

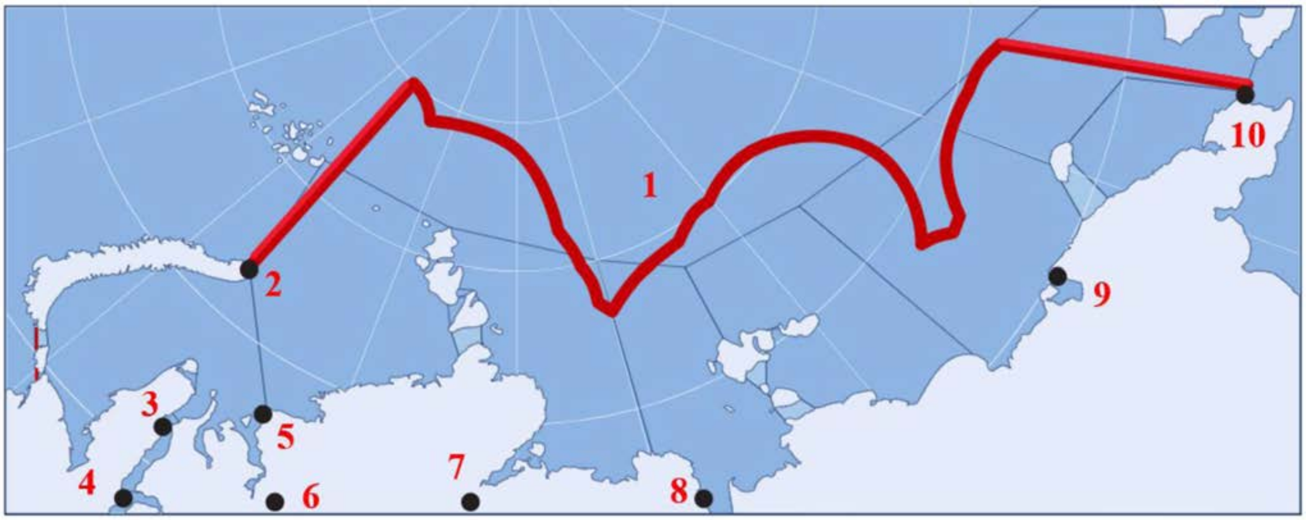


Figure 1—The water area of the Northern Sea Route.Source: Federal State Budgetary Institution "The Northen Sea Route Administration", http://www.nsra.ru/en/ofitsialnaya_informatsiya/granici_smp.html where 1 – bondaries of the Northern sea route; 2 – Zhelanya cape; 3 – port of Sabetta; 4 – Kamennyy cape; 5 – port of Dickson; 6 – port of Dudinka; 7 – port of Khatanga; 8 – port of Tiksi; 9 – port of Pevek 10 – Dezhneva cape.

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 (Dmitrievsky, 2013) (Eremin, 2017a) (Eremin, 2018).

The freight traffic along the Northern Sea Route will be dominated by liquefied natural gas, gas condensate and oil companies of PJSC Gazprom, PJSC NK Rosneft, PJSC NOVATEK, PJSC Gazpromneft, JSC Neftegaz Holding and other companies. Natural gas reserves of PJSC Gazprom constitute 17% of the World, and 72% of Russian. The Gazprom company accounts for 12% of world and 68% of domestic gas production. Natural gas production in the Arctic zone along the Northern Sea Route has stabilized and is about 83% of all-Russian production. PJSC "NOVATEK" plans to bring the shipment of liquefied natural gas (LNG) to 33 million tons, which will be about 7% of its total production in the world. According to experts, the share of LNG in world gas trade will increase from 40% of total trade in 2018 to 60% by 2040. Minister of Energy Novak A.V. estimates the potential growth of LNG production in Russia in 40-80 million tons, which together with the already announced production projects gives the total possible volume of LNG production in Russia in the amount of 123-163 million tons per year. PJSC "NOVATEK" is building the "Utrennii" liquefied natural gas and gas condensate terminal in the sea port of Sabetta. LLC Gazpromneft-Yamal is developing the Novoport oil and gas condensate field. The year-round shipment of hydrocarbons is carried out through the unique oil terminal "Gates of the Arctic" and will reach 8.5 million tons. LLC Gazprom Neft Shelf produces oil at the Prirazlomnoye oil field, and conducts exploration at the Dolginksky oil field, Severo-Dolginsky, Heysovsky and North-Wrangel license areas on the Arctic shelf of the Russian Federation. The plans of JSC Neftegazholding to reach the ceiling for the shipment of oil from the Payakha group of fields to 7.3 million tons, in connection with which it is planned to build a marine terminal in the «Sever» harbor.

According to the US Geological survey, the subsoil of the Arctic zone of Russia contains at least 315.4 billion BBOE, including in the Arctic zone of the Siberian platform 93.9 billion (Gautier, 2009). Analysis and systematization of the results accomplished during the period from 1927 to 2019 years of oil exploration activities in the North of the Siberian platform and adjacent continental shelf shows that the total area of prospective oil and gas lands onshore is over 0.7 of the total platform area of 3.5 million sq. km. or 20%, and the total initial resources in accordance with the coastal shelf for at least 41 billion tons of oil equivalent (Gert, 2013).

Paleotectonic analysis

By paleotectonic analysis, in the North of the Siberian platform allocated Turukhan-Noril'sk, Yenisei-Khatanga, Anabar-Lena and Verkhoyansk foredeep systems stand out, which were formed in the pre-Paleozoic stage of development of the northern part of the Siberian platform (Fig. 2).

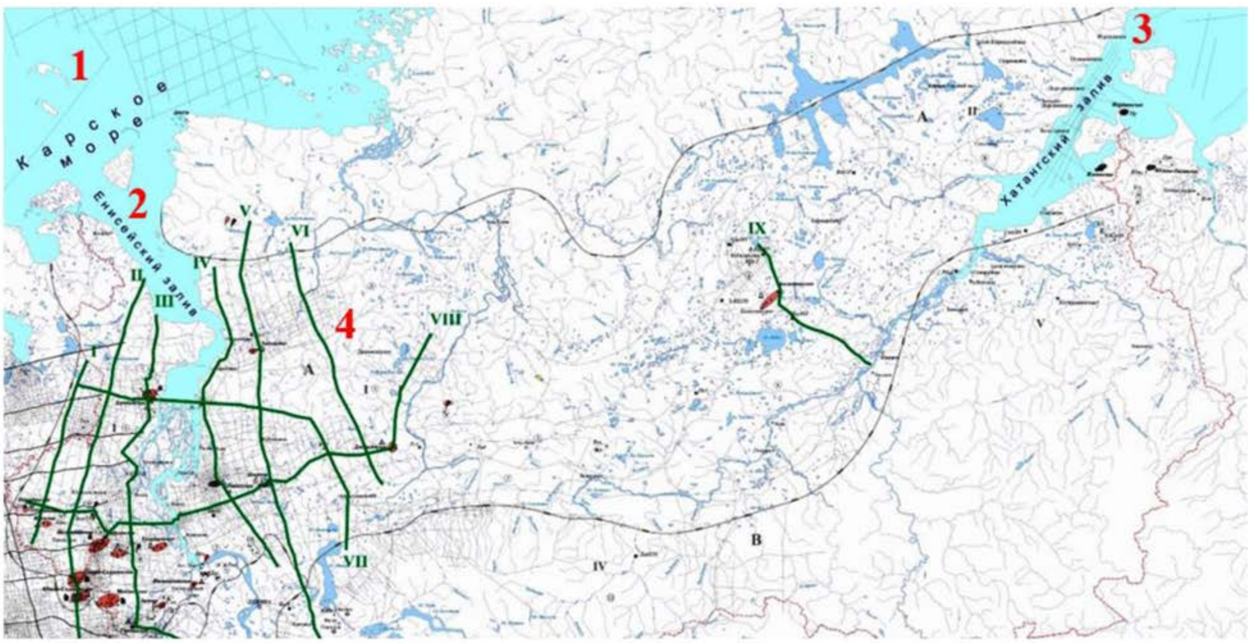


Figure 2—Overview map of seismic exploration routes, where 1 - the Kara Sea; 2 - Yenisei Gulf; 3 - Khatanga Bay and 4 - I, II, …, IX - seismic survey routes (Dmitrievsky, 2018a) (Larichev, 2007) (Savchenko, 2014).

The internal structure of the foredeep systems of the Siberian platform, primarily due to the physical properties of the underlying basement - the crystalline basement, largely controls the oil-and-gas conditions of the basal strata of the sedimentary cover, determines the direction of movement of the most ancient hydrocarbon fluid flows to the petroleum accumulation zones. The basal part of the cover (Riphean-Vend) is mainly confined to aulacogenes, which are embedded in the Riphean and play an important role in the development of elements of the foredeep systems of the Siberian platform (Belokon, 2004) (Larichev, 2007). In addition to aulacogens, the sedimentation occurred in pericraton paleo - lagoon, located on the passive margins of the Siberian platform. The paleotectonic analysis of the foredeep systems of the north of the Siberian platform indicates the inherited nature of the geological development of structural elements (Table 1).

Table 1—The tectonic-geodynamic stages of development of foredeep systems of the north of the ancient Siberian platform (Savchenko, 2014).

Foredeep system	Geodynamic regime and its age	Structural element	Lithodynamic complexes, their associations
1	2	3	4
Turukhan-Noril'sk	Rifey. Rift-spreading (Igarka part)	Passive edge of the continent (pericraton trough)	Riphean, carbonate-terrigenous and volcanogenic sediments (lava, tuff mainly of basic composition)
	Carboniferous - Permian. Collision	Edge trough	Lagoonal -continental formations of the Tungus series
	Permian -Triassic. Pericollisional	Volcano-plutonic belt	Volcanic and sedimentary-shallow flysch formations (mudstones, aleurolite ashes, tuffs and tuffites, rarely layers of limestone)
Yenisei-Khatanga	Middle Riphean - Carboniferous. Rift-spreading (near the Malokhetsko-Rassokha-Balakhna deep fault)	1 - Spreading center	Allocated on the basis on the Common Depth Point method
		2 - Passive edge of the continent (pericraton trough	Molassoid sediments, terrigenous-carbonate and coal-bearing
	Triassic - Jurassic. Rift-spreading (near the Malokhetsko-Rassokha-Balakhna deep fault)	3 - Spreading center	Allocated on the basis on the Common Depth Point method
		4 - Passive edge of the continent (pericraton trough	Continental and marine sedimentary-volcanogenic formations, as well as cyclic formations of transgressive clayey packs and suites and sandy-aleuritic regressive suites and strata
	Jurassic - Cretaceous. Collision	5 - Mountain trough	Coastal marine sediments (sandstones, siltstones)
		6 – Nappe -Thrust belts	Formation of a complex of nappe tectonic cover - thrust dislocations
Anabar-Lena	Rifey. Rift-spreading	Passive edge of the continent (pericraton trough	Terrigenous shallow and deep-sea sediments (sandstones, siltstones, mudstones)
	Jurassic - Cretaceous. Collision	Edge trough	Continental and marine terrigenous sediments of the Jurassic age and coal-bearing molasses
Verkhoyansk	Carboniferous - Middle Jurassic. Rift-spreading.	Passive edge of the continent (pericraton trough	Coastal and marine lagoon-continental sediments (sandstones, siltstones, mudstones, carbonates)
	Late Jurassic - Paleogene. Collision	Edge trough	Marine, lagoon-continental and continental sediments (sandstones, alvevrolites, mudstones, carbonates, coals)

The formation of hydrocarbon fields in the carbonate strata and in the pinch-out zone of sandstone reservoirs of the Riphean - Upper Proterozoic terrigenous strata should be expected, provided that the catagenetic maturity of the organic matter is satisfied with the possibilities of hydrocarbon generation in areas of the evolution of foredeep systems and the adjacent territory (Fig. 3).

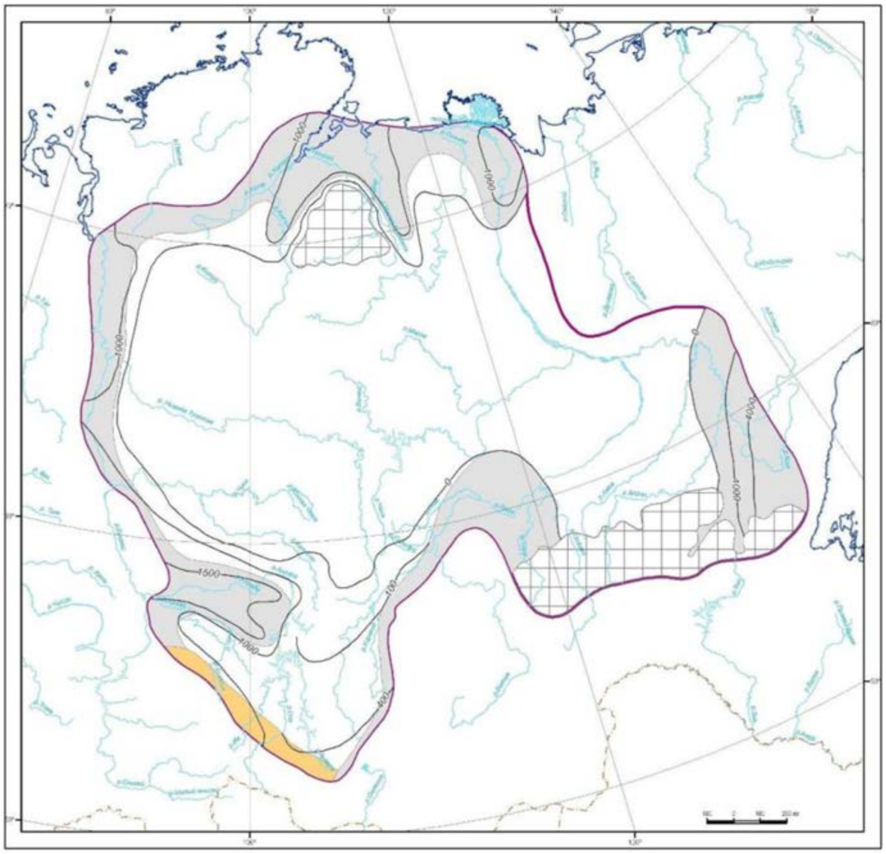
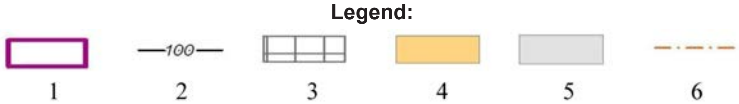


Figure 3—The lithofacies characteristic of the Upper Proterozoic sediments of the foredeep systems of the ancient Siberian platform (Milanovsky, 1996).
Legend:



Where 1 - platform boundaries; 2 - thickness isolines of the Upper Proterozoic sediments; 3 - exits to the surface of the crystalline basement. The lithologic-facial characteristics of the Upper Proterozoic sediments of the foredeep systems: 4 - continental proluvial (sandy-clayey, cross-layer, red-colored); 5 - slope (clay, carbonate-clay, dark gray). 6 - state borders.

In the Riphean - Precambrian, the Yenisei-Khatanga and Turukhano-Noril'sk foredeep systems are formed. In the Lower Paleozoic - Precambrian, from the northwestern part of the Epi-Archean Siberian plate / platform a large block breaks off. This large block later became part of the heterogeneous base of the West Siberian Plate and the adjacent Yenisei – Khatanga trough when immersed in the Jurassic – Cretaceous (Permian – Triassic) time (Kosygin, 1962) (Larichev, 2007) (Migursky, 2010) (Milanovsky, 1996) (Paramonova, 2010) (Prokoptseva, 2014) (Ushakov, 1972).

In the Permian – Triassic, from the northern part of the Epi-Archean Siberian plate / platform, the microplate of mountain Taimyr / Taimyr microcontinent separates and moves to the north. The eastern part of the Yenisei - Khatanga regional trough and the Anabaro-Khatanga saddle are being formed.

The basic concepts of the geological and tectonic structure and oil and gas potential of the northern part of the Siberian platform and the adjacent shelf of the marginal seas of the Arctic ocean are currently based on seismic survey data using the common depth point (CDP) method, tied to the existing deep parametric and exploratory wells. In the modern contours, the Siberian platform in the north and northwest is bordered by the Yenisei-Khatanga regional trough, the eastern part of which merges with the Anabar-Lena trough framing the north-eastern part of the Siberian platform. In the oil and gas geological plan the considered territory is located in the Yenisei-Khatanga, Anabar-Khatanga and Anabar - Lena oil and gas regions of the Lena-Tunguska oil and gas province.

Seismogeology

The unified nomenclature of reference/regional seismic horizons in the accepted stratigraphic schemes for the Arctic zone of the Siberian platform has not been developed to date. According to the speed of propagation of the geological section in a generalized form today is fairly reliably identified five seismostratigraphic complex (Table 2). The regional distribution of the above-described reflecting horizons argues in favor of a single sedimentary hyperbassin existing from early Riphean.

Table 2—Seismic stratigraphic complexes of the Arctic zone of the Siberian platform.

Seismic stratigraphic complex	Reflective Horizons	Reservoir wave speed, km / s	Lithology
Mesozoic - Cenozoic	I-II	From 1.7 − 2.5 to 3-3.5	Terrigenous
Permian - Lower Triassic	III, IV, V, VI	From 3.5 to 4.5	Volcanogenic - terrigenous
Upper - Middle Paleozoic	VI, VIII	From 4.8 to 5.8	Terrigen-carbonate
Upper Proterozoic - Cambrian	Vi, VII, VIII	From 5.1 to 5.6	Predominantly carbonate
Foundation surface	F (Φ)	From 5.9 to 6.4	Crystal and metamorphic formations

Note. The upper part of the section is composed of permafrost with a capacity of 500–800 m. The stratified wave velocity in frozen rocks is from 3.1 to 4.4 km / s, and in thaw zones, in river beds, lakes, interval velocities do not exceed 2.0 km / s.

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 (Eremin, 2017b) (Ulmasvay, 2017).

Oil and gas complexes. In the Yenisei - Khatanga foredeep system, the Yenisei - Khatanga oil and gas region includes the territory of the Yenisei - Khatanga regional trough, the Yenisei Bay and the western part of the Anabar - Khatanga saddle. In the western part of the Yenisei - Khatanga regional trough, the foundation lies at a depth of 14-16 km. In the sedimentary cover of the Yenisei - Khatanga regional trough in the Meso-Cenozoic stratigraphic complex, I and II reflecting horizons are clearly traced (Table 3).

Table 3—Reflecting horizons in the Yenisei - Khatanga regional trough.

No. p/p	Reflecting horizon	Stratigraphic binding	Seismostratigraphic complex
1	Ia	Sole of the Dorozkov suite. Upper Cretaceous	Mesozoic-Cenozoic
2	Ia1	Roof of the Yakovlev suite. Lower Cretaceous	Mesozoic
3	Iб	Sole of the Yakovlev suite. Lower Cretaceous	Mesozoic
4	Iв	Sole of the Malokhet suite. Lower Cretaceous	Mesozoic
5	Iг	Sukhodudin suite. Lower Cretaceous	Mesozoic
6	Iд	Sole of the Nizhnekhet suite. Lower Cretaceous	Mesozoic
7	IIa	Yanovstan suite. Upper Jurassic	Mesozoic
8	IIб	Sole of the Tochin suite. Upper-Middle Jurassic	Mesozoic
9	IIв	Sole of the Leontief suite. Middle Jurassic	Mesozoic
10	IIг	Jangodi suite. Middle-Lower Jurassic	Mesozoic
11	III	Sole of the Zimnii suit	Mesozoic
12	V	Sole of the Upper - Roof of the Middle Triassic	Mesozoic
13	VI	Sole of the Kozhevnichev suite. Lower Permian	Upper Paleozoic, sporadically
14	VII	Sole of the Lower Permian	Upper Paleozoic, sporadically
15	VIII	Sole of the Middle - roof of the Lower Paleozoic	Lower Paleozoic, conditionally
16	F (Ф)	Surface of the crystalline basement	

In the Yenisei Gulf, according to seismic data, the common depth point (CDP) method also reflects reflecting horizons in pre-Jurassic sediments (Table 4).

Table 4—Reflecting horizons in the area of the Yenisei Bay.

No. p/p	Reflecting horizon	Stratigraphic binding	Seismostratigraphic complex
1	M	in the roof of the Aptian sediments	Mesozoic
2	K	in the roof of the Neocomian sediments	Mesozoic
3	II_a	in the roof of the Upper Jurassic - the sole of the Upper Jurassic – Cretaceous terrigenous complex (J_3-K) roof of the J_2-$_3$	Mesozoic
4	T3	in the sole of the Middle Jurassic sediments	Mesozoic
5	T4	in the Lower Jurassic complex	Mesozoic
6	III	in the sole of the Lower Jurassic complex	Mesozoic
7	VI_6	in the Upper Permian-Triassic complex (P_2-T)	Permian-Triassic
8	VII	in the roof of the Upper Devonian-Lower Carboniferous Complex (roof D_3-C_1)	Upper Proterozoic-Cambrian
9		in the roof of the Lower-Middle Devonian complex (roof D_{1-2})	Upper Proterozoic-Cambrian
10		in the roof of the Silurian-Lower Devon complex (roof S-D_1)	Upper Proterozoic-Cambrian
11		in the roof of the Upper Cambrian-Ordovician complex (roof $Є_3$-O)	Upper Proterozoic-Cambrian
12		in the roof of the Vendian-Cambrian complex (roof V-$Є_2$)	Wend-Cambrian
13	R	in the roof of the Riphean complex (roof R)	Riphean
14	F (Φ)	Foundation surface	

The marine and coastal-marine facies of the Jurassic and Cretaceous with a thickness of 6-7 km quietly lie on the Paleozoic-Triassic complex, whose thickness exceeds 6 km. Oil shows are set in the interval from Riphean to Cenozoic. Ordovician and Silurian sediments are oil and gas bearing on the right bank of the Yenisei in the Norilsk region. To the north, six fields with oil and gas reserves have been discovered, explored and partially developed (Fig. 2). In the eastern part of the Yenisei - Khatanga regional trough in the Triassic, intensive deflection occurs with the accumulation of sediments of high thickness.

Anabaro-Khatanga oil and gas region

In the Anabaro-Khatanga oil and gas region, the territory of the Anabaro-Khatanga saddle is the most studied by seismic exploration and deep drilling. On the Anabar-Khatanga saddle, the seismic-geological breakdown of the section is generally close to that in the Yenisei-Khatanga oil and gas region.

In the Mesozoic part of the section in the Anabar-Khatanga saddle, there are tracing reflecting horizons associated with Cretaceous, Jurassic and Triassic sediments. In the Paleozoic part of the section, the reflecting horizons in the Permian sediments are traced; in the Proterozoic, the reflecting horizon is attached to the surface of the Proterozoic sediments. With varying degrees of confidence within the saddle, the following reflecting horizons can be traced (Table 5).

Table 5—Reflecting horizons in the Anabar-Khatanga saddle.

No. p/p	Reflecting horizon	Stratigraphic binding	Seismostratigraphic complex
1	IIb	roof of the Middle Jurassic	Mesozoic
2	III	sole of the Jurassic	Mesozoic
3	V	roof of the Tuffolava suite of the Ind stage of the Lower Triassic	Mesozoic
4	VI	roof of the Upper Permian	Upper Permian
5	VI_a	roof of the Lower Kozhevnokov suite of the Lower Permian	Lower Permian
6	VI_b	roof of the Tustakh suite of the Lower Permian	Lower Permian
7	VII	roof of the Lower Carboniferous carbonates (sole of the Tustakh suite of the Lower Permian)	Lower Permian
8	VIII	roof of the Cambrian (Lower Cambrian) terrigenous-carbonate complex	Lower Paleozoic
9	R	surface of the Riphean rocks	Proterozoic. Traced sporadically, conditionally highlighted
10	F (Ф)	surface of the Archean-Lower Proterozoic crystalline basement.	Traced sporadically, conditionally highlighted

Oil and gas complexes.. Within the Anabaro-Khatanga saddle, in the context of sediments from Riphean to Mesozoic, the formation of several oil-and-gas-bearing complexes is assumed:

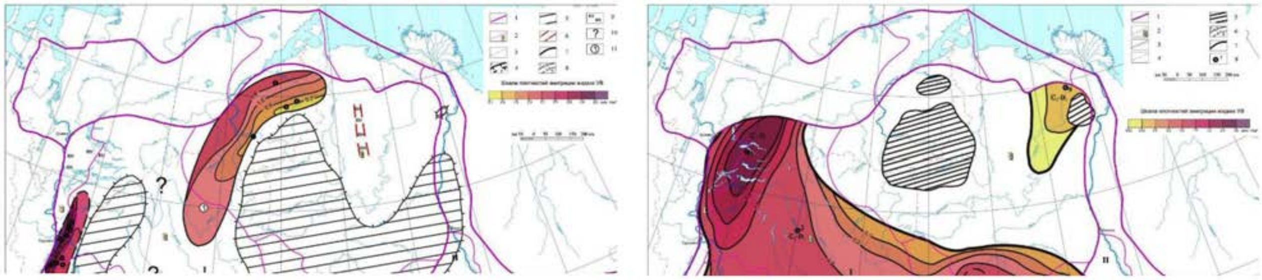
- Riphean terrigenous-carbonate;
- Vendian-Cambrian terrigenous-carbonate;
- Ordovician-Middle Devonian terrigenous-carbonate;
- Upper Devonian-Carboniferous carbonate;
- Middle Carboniferous-Permian terrigenous;
- Triassic terrigenous;
- Jurassic-Cretaceous terrigenous.

A composite lithologic and stratigraphic section of the Anabaro-Khatanga saddle from drilling data with additions is presented in works (Gorshkov, 2012) (Shabalin, 2018b).

The Riphean terrigenous-carbonate oil and gas complex is composed of carbonate deposits rich in organic matter containing C_{org} or Total Organic Carbon - TOC to 1.8 wt. %. Bituminous coefficient in mudstones - from 4 to 8%, in sandstones - up to 80%. (Sidorenko, 1991) (Bazhenova, 1993fond, 2011fond); (Botneva, 1995fond).

The Vendian-Cambrian terrigenous-carbonate complex, represented by carbonate-terrigenous sediments, is characterized by low reservoir-filtration properties. Porosity does not exceed 4%, permeability is the tenth of mD, the content of C_{org} (TOC) is from 0.05 to 0.21 wt. % (Savchenko, 2012fond).

The main source of petroleum potential of the *pre-Mezozoic megabasin* of the Siberian platform is the upper Proterozoic (Riphean and Vendian). Figure 4 shows the copies of schematic maps of the scale of emigration of liquid hydrocarbons from the Riphean (a) and Vendian (b) oil and gas formation sites of the Siberian Platform, which operated in the post- Riphean time (Bazhenova, 2011).



a b

Figure 4—Copies of schematic maps of the scale of emigration of liquid hydrocarbons from Riphean (a) and Vendian (b) oil and gas centers of the Siberian platform, which operated in post - Riphean time. Where for a) 1-4 - borders: 1 - oil and gas provinces (I - Lena-Tungus, II - Khatanga-Vilyui), 2 - oil and gas bearing regions, 3 - administrative, 4 - distribution of Riphean sediments (a - established, b - estimated); 5 - areas of absence of Riphean sediments; 6-disjunctive disorders; 7 - boundary of oil and gas bearing zones; 8 - lines of equal density of emigration of liquid hydrocarbons (million tons / km²): a - basic, b - additional; 9 - areas with established catagenetic disagreement at the Riphean / Vendian border; 10 - areas where there is no information about the presence of Riphean centers of oil and gas formation; 11 - Riphean centers of oil and gas formation operating in the Vendian-Paleozoic: 1 - Kotui, 2 - Turukhansky; The numbers on the map in the squares: 1 - Turukhan-Norilsk oil and gas region, 2 - North-Tungus oil and gas area, 3 - Anabar oil and gas area. For b) 3 - modern sediment distribution; 4 - administrative; 5 - areas without Vendian sediments; 6 - lines of equal density of emigration of liquid hydrocarbons (million tons / km²): a - basic, b - additional; 7 - boundary of Vend oil and gas bearing zones; 8 - points for calculating the time of action of oil and gas bearing zones. The rest of the legend, see fig. 4 a) (Bazhenova, 2011).

Ordovician-Middle Devonian Terrigenous-Carbonate Oil and Gas Complex. The Lower Paleozoic Ordovician-Middle Devonian subsalt potential oil and gas complex is assumed to be in the deepest part of the Anabar-Khatanga saddle.

Upper Devonian-Lower Carboniferous Carbonate Complex. Drilling revealed Upper Devonian and Lower Carboniferous sediments on the slope of the Anabary massif. Upper Devon is represented by clayey, limestone, carbonaceous clayey, siliceous clay shale, limestone, dolomite. Lower carbon sediments are represented by limestones with a pelitomorphic and even aphanite structure, which excludes the possibility of movement of liquids in them. According to logging data, no permeable formations were identified (Boldushevskaya, 2009fond), (Savchenko, 2014).

The Middle-Carboniferous-Perm oil and gas complex is composed of a powerful terrigenous stratum of Permian age. The thickness in the wells varies from 500 m on the southern side to 2500 m in the central part of the Anabar-Khatanga saddle, in the Tigyan-Anabar shaft. The section is represented by rhythmically alternating packs of silty sand and silty clay rocks (Kalinko, 1954fond), (Tkach, 1983fond) Numerous macro- and micro-manifestations of bitumen are established in the Nordvik, Yenisei-Khatanga, Anabar-Lena and Olenek areas. Bituminous saturation in the rocks of the complex reaches 7%. In the Lower Permian sediments represented by samples of mudstones, the C_{org} (TOC) content varies from 0.01 to 5.10 wt. %. The type of organic matter is humus, or belongs to the category of highly dispersed organic matter. The oil content of the Permian terrigenous strata, distributed over Anabar-Khatanga area of 4500 km², 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 / cm³. 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 (Dmitrievsky, 2013). 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 (Vasilyeva, 2015). 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 (Dmitrievsky, 2018b) (Shabalin, 2018a).

Triassic oil and gas complex. In the majority of the territory under consideration, the Triassic oil and gas-bearing terrigenous complex is represented by the Middle and Upper sections. Oil manifestations in the sediments of the Lower Triassic are secondary in nature and are associated with migration from underlying rocks. Middle Triassic sediments contain a large number of sandstone beds with good reservoir properties. The porosity of sandstones varies widely - from 7 to 29%, and the permeability also changes - from impermeability to 163 mD (Lazurkin, 1978). On the Volochansky area, Middle - Upper Triassic sediments contain C_{org} (TOC) from 0.43 to 1.46 wt. %. By pyrolytic indicators, they are characterized by low generation potential ($S_1 + S_2 = 0.11 - 0.37$ mg / g C_{org} or TOC) and very low hydrogen index values (HI = 50-79 mg / g C_{org} or TOC). According to pyrolysis, T_{max} varies from 443 to 462 °C, which implies a rather high degree of sediment conversion (Savchenko, 2014). On the Ulakhan area, rocks of the middle-upper Triassic contain from 0.51 to 5.81 wt. % C_{org} or TOC. Average C_{org} value for siltstone is 1.41 wt. %. In the mudstones, this figure is higher − 2.18 wt. % (Jan, 2013fond). Figure 5 shows the distribution of organic carbon C_{org} in the Triassic (a) and Lower Middle Jurassic (b) sediments of the Eastern Yenisei-Khatanga regional trough and Anabar-Khatanga saddle.

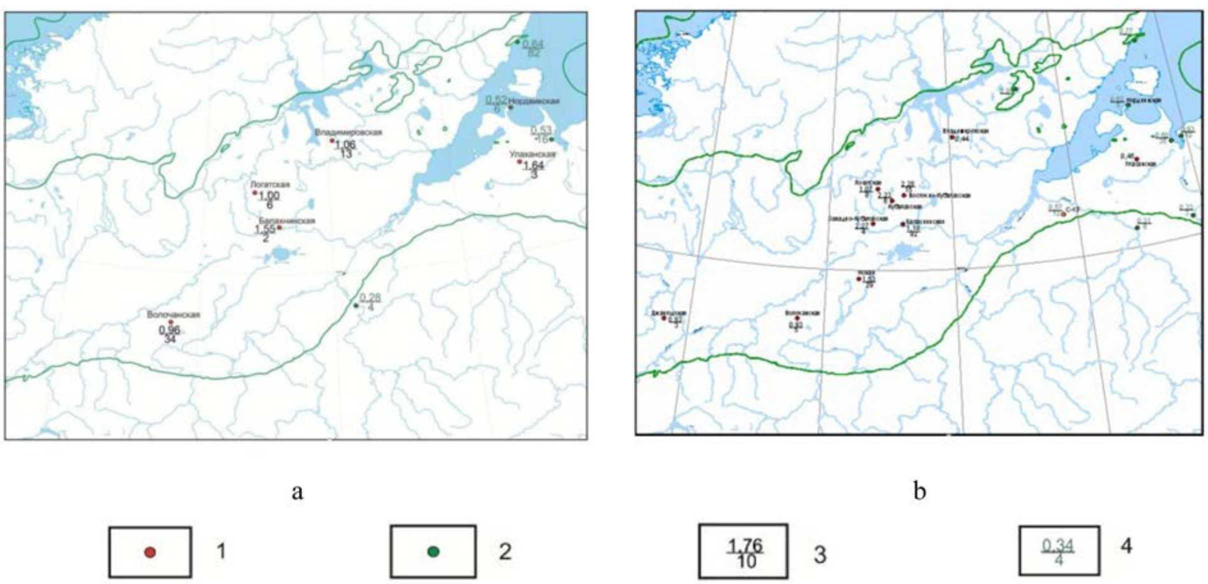


Figure 5—The distribution of organic carbon C_{org} (TOC) in the Triassic (a) and Lower Middle Jurassic (b) sediments of the Eastern Yenisei-Khatanga regional trough and Anabar-Khatanga saddle. Legend: 1 - exploration wells; 2 - natural outcrops; 3 - C_{org} (TOC) values in wt.% per rock (in the numerator - the average value, in the denominator - the number of samples); 4 - C_{org} value in wt.% per rock according to Stepanenko G.F., 1985.

The average values of C_{org} in weight % in Cretaceous sediments vary for argillite from 0.14 to 1.87, sandstone from 0.1 to 0.91, and clay from 1.49 to 1.50; in the Jurassic sediments - for argillite from 0.57 to 8.21 and siltstone from 0.49 to 1, 75; in the Triassic-Permian sediments - for clay it is 0.7; siltstone varies from 0.75 to 1.04 and mudstone from 0.08 to 1.48.

Jurassic Cretaceous oil and gas complex. Jurassic-Cretaceous sediments covering the whole complex of rocks of the sedimentary cover of the northern Siberian platform with a capacity of 6-7 km in the western part of the Yenisei-Khatanga regional trough are composed of alternating sandy and clayey interlayers (Dmitrievsky, 2013).

Anabar-Lena oil and gas area

Within the boundaries of the Anabar-Lena oil and gas region, the territories of the Anabar-Lena trough, the Olenek folded zone, the shelf of the Anabar and Olenek bays of the Laptev Sea (Meisner, 2010) are considered. In 2012, the process of linking new and previous seismic data with the revised stratigraphic breakdowns by parametric wells Ust-Olenek 2370, Charchyk 1, Hastakh 930, Bur 3410 (Fig. 6) and available for these deep wells geological and geophysical information more reliably identified in time sections of the reference reflecting horizons in the Paleozoic and Proterozoic sediments and identified the following seismological complexes: Mesozoic, Permian, Cambrian, Vendian and Riphean (Eremin, 2018). Table 6 presents the reflecting horizons on the southern side of the Anabaro-Lena deflection.

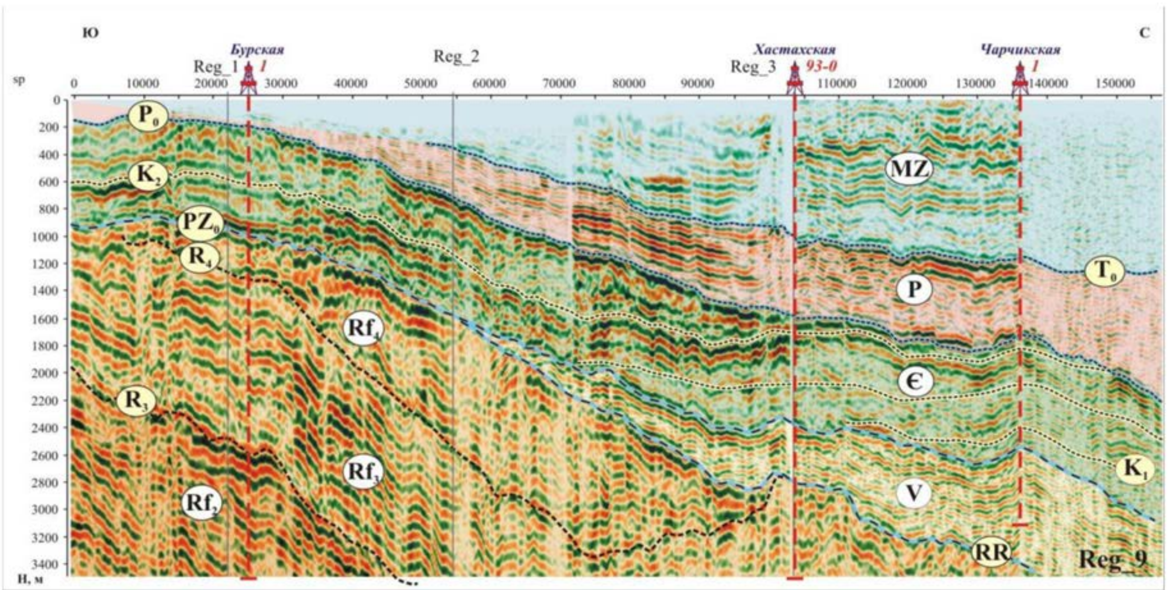


Figure 6—Clinoforms of the Cambrian complex on a seismic-geological profile along the lines of Reg_1, Burskaya-1, Reg_2, Reg_3 and wells: Hastakh, Charchyk −1 (Eremin, 2018) (Meisner, 2010).

Table 6—Reflecting horizons on the southern side of the Anabaro-Lena trough.

No. p/p	Reflecting horizon	Stratigraphic binding	Seismostratigraphic complex
1	To	sole of the Triassic	Mesozoic
2	Po	sole of the Permian	Permian
3	PZo	sole of the Paleozoic / roof of the Vend	Cambrian
4	PR	roof of the Riphean	Riphean
5	R_1-R_4	inside Riphean	Riphean
6	Ro	sole of the platform Riphean/ roof of the Archean	

The thickness of the Riphean sediments exceeds the capacity of the entire overlying Vendian-Mesozoic strata of rocks. As a part of the Riphean complex it is possible to distinguish five independent complexes controlled by reflecting horizons and having various areas of distribution. A large field of bitumen on the northern slope of the Anabar anteclise in the Fomich-Rassoha river basin is the age analogue of the most ancient oil of the Earth, namely, the early Riphean oil of the MacArthur basin in Australia. "Bitumens saturate the basal sandstones of the Mukun series (R_1), overlapped by the UstIlin suite, also of the Lower Riphean - the oldest oil and gas source in the cover of the Siberian platform" (Bazhenova, 2009).

The Mesozoic seismic complex on time sections is controlled by the reflecting horizon T_0 in the sole of the Triassic. The thickness of the Mesozoic sediments varies in the range from 0 to 1645 m, regionally increasing in the northern direction. A drastic reduction in the power of the Mesozoic is observed over the Pronchishchev, Allah and Ust-Olenek structures, in the south of the territory under consideration the complex is completely absent in the time sections.

Within the Anabar-Lena saddle and Anabar-Lena throgh in the Upper Proterozoic-Paleozoic sediments, three oil and gas bearing complexes are quite confidently identified: Upper Paleozoic, Lower- Middle Paleozoic and Upper Proterozoic.

Upper Paleozoic oil and gas complex

The Upper Paleozoic oil and gas complex is associated with the Upper Middle Paleozoic seismic stratigraphic complex, traced by the VI and VIII regional reflecting horizons. The oil-and-gas-bearing complex is composed of rhythmically alternating aleuric-sandy and aleuritic clayey packs of Middle Carboniferous-Permian age. The nature of the oil and gas complex studied in the areas in the Anabar-Khatanga interfluve. The Carboniferous sandy horizons have low reservoir properties, and Permian sediments have higher reservoir properties. The maximum oil saturation is observed in the rocks of the Lower-Kozhevnikov suite, the oil inflows from which range from 8.1 to 12.3 m3 / day (well R-102). The maximum values of porosity reach 49%, and permeability − 96 mD.

Lower Middle Paleozoic oil and gas complex. Associated with the Upper Proterozoic-Cambrian seismic stratigraphic complex. The oil and gas complex are composed of sediments from the Cambrian to the Lower Carboniferous. The greatest oil and gas potential of this oil and gas complex is associated with the Chabur horizon of the lower Cambrian, composed of terrigenous-carbonate rocks. The lower part, represented mainly by conglomerates, gravelites, sandstones, is characterized by high capacitance and filtration properties that are well maintained along the strike. Porosity varies from 15% to 20%, permeability from tens to thousands of millidarcies. Possible roof - dense, low-permeable rocks in the range, from the Middle Cambrian to the Lower Carboniferous. Various hydrocarbon traps can be associated with salt-bearing deposits of Devonian.

The Upper Proterozoic oil and gas complex is represented by the Riphean and Vendian strata, in which the reflecting horizons R_1-R_4 can be traced. These sediments are opened by wells in Kostromin and Khorudalakh areas. When testing these reservoirs, the inflow of formation waters was obtained − 33.6 and 161.3 m3 / day, respectively. In this oil and gas complex, the increased tar tariness of the sandstones of the Labaztakh and Burdur suite of the Riphean is noted. Collectors are composed of Riphean terrigenous formations and Vendian phytogenic dolomites. The porosity of the horizons R_1-R_4 ranges from 10% to 18%, and the permeability - from units to the first tens of millidarcies (Larichev, 2007), (Savchenko, 2014).

Conclusion

The development of oil and gas fields in the Arctic zone of the Northern Sea Route is the key to economic sustainability and energy security not only in Russia, but in the whole world. To date, ideas about the geological - tectonic structure and oil and gas potential of the northern part of the Siberian platform and the adjacent shelf of the marginal seas of the Arctic Ocean are based on seismic survey data using the common depth point (CDP) method attached to existing deep parametric and exploratory wells. In the geological section, nine reference reflectors and over eight oil and gas bearing complexes are distinguished. In the regional systems of the Siberian platform, a high level of hydrocarbon generation, and therefore should be considered the main sources of hydrocarbons. As it was noted in works (Dmitrievsky, 2018a) (Dmitrievsky, 2018b) (Dmitrievsky, 2013) (Shabalin, 2018a) (Shabalin, 2018b), in general, localized resources in the Arctic zone of the Siberian platform along the Northern Sea Route make up 41,017, of which on land 27,582 and on the shelf 13,435 million tons of oil equivalent. In the Yenisei-Khatanga oil and gas region, oil manifestations on the right bank of the Yenisei are set in the stratigraphic interval from Riphean to the Lower Cretaceous. Ordovician and Silurian sediments are oil and gas bearing in the Norilsk region (Verba, 1969). To the north, the Payakha, North-Payakha, Baikal, Khabey and Ozernoye fields are discovered, explored and partially developed, OOIP of which amount to 425.3 million tons of oil equivalent in categories C_1 + C_2 (Dmitrievsky, 2013). By 2018, operational licenses were issued for 4 sites in the Yenisei-Khatanga oil and gas region. In Anabar-Khatanga oil and gas region licenses were issued for one onshore license area and some offshore license areas in the Khatanga Bay.

Given the numerous tectonic unconformaties, faults and high deployment of the section from Riphean to Middle Paleozoic inclusive, it can be assumed that in the Khatanga mesovalley and Yenisei-Khatanga regional trough there is a strong vertical migration of fluids and, accordingly, there is a dependence of the hydrocarbon reserves on the location of low-permeable rocks. As the depth of seismic prospecting increases by the common depth point (CDP), the software improves the processing and interpretation of seismic data, drilling deep wells, the understanding of the depth structure and oil and gas potential of specific areas, the reserves and resources of oil and gas complexes may increase dramatically.

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