Seismogeological characteristics and oil and gas potential of the Arctic regions of the Siberian platform and the Laptev Sea

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Abstract. During the research seismogeological models of the Neoproterozoic-Phanerozoic sedimentary complexes of the Siberian Platform (Anabar-Khatanga and Lena-Anabar oil and gas regions) northern part were constructed. It is concluded that in the Anabar-Khatanga and Lena-Anabar oil-and-gas areas Permian anticlinal traps complexly related to the salt diapirs have the best prospects of petroleum production. The carbonate deposits of Riphean-Carbon are also of interest. The existing geological and geophysical materials do not allow precisely stratify the Laptev Sea basin sedimentary cover. The thickness of platform deposits in which reaches 14-15 kilometers. From the structural-tectonic and general-scientific positions, this sedimentary basin is located in favorable conditions for the formation of hydrocarbon fields.

1. Introduction
According to modern schemes of oil and gas zoning, the Arctic regions of the Siberian platform and the Laptev Sea shelf cover the Anabar-Khatanga and Lena-Anabar oil and gas areas (OGA) of the Lena-Tunguska oil and gas province (OGP) and the Laptev Sea prospective oil and gas province (POGP).

At present, 16850 km of seismic CDP profiles have been worked out in this territory and deep wells have been drilled in the continental part, the complex analysis of which allows to build regional models of the geological structure on a new level and to specify oil and gas potential of this region.

2. Geological structure and oil and gas content of the Anabar-Khatanga and Lena-Anabar OGA
The Anabar-Khatanga and Lena-Anabar OGA, tectonically located within the Anabar-Khatanga saddle and the Lena-Anabar regional depression, are in the extreme north of the Siberian Platform and administratively located in the north-east of the Krasnoyarsk Territory and the north-west of the Sakha Republic (Yakutia), on the coast of the Laptev Sea. The analysis of geological and geophysical data allows to draw a conclusion that a Neoproterozoic-Mesozoic sedimentary basin has developed in this territory, within which the thickness of platform sediments reaches 14-16 km [1-3].

2.1. Seismogeological characteristics.
The analysis of seismic cross-sections and drilling data allows to identify 5 regional-developed seismogeological megacomplexes in the sedimentary cover of this region: Riphean, Vendian, Paleozoic, Permian and Mesozoic, which are controlled by seismic marker horizons in the top and bottom [4] (figure 1).
Figure 1. Seismic section showing seismogeological characteristic of the Neoproterozoic-Phanerozoic deposits of the Siberian platform Arctic regions. Legend: 1 - reflector, 2 - seismic complex, 3 – faults, 4 – seismic line.

Mesozoic seismogeological megacomplex. It lies in the upper part of the sedimentary cover and includes terrigenous deposits of the Triassic, Jurassic and Cretaceous. At the time cross-sections, the Mesozoic seismocomplex in the bottom is controlled by the reflecting horizon $T_0$, in the top by the surface. In the north of the Siberian platform, the thickness of the Mesozoic region decreases regionally from 3000 m to 0 m in the south. Reducing the thickness of these deposits also occurs over the Beregovaya ridge, the Solanocupole mesoswell and the contrasting anticlinal structures.

In the north of the Lena-Anabar depression and in the Anabar-Khatanga saddle, in areas where the thickness of the Mesozoic is more than 1000 m, a reflecting horizon $K_0$, characterized by a high energy level, is identified in this megacomplex, associated with the top of Jurassic.

Permian seismogeological megacomplex. It is controlled by the reflecting horizons $T_0$ at the top and $P_0$ at the bottom. The reflector $P_0$ is identified practically on the entire studied territory and is absent only in the southeast, where the Cambrian emerges on the surface. The reflecting horizon $P_0$ controlling the bottom of the Permian complex, is at the same time associated with a large pre-Permian (early Permian) sedimentation break. In the Lena-Anabar OGA, this break is clearly fixed on time cross-sections and in various parts of this region the underlying Riphean-Cambrian reflecting horizons are cut off by this erosion surface.

In the Permian megacomplex two stable reflection horizons are identified, associated with the tops of the Lower Kozhevnikov and the Tustakh formations. The thickness of Permian deposits also regionally increases in the north direction; the maximum thicknesses, reaching 2500-3000 m, are fixed in the northern part of the Khatanga Bay.

Paleozoic seismogeological megacomplex. It is controlled at the top by reflector $P_0$, the reflection horizons $PZ_0$ in the Vendian development zone and RR in the areas of its absence is associated with the bottom of the complex. The reflecting horizons $PZ_0$ and RR, associated, respectively, with the tops of the Vendian and Riphean, are characterized by a high energy level and reliably traceable on time cross-sections.
In the Lena-Anabar and Anabar-Khatanga OGA, the volume of the Lower-Middle Paleozoic deposits is significantly different.

In the Lena-Anabar OGA, the Paleozoic megacomplex of rocks is represented mainly by Cambrian carbonates, which are overlapped with terrigenous Permian sediments with nonconformity; the deposits of Ordovician-Silurian and Devonian-Carboniferous in most of this area are eroded and are not present in the section. In the southeast of the Lena-Anabar OGA, on the seismic cross-sections in a Paleozoic megacomplex it is identified two stable reflecting horizons, K₁ and K₂, which are formed at the geological boundaries, associated respectively with the basal and upper parts of the Cambrian deposits. In the south-west direction, to the Anabar dome, the thickness of the Cambrian deposits is first significantly reduced, and then the upper part of the Cambrian and the horizon K₁ are cut off by the horizon P₀, associated with the pre-Permian regional sedimentation break. On the seismic cross-sections of this region in the Paleozoic seismocomplex also the cross-bedded (clinoform) pattern of the seismic record is clearly fixed (figure 1). Reflecting horizon K₂, which is associated with the geological boundary lying near the Cambrian top, in the southern direction is submerged first to the middle, and then to the bottom of the complex, forming the clinoforms of the southern fall.

In the Anabar-Khatanga OGA located in the west of the study area, at the base of the Paleozoic megacomplex lies the Cambrian mainly carbonate deposits, which, with a break, is covered with limestones of the Devonian-Carboniferous, or terrigenous Permian deposits, which are characterized by a series of subparallel reflective horizons at the time cross-sections. A feature of the Paleozoic deposits geological structure of the Anabar-Khatanga saddle is the presence in the Early Middle Devonian salt layer and the associated series of salt domes, which largely determined the structural-tectonic construction of this region [1,4]. Located on this territory, the Nordvik and Kozhevnikov diapirs break through the upper Devonian-Carboniferous, Permian and Mesozoic deposits and come to a surface. The analysis of geological and geophysical data allows to consider that the most of local high-amplitude positive structures identified in the Anabar-Khatanga OGA are associated with the coming to a surface and buried salt diapirs which on seismic cross-sections are characterized by a columnar outphasing and decreasing of the wave fields amplitude-energy characteristics – a chaotic seismic pattern recording (see figure 1).

The Ordovician-Silurian deposits in the Anabar-Khatanga OGA are also eroded and absent in the section.

**Vendian seismogeological megacomplex.** It is controlled at the seismic cross-sections by the reflecting horizon PZ₀ at the top and by the reflector RR at the bottom. The megacomplex is characterized by a two-membered structure. The lower part of the Vendian is represented by carbonates and has a thickness of 650-700 m, the upper part is composed of sandstones, siltstones and argillites of the Kessyusin formation. Lying at the top of Vendian-the lower parts of Cambrian, the terrigenous deposits of the Kessyusin formation is enriched with organic matter and is considered as an oil producing one.

The fundamental difference between the Vendian megacomplex and the overlying deposits is that it is not cut off by the erosion surface, but is wedged out to the elevated blocks of the Riphean.

**Riphean seismogeological megacomplex.** It is controlled at the bottom by the reflection horizon R₀ and at the top by the reflector RR. Associated to the base of the Riphean megacomplex, the reflecting horizon R₀ separates at the seismic cross-sections high-amplitude Riphean wave fields, emphasizing the platform shape of the sediments, from the rocks of the Archaean-Proterozoic basement characterized by a chaotic seismic record.

In the most complete sections of the Riphean, developed in the southeast of the Lena-Anabar depression and in the Anabar-Khatanga saddle, the thickness of the Riphean megacomplex reaches 8 km, and in it are identified from four to five conformable seismogeological complexes for which tops the energetically expressed reflecting seismic horizons are confined. In the southern direction, towards the Anabar dome, the Riphean reflecting horizons regionally rise and are successively cut off by the reflecting horizon P₀, confined to the pre-Permian sedimentation break. At the same time within the most contrasting basement highs the thickness of the "cut off" Riphean deposits is 3-4 km.
2.2. **Regional structural-tectonic characteristics.**

Within the studied region, the Neoproterozoic-Paleozoic reflecting horizons regionally plunge to the north. The lowest depths are fixed in the southern part of the study area, within the North-Siberian megamonoclysis and in the northeast, in the Pritaymyr zone; the largest - in the most submerged parts of major depressions - the Yenisei-Khatanga regional depression, the South Laptev and Lena-Anabar synclises (figure 2).

![Figure 2. Tectonic map of the Permian structural stage of the Arctic regions of the Siberian Platform (Lena-Anabar and Anabar-Khatanga OGA). Legend: 1 - administrative boundaries, 2-coastal line, rivers, 3 - zone of absence of platform sediments. Tectonic elements: positive structures: 4 - superorder, 5 - I rank (: I - Yuryangsky megaswell; II - Pogranishny megaswell; III - Salt-dome mezaswell; IV - Druokhansky megaswell), 6 - II rank, 7 - III rank, 8 - IV rank, negative: 9 - superorder, 10 - I rank (I - Begichevsky megadepression; II - Hetsky megasag; III - Yuryang-Khayansky megasag; IV - Taymylarsky mezaswell), 11 - II-III rank; intermediate structures: 12 - saddles, 13 - monoclasses, 14 - monoclines.](image)

In the northern part of the study area the South Laptev syncline is located, in the western part of which the Begichev megadepression is allocated, separated from the Yenisei-Khatanga regional depression by the Solanocupole mesoswell.

To the west of the Solanocupole mesoswell there is a large superorder positive structure, stretched latitudinal direction – the Beregovaya ridge. The ridge is complicated by a series of positive structures of I-II orders and extends along the entire coast from the Khatanga Bay to the estuary of the Lena River, separating the South Laptev syncline from the Anabar-Lena syncline.

Controlled by the Beregovaya ridge in the north and the North-Siberian monocline in the south, the Lena-Anabar syncline is a large depression, stretched out in the latitudinal direction, complicated by the Yuryang-Khayans and Taimylyr megadepressions.

The most of the III-IV orders uplifts of the Lena-Anabar and Anabar-Khatanga, which are traditional anticlinal oil and gas perspective objects, are located within larger positive structures, or in saddles that separate the 0-II orders depressions. For example, the Solanocupole mesoswell is complicated by the Nordvick and West Nordvick local uplifts, in the southern part of the Beregovaya ridge, the Ulakhan-Yuryakh and Ust-Olenek uplifts are identified, the group of Kozhevinov structures and the Chidak uplift are identified in the junction zone of the Yenisei-Khatanga regional depression and the Lena-Anabar syncline.
The analysis of geological and geophysical data also allows us to conclude that the dominant influence of the modern structural and tectonic structure of the northern areas of the Siberian Platform has had three fundamentally important tectonic processes:

1. The pre-Permian (early Permian) sedimentation break, as a result of which the paleorelief of the studied territory was leveled and a poorly dislocated surface - peneplain was formed. Given that in the Anabar-Khatanga OGA under the terrigenous sediments of Perm there is the Devonian-Carboniferous, and in the Lena-Anabar OGA – Cambrian, it can be assumed that to the beginning of the pre-Permian sedimentation break the relief of the studied territory was plunging regionally in the west direction, towards the Yenisei-Khatanga regional depression.

2. A salt tectogenesis, as a result of which in the Anabar-Khatanga OGA have been created coming to the surface and buried salt diapirs that formed in the structural plans of the Upper Devonian, Carboniferous, Permian and Mesozoic anticlinal structures.

3. The intensive young Late Cretaceous and Cenozoic tectonic movements, which have predetermined the differentiation of the relief and the formation of positive and negative structures of various orders.

These tectonic processes have predetermined the similarity of structural plans and the modern relief of the marker stratigraphic levels in the lower and upper parts of the sedimentary cover of the Lena-Anabar and Anabar-Khatanga OGA.

2.3. Oil and gas prospects.

The main prospects for the oil and gas potential of the Anabar-Khatanga OGA are associated with Permian terrigenous deposits, to a lesser extent with the carbonates of the Devonian-Carboniferous and Cambrian. In the Perm rock complex in the Lower Kozhevnikov and the Tustakh formations, clayey packs enriched with organic matter are capable of generating significant volumes of hydrocarbons are identified.

In the Anabar-Khatanga region, the most interesting in relation to oil and gas are the anticlinal structures associated with the salt domes. Near the known diapirs intersecting the entire of the Upper Devonian, Carboniferous and Permian deposits, structural-tectonic traps associated with the wedging out of terrigenous and carbonate reservoirs onto salt stocks can form; over the subsurface salt domes, in the Permian and Mesozoic deposits classical anticlinal traps can be formed. The analysis of the seismic cross-sections also allows to identify in the Cambrian, Devonian and Carboniferous carbonates the wave fields characteristic of organogenic structures, which may also be of interest in the oil and gas potential.

The deposits of Perm, Cambrian, Vendian and Riphean represent the interest in the Lena-Anabar OGA in relation to oil and gas.

Oil and gas perspective objects in the Permian sediments can be associated with anticlinal structures located on the coast of the Laptev Sea and in the saddle separating the Yuryang-Khayan and Taimylyr megadepressions.

The Cambrian and Vendian are perspective, mainly in the southern part of the Lena-Anabar OGA, where hydrocarbon reservoirs can be controlled by stratigraphic, structural-lithological and structural-tectonic traps in the zones wedging, cutting and lithologic substitution of reservoir rocks. The erosion-tectonic ridges of Riphean located in the depths of 1400-1500 m and overlapped with Permian deposits are also of interest in the oil and gas content in the southern part of the Lena-Anabar OGA.

3. Geological structure and oil and gas potential of the Laptev Sea POGP.

3.1. Seismogeological characteristics.

The analysis of time cross-sections indicates that a thick mass of normally sedimentary platform deposits has developed in the Laptev Sea POGP, within which it is possible to identify 6 seismogeological complexes controlled by reliably traced reflecting seismic horizons – seismic markers indexed (bottom-up) S₁-S₅. At the base of the platform sediments, a reflecting horizon F is
identified, which is associated with the base of the platform deposits – the top of the basement (figure 3).

At present, the views on the geological structure of the Laptev Sea area, in which no wells have been drilled, differ markedly. Many researchers consider that the western and central parts of the Laptev Sea shelf are a continuation of the ancient Siberian platform, and both ancient and young sedimentary complexes from the Riphean to the Cenozoic are developed on this territory [5,6].

Figure 3. Seismogeological cross-section along the line reg_1 "Anabar-Khatanga OGP – Laptev Sea". Legend: 1 - reflector, 2 - seismic complex, 3 – faults, 4 – seismic line.

Another group of experts adheres to a fundamentally different point of view and believes that in the water area the sedimentary cover is composed of Upper Cretaceous-Cenozoic terrigenous deposits lying on the Early Cimmerian basement [7,8].

The analysis of available seismic materials does not allow answering this question. The analysis of wave fields allows us to note that the Anabar-Khatanga and Laptev Sea basins are separated by a contrasting basement high, characterized by a chaotic wave field character that does not allow stratifying seismic complexes identified in sea cross-sections.

3.2. Structural-tectonic characteristics.

Within the researches, structural constructions were made for all marker seismic horizons. The analysis of the structural map on the reflecting horizon F associated with a bottom of platform deposits indicates that in the studied part of the Laptev Sea basin the thickness of platform deposits varies in the range of 1500 up to 16000 m. The minimum thickness of the platform sediments is fixed in the western part of the basin, in the Pritaymyr region, where a large positive structure extended in the northwestern direction is identified – a ridge complicated by a series of uplifts of I-III orders. A large positive structure, unfolding in the northeastern direction, is also identified in the southeastern part of the basin. The submerged part of the Laptev Sea basin, within which the Central-Laptev megadepression is allocated, is also complicated by a series of large closed positive structures. At the regional level, the reliefs of the overlying reflecting horizons have a similar structure.

The subparallel occurrence of reflecting horizons, the similarity of structural surfaces, and minor change of seismic complexes thicknesses make it possible to conclude that the modern relief of the Laptev Sea POGP is formed due to intensive young tectonic movements. The analysis of seismic
3.3. Oil and gas prospects.
From the structural-tectonic and general geological positions, the Laptev Sea POGP is in favorable conditions for the formation of hydrocarbon reservoirs. In this basin:

- a large sedimentary cover is allocated, the thickness of the platform sediments reaches 15-16 km;
- modern reliefs of the sedimentary complexes are largely differentiated and they contain large, deep depressions that can be associated with oil and gas formation zones and large positive structures located on their periphery – oil and gas accumulation zones;
- large positive and negative structures are complicated by closed uplifts of II-III orders – potential anticlinal traps for oil and gas reservoirs;
- the sedimentary cover is broken by a large number of faults that intersect almost the entire platform deposits.

4. Conclusion
Within the researches on the basis of complex interpretation of seismic data, well-logging and drilling results regional models of the Neoproterozoic-Phanerozoic deposits geological structure of the Arctic regions of the Siberian Platform and the Laptev Sea were constructed.

The analysis of the results has shown:
1. In the Anabar-Khatanga and Lena-Anabar OGA, the structural surfaces of various sedimentary complexes are largely similar. The main influence on the modern structure of these regions was rendered by: the pre-Permian sedimentation break, as a result of which the relief of the territory has been leveled; processes of salt tectogenesis, which predetermined the formation of salt domes and associated anticline structures and young Upper Cretaceous and Cenozoic tectonic movements, which predetermined the modern differentiation of the reliefs of various sedimentary complexes. Prospects for the oil and gas potential of the Anabar-Khatanga OGA are related to the Permian terrigenous deposits and Cambrian-Devonian carbonates, and the platform deposits of Riphean and Vendian are also of interest in the Lena-Anabar OGA.

2. Modern geological and geophysical data do not allow to stratify seismogeological complexes in the Laptev Sea shelf. At the same time, from the structural-tectonic and general geological positions of the Laptev Sea basin is in favorable conditions for the discovery of hydrocarbon reservoirs. There is a large sedimentary basin, which consists of six seismogeological complexes; the relief of the territory is largely differentiated and in the structural plans of the marker reflecting horizons large positive and negative structures of 0-I orders are identified - oil and gas formation zones and oil and gas accumulation zones.

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