Lithological Features and Conditions for the Development of Salt-Containing Rocks in Oil Reservoirs of the East Siberian Province

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Abstract. Along with the identification of oil and gas deposits, studying the physical and mechanical properties, lithological and mineralogical composition, reservoir properties of rocks, and investigating the correlation between capacitive properties and field-geophysical parameters of productive horizons are most important tasks of prospecting and exploratory drilling. Core description and microscopic analysis of thin sections identified 3 lithotypes of salt-containing rocks composing oil reservoirs and allowed compiling a detailed description of the rock structure and texture, mineralogical and material composition, type of cement, and rock formation conditions.

1. Introduction

In accordance with the adopted scheme of oil and gas geological zoning of the Siberian platform, the Talakan field is located in the Nepa-Botuobinskaya petroleum bearing area of the Lensko-Tunguska oil and gas province. Sedimentary section deposits of the Nepa-Botuobinskaya petroleum bearing area are characterized by a large oil and gas potential [1]. The major prospects here are associated with subsalt formations of the Upper Vendian-Lower Cambrian complex of carbonate deposits and the Vendian terrigenous complex. These two stratigraphic levels, coinciding with all the oil and gas deposits identified in the area, are the main objects of oil exploration.

2. Geological and geophysical characteristics of oil reservoirs of the East Siberian province

2.1. Lithological and stratigraphic characteristics of the section

The geological structure of the Talakan field is developed through crystalline basement formation, Riphean, Vendian, Cambrian, Jurassic, Quaternary deposits, as well as igneous rocks of the Triassic. The main role in the structure of the sedimentary cover is played by the Vendian terrigenous-carbonate deposits and Cambrian halogen-carbonate formations.

2.2. Tectonic structure of the Siberian platform

The deposits of the Siberian platform have two distinguished structural-tectonic floors. The lower floor is represented by crystalline rocks of the Archean - Early Proterozoic basement. The upper structural tectonic floor is composed of sedimentary cover formations.
According to the map of tectonic zoning of the Siberian Platform foundation (Fig. 1), the Talakan field is located within the southern part of the western branch of the Anabar folded system of early archaeids composed of metamorphic complexes of the Early Precambrian, broken through by main and ultrabasic intrusive bodies. The metamorphic complexes of the Anabar massif are crumpled into a complex system of anticlinoria and synclinoria of north-north-western strike, complicated by second-order rock-shaped structures and smaller isocline and brachiform folds.

The surface of the foundation is complicated by extended structural noses, arch elevations and ramparts, deep troughs and grabens associated with the development of the Riphean Baikal-Patom rift system.

The sedimentary cover of the area under study is represented by two structural-tectonic layers, including Riphean-Lower Paleozoic layer (1-2 km) and overlapping Jurassic layer (up to 100 m). The total thickness of sedimentary rocks from the basement surface to the Quaternary sediments varies widely from 1126 to 1760 m. The lower layer includes four lithologic-stratigraphic complexes, such as Riphean-Khoronokh (Riphean-Lower Vendian), Talakh-Nizhnebuk (Lower Vendian), Upper Byuk-Bilir (upper Vendian-lower Cambrian) and Yurga-Verkholesk (Bordon) (Lower-Upper Cambrian), differing in structural plans and manifestation of deformations.

In the modern structural plan, large positive and negative structural elements of the first order with amplitudes up to 200-300 m (Nepa arch, Mirny ledge, Vilyuchanskaya saddle) are distinguished as part of the Nepsko-Botubinskaya anteclise (NBA) [2]. Being the largest platform superordinate structural element, the anteclise, in its turn, is part of the Precambrian Siberian platform. The NBA extends from south-west to north-east and covers the territory of Irkutsk region and the Republic of Sakha (Yakutia). The Nepa arch in its elevated part is complicated by transverse graben-like troughs of the submeridional and northwestern strike, dividing it into four large megablocks: Talakansky, Taransky, Alinsky and Chayandinsky (Fig. 2).
2.3. Lithological and petrographic characteristics of the reservoir rocks

The lithological characterization of the formation is given from top to bottom along the section and affects the productive horizon and fluid supports. For the Osinsky productive horizon, the saline stratum of the Yuregin suite is the top regional fluid support of very good quality (more than 150 m thick).

The total thickness of the reservoir varies from 52.8 to 64.8 m, naturally increasing in the southeast direction towards the deepening of the paleobasin. Such an increase is probably due to the zone of reef structures running along the central part of the Talakan field. To the south of this zone, the thicknesses are sharply reduced and form a steep slope of the reef, with deposits developed in the shallow shelf with depths of up to 30 m, forming a pre-reef zone, and backreef sediments of coastal shallows and lagoons with sea depths of 5 to 10 m developed on the gentle northern side of the reef.

The Osinsky horizon was formed during uncompensated deflection, under conditions of widespread occurrence throughout the entire Talakan-Verkhnechonsky zone of marine transgression spreading from the north. The deposits accumulated within the upper shelf, as the marine sedimentation basin deepened and the coastline shifted in a southeast direction. They formed strip-shaped bodies of northeastern strike, composed of limestones and dolomites mixed with anhydrite, siliceous and clayey material and marlstone interlayers. Occasional minor changes in depths caused the shore deposits of thin clay interlayers in the carbonate reef layer. The formation is characterized by wavy and half-wavy textures, underlined by single layers of mudstone, lenses and layers of carbonate material, enriched with clay material to different degrees, thin bitumen deposits along separate stratification planes and stylolitization seams, also underlined by bituminous deposits.

As for the lithological and petrophysical characteristics, three lithological and petrophysical types of rocks were identified in the layer. In each type, we observe individual patterns of changes in the lithological composition and petrophysical properties: lithotype 1 - anhydritized and silicified limestones and dolomites, lithotype 2 - homogeneous porous dolomites, lithotype 3 - dense calcareous dolomites and dolomitic limestones.

**Lithological and petrophysical type 1. Anhydritized and silicified limestones and dolomites** (Fig. 3. a, b). The rocks are represented by gray and whitish dolomites (due to finely dispersed anhydritization), with a brownish tint, uneven anhydritized and silicified spots in the case of gas and oil saturation. The drill core contained some thin straticules and lenticules, enriched with clay material to varying degrees (to mudstone). As for the mineral composition determined by several laboratory methods, the prevailing rock is dolomite (62%-72%), with 6%-10% of calcite, 12% -15% of anhydrite, 2% -10% of siliceous material and 2%-6% of clay material. The grain size of dolomite can vary from fine to medium fine (0.02-0.15 mm). The rock is formed by pelitomorphic calcareous clots of algal origin, sometimes by well-preserved colonial algae (Epiphron, Renalcis), cemented by mosaic-crystallized calcite cement. In dolomite intercalations, calcite crystallizes mainly in the intergranular space as poikilite crystals between the rhombohedrons of dolomite as is unevenly distributed. The anhydrite forms large poikilite crystals with distinct faces, sometimes affected by dissolution processes, as well as large nest-shaped clusters of small-scale aggregates. The siliceous material is present in the form of small lenticules, it crystallizes in the pores or mixes unevenly with anhydrite forming vast areas of irregular shape. The composition is quartz-chalcedony with a diverse structure from microaggregate (chalcedony) to fine-grained (quartz with regular crystallographic faceting). Chalcedony spherulites are found.
Figure 3. Structure thin sections in the void space of the rocks of the Osinsky horizon (Talakan field):
a – b. Fine-grained dolomite. The bulk of the rock is developed by rhombic dolomite crystals, the pore space between them is cemented by calcite, siliceous material and anhydrite;
c – d. Fine-grained cavernous-porous dolomite. It has a cellular (sieve) structure due to the large number of large voids evenly distributed in the rock;
d – e. Dense fine-grained dolomite. The space between the dolomite crystals is filled with calcite cement.

Secondary processes improving reservoir quality (recrystallization) are not universally developed. Algal limestones experienced a weak degree of recrystallization and enleaching. The replacement of calcareous clots with dolomite and the conversion of limestones to substitution dolomites is only observed in interlayers. Secondary negative processes (sulfatization, silicification) are widespread here, and some of the pores, cavities, and cracks are sealed, and, as a consequence, the reservoir-filter
properties deteriorate. The available primary analytical data of mass analyzes determining the elemental composition of rocks (XRF) shows an increased content of 4.8% of lithium oxide $\text{SiO}_2$ (silicification) and 8.8% of sulfur oxide $\text{SO}_3$ (anhydrite).

The terrigenous material is deposited in a sharply subordinate amount on the shelves of arid regions of carbonate accumulation, where intense generation of carbonates occurs. The average content of insoluble residue in the rocks of the Osinsky horizon is 1.3%-1.8%, increasing to 8.8% in lithotype 1 rocks, where anhydritization and silicification processes are developed. The predominantly silt composition of the grains in the terrigenous part of the insoluble residue, with a large admixture of the pelitic fraction and low sand content, may indicate the formation of sediment in the moderately deep water zone, at a small distance from the coastal zones where sand and silt material is concentrated.

*Lithological and petrophysical type 2. Homogeneous porous dolomites.* According to the drill core, the deposits are mainly represented by brown fine and medium grained dolomites, less often brownish-gray or with oil saturation spots. In interlayers, the dolomites are porous and cavernous, with caverns reaching 2 × 4 cm, but mostly they are small (up to 3 mm), hollow, with dolomite brushes. Oil exudations and bitumen precipitates along separate bedding planes are observed in the core, which emphasizes weak stylolitization with an amplitude of 2-6 cm. Subhorizontal and subvertical cracks, hollow or partially filled with salt, are observed. Salinization is also noted in pores and caverns [3].

In thin sections, lithotype 2 rocks are represented by fine-grained, uniformly crystallized dolomite with a predominant crystal size of 0.05-0.12 mm to 0.20 mm. There are areas of denser fine-grained dolomite (up to 0.02-0.05 mm) with an admixture of clay material richly pigmented with oxidized bitumen, which also partially covers the surfaces of numerous pores and caverns. As for the mineral content, the rocks of this lithotype are dominated by dolomite (92%-98%), with 0.2%-0.9% of calcite, 0.5%-1.2% of anhydrite, 0.2%-0.8% of quartz, and 0.3%-0.9% of clay material as minor impurities. The analysis of the rocks elemental composition (XRF) confirms the predominance of the dolomite component in lithotype 2. In accordance with the classification of calcareous-dolomite rocks by chemical and mineral composition (V.G. Kuznetsov, 1998), the average ratio of calcium oxide to magnesium oxide ($\text{CaO} / \text{MgO}$) is 1.5, which implies 90-100% of dolomite. The admixture of silicon oxide $\text{SiO}_2$ (silicification) and sulfur oxide $\text{SO}_3$ (anhydritization) is insignificant and amounts to 0.8% and 0.4%, respectively. In such dolomites, the pores are usually evenly distributed, and their size is almost the same. In this case, the rock has a lattice (cellular) structure (Fig. 3 c, d) caused by loose packing of grains: a vertex with a face, a face with an edge. Dolomite is characterized by idiomorphic rhombohedral crystals that are in contact with each other through point and semilinear contacts. Secondary intercrystalline pores are widely developed, with the walls of the pores as even faces of dolomite crystals (Fig. 4 a-f). The rocks underwent significant dia- and catagenetic recrystallization, resulting in an increased amount of free pores of recrystallization and leaching caverns.

Speaking about the secondary processes worsening the reservoir properties, we should emphasize salinization [4]. Halite fills the pore space of rock samples from the best reservoirs, distributed unevenly in the rock (foci, interlayers). Its content is insignificant or, conversely, in foci of concentration it can reach 20%-30% (under surface conditions).
**Figure 4.** Talakan field, Osinsky horizon. The sampling interval is 1263.0–1269.2 m. Porous dolomite from fine-fine to medium-grained.

A-f – electron microscopic images of cleavage; general rock structure and structural features of the pore space of the dolomite reservoir. The walls of the pores are smooth faces of rhombohedral dolomite crystals.

*Lithological and petrophysical type 3. Dense calcareous dolomites and dolomitic limestones* (Fig. 3-e-f). In the lower part of the Osinsky horizon, dolomitic limestone predominates significantly before transitioning to calcareous dolomite. The intercalations of sediment are anhydritized to varying degrees. Bitumen precipitates are also observed on the individual bedding planes in the core, emphasizing stylolithization with an amplitude of up to 1.5 cm, unevenly distributed free pores, small caverns (2x3 mm) are found. Interbeds show oil effusions of different intensities, subvertical cracks
and microcracks. According to the mineral composition, the content in the rocks of dolomite and calcite is equal (an average of 44%-51%). In addition, the layer contains anhydrite (1%-3%), quartz (0.1%-1.2%), clay material (0.5%-1.6%). According to the elemental composition, the average calcareous value of the carbonate complex (CaO / MgO) is 10.4, which, according to the classification of V.G. Kuznetsov, corresponds to a content of up to 50% of dolomite component in limestone. An admixture of silicon oxide SiO₂ (0.9%) and sulfur oxide SO₃ (2.2%) indicates the presence of silica and anhydrites in lithotype 3, but their content is much lower than in the upper part of the formation (lithotype 1).

Limestones are often clotted, containing a large number of rounded pelitomorphic clots of different sizes. They are cemented by calcite cement: the calcite grows perpendicular to the surface of the clumps in the form of columnar or conical-crystalline grains forming drusy rims. Connecting with each other, they form pores, sealed inside with sparite lime cement. The calcite crystals, located in pores, increase in size from the periphery of the pores to the center. Dolomite crystals have clear crystallographic faces and are distributed mainly over calcareous cement and clots. The crystals form clusters formed as lenticular bodies. The rock also contains series of stylolite joints filled with bituminous-clay material. Typically, stylolites are accompanied with clusters of dolomite rhombohedrons arranged in chains and repeating their shape. Closer to the bottom of the formation, oncolitic calcareous-dolomite rocks may appear; clastic limestones can appear in the bottom [5].

Secondary processes degrading the quality of the reservoirs are widely developed in the rocks. After the formation of calcite cement of the first generation, sulfatization occurred (some clumps were replaced by anhydrite), and in the later stages, dolomitization took place (where dolomite rhombohedrons replaced shaped elements, cement and anhydrite inclusions). The last stage was the period of compaction, or stylolitization (with traces of dissolution at the contacts of grains of anhydrite and calcite and their deformation and compaction at the points of dissolution). Stilolithic seams trace the bedding and are characteristic of lithotype 3, which is common in the lower third part of the Osinsky horizon. The presence of styrrolites causes the deterioration of the reservoir properties, since they are barriers in hydrodynamic systems formed by rocks with intercrystalline pores and crack systems.

3. Conclusion
Layer development in the conditions of a shallow shelf and the rifogenic genesis of carbonates led to lithological heterogeneity, complex internal structure of the formation and the morphology of the reservoirs inside the carbonate bodies.

Considering the lithological and petrophysical characteristics, we have identified three lithological and petrophysical types of rocks in the layer, each of which with individual patterns of changes in the lithological composition and petrophysical properties: Lithotype 1. Anhydritized and silicified limestones and dolomites, Lithotype 2. Homogeneous porous dolomites, Lithotype 3. Dense calcareous dolomites and dolomitic limestones. Lithotype 1 and Lithotype 3 are characterized by low reservoir properties: for the first type, the decline in properties is due to increased anhydritization and silicification, for the second, due to the preserved high calcareousness (low degree of recrystallization and leaching). Reservoirs with high filtration-capacitive properties and increased productivity correspond to Lithotype 2, represented mainly by cavernous-porous dolomites with a wide development of processes of recrystallization and leaching of carbonate material.

Studying the mineral and particle size distribution of the insoluble residue allows us to assess the sedimentation environment and to obtain data on the conditions for the formation of carbonate deposits.

4. References
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