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Fracturing in the High-Carbon Formation of the Northern Flank of the South-Tatar Arch

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Abstract—The problem of studying the Domanik deposits and their reservoir potential is among the most important ones. The discovery of hydrocarbon deposits in similar rocks at various depths, the considerable variability of reservoir properties, and ambiguity in establishing the values of the effective thickness set the task for researchers to estimate them more reliably. The high-carbon kerogenic-carbonate-siliceous stratum that is characterized by the development of differently-oriented systems of fractures is of outstanding interest.

Keywords: high carbon formation, Domanik deposits, fracturing, reservoir properties, the South-Tatar arch

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INTRODUCTION

The explored oil reserves from conventional reservoirs are being reduced, which leads to a decrease in oil production. One of the possible sources for maintaining the production at the modern level is to develop hydrocarbons (HCs) that are contained in complex and nonconventional reservoirs. The main task in studying complex and unconventional reservoirs is to identify the morphology of voids, to study fracturing, and to estimate the variability in the reservoir properties. This is possible by using the method of capillary defectoscopy, which is based on the phenomenon of capillary penetration of a luminescent liquid into the smallest open cavities of a cubic sample with a side of 5 cm (Bagrintseva et al., 2013). The cubic form of a sample enables one to calculate the oriented gas permeability and the core saturation allows estimation of the effective capacity of internal voids and identification of the morphology, fracture, and cavern openness when taking photos of a sample in an ultraviolet light source after it is processed by special sorbents.

Study of the morphology of the void space and the determination of reservoir properties. The effective thickness of a high-carbon formation is related to the intervals of the section that were most involved in the processes of fracture and cavern formation. The connecting fractures and voids that are located in a high-carbon strata and in the adjoining strata of low-capacity siliceous–carbonate rocks determine the common void space in the high-carbon formation. The effective thickness is often an interval of a section in the entire high-carbon formation, although it would be correct if it were the total thickness of the separate interlayers of rocks that act as a reservoir that is located among the carbon oil-and-gas source strata.

The artificial creation of a void space in siliceous–carbonate rocks that results from human action on a stratum, and the generation of the additional system of fractures increase the effective thickness and causes hydrocarbons to inflow from adjacent oil-source strata, thus increasing the well productivity.

The study of the material composition of rocks and secondary alterations in the colored thin sections showed the great variety of the lithogenetic types and the variability in their properties with depth in the well sections.

The use of the geophysical well-logging data, the identification of the lithogenetic types of rocks, and the analysis of postsedimentation transformations in the deposits made it possible to construct a geological–geophysical section of the northern flank of the South-Tatar arch. In Fig. 1, the section shows the exclusive development of low-capacity fractured reservoirs.

The Sargaev–Semiluk high-carbon stratum is both an oil-and-gas source (OGS) and an unconventional reservoir. According to the data of the geophysical well-logging core complex, this stratum can be divided into several rhythmic strata: compact carbonates, a carbonaceous–siliceous-carbonate stratum, a kerogenic–carbonate stratum with interlayers of compact carbonates, a stratum of thin interlayering of siliceous–carbonate deposits, and a high-carbon kerogenic–carbonate–siliceous stratum; the bottom and the roof of the strata contain limited biotherm structures (Stupakova et al., 2015).

The clayey-carbonate stratum with interlayers of compact carbonates is represented mainly by interlayered tentakulite limestones that are nonuniformly recrystallized with carbonate–siliceous and siliceous

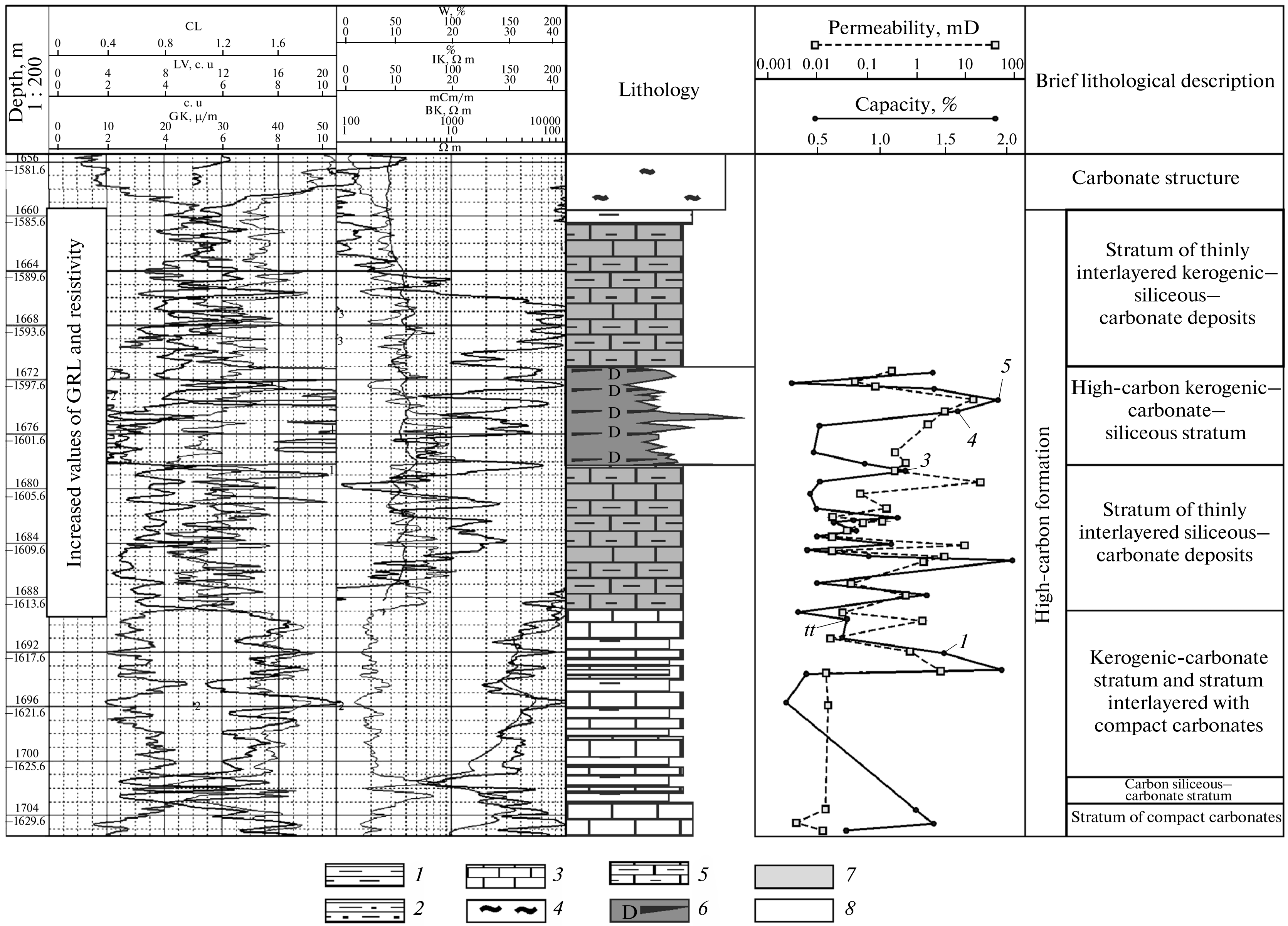

Fig. 1. The lithological–stratigraphical characteristics of the northern flank of the South-Tatar arch (Stupakova et al., 2015) with the changes: *1*, carbonate clays; *2*, argillites with interlayers of limestones, siltstones, and sandstones; *3*, carbonate rocks; *4*, bioherm structure; *5*, clayey carbonates; *6*, high-carbon siliceous carbonate shale rocks; *7*, clayey-carbonate deposits; *8*, carbonate deposits; *1–5*, sample numbers

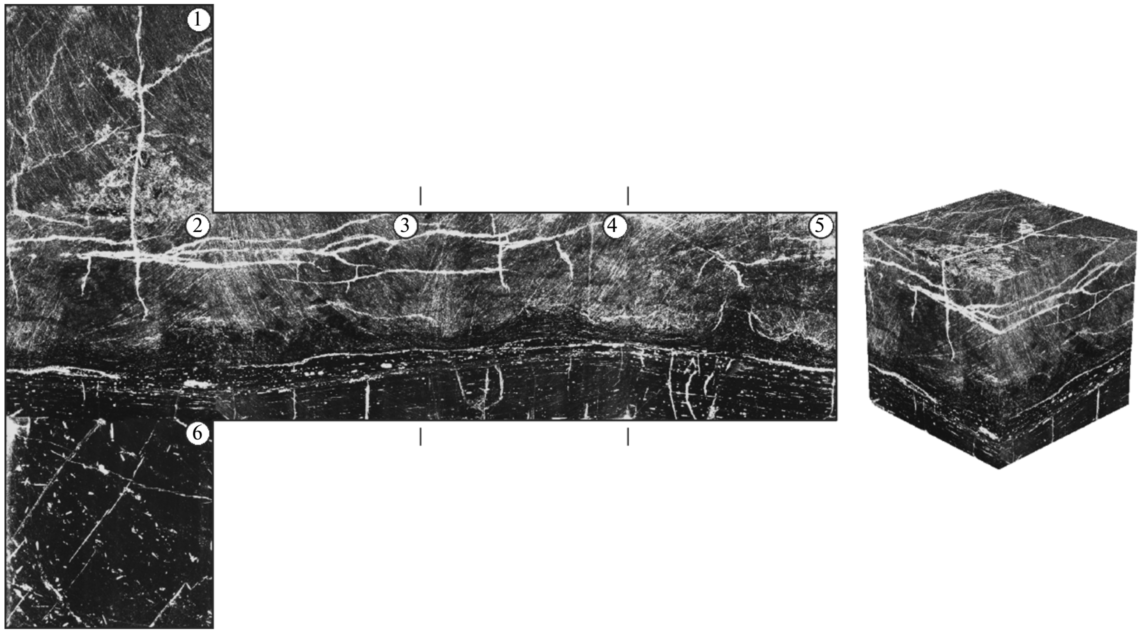

Fig. 2. System of noninterconnected fractures, sample no. 1, depth is 1692.12 m; capacity is 1.5%. Permeability along the directions (mD): I is 0.045; II is 0.642; III is 0.067. The surface density of the fractures over six sides of the cube (cm/cm^2): 1 is 0.61; 2 is 0.88; 3 is 1.36; 4 is 0.91; 5 is 0.98; 6 is 0.68 (the average is 0.89). Openness of the fractures (μm): 5 is the minimum; 130 is the maximum; 45 is the average.

rocks. Here, from the bottom to the top (sample no. 1) a layer occurs with a visible thickness of up to 1.5 cm that is composed of siliceous rocks, which contains rare (up to 5–10%) bioclasts of tentaculites with a longitudinal section of up to 1–1.5 mm and a siliceous–carbonate interlayer of irregular thickness (0.5–1 cm) due to pocket-like cuts in the upper segment of the latter.

The unclear layering is emphasized by numerous bioclasts of tentaculites (30–40%) that are 0.5 mm in length; an interlayer with a visible thickness of 2.2–3 cm is represented by bioclast tentaculite limestone that is nonuniformly recrystallized and has a massive texture. The lower boundary of the interlayer is erosive with an amplitude of the intrusion pockets of up to 1 cm.

In sample no. 1 (Fig. 2) two systems of nonconnected fractures occur. The first system is confined to the tentaculite limestones at the base of the sample; it has developed thin straight short fractures that feather the weakly-curved horizontal transverse fracture with an openness of up to 35–40 μm.

The second system of the fractures is developed in the carbonate–siliceous interlayers in the upper segment of the sample, where horizontal transverse fractures that are interconnected by a few vertical fractures are dominant. The surface density of this system of fractures is high, up to 1 cm/cm^2, and the average openness is 45–50 μm. Due to this, the lateral permeability of carbonate–siliceous rocks reaches 0.642 mD. The effective capacity of the stratum is ~1.5%.

A stratum of thin interlayering of siliceous–carbonate deposits is presented in sample no. 2 by the oblique lens-shaped alternation of dark gray carbonate siliceous rhythmites and black kerogenic–siliceous rocks, as well as lenses and concretions of gray limestones. From bottom to top, there are carbonate–siliceous and kerogenic–carbonate–siliceous rhythmites with thin rhythmic alternation of dark-gray and gray straticules. The range of alternation is 1–3 mm. The bioclasts of tentaculite shells were found along the planes of stratification; the angle of the slope of the straticules varies from 5°–7° to 10°–15°. At the base of this interlayer, there is a concretion carbonate formation with a visible diameter of greater than 2 cm; 1 cm is a black kerogenic–siliceous interlayer. Single bioclasts of tentaculites (up to 3 mm in longitudinal sections) occur that are often pyryrized. The roof has pocket-like erosive incisions; 2.5 cm are gray siliceous–carbonate interlayers. The interlayer boundaries are uneven; the texture is spotted and oblique-lens-shaped (up to 20°). In the upper segment of the sample, gray limestone lenses occur that have an irregular shape with a size of 0.5–1 × 1.3 cm that are saturated with tentaculite bioclasts.

In the sample we identified a system of horizontal transverse echelon-like fractures with irregular openness, which are confined to the rock strata (Fig. 3). The lenses contain short vertical fractures. The dominant development of the horizontal system of fractures determines the anisotropy of the permeability. The lateral permeability equals 1.113 mD, while the horizon-

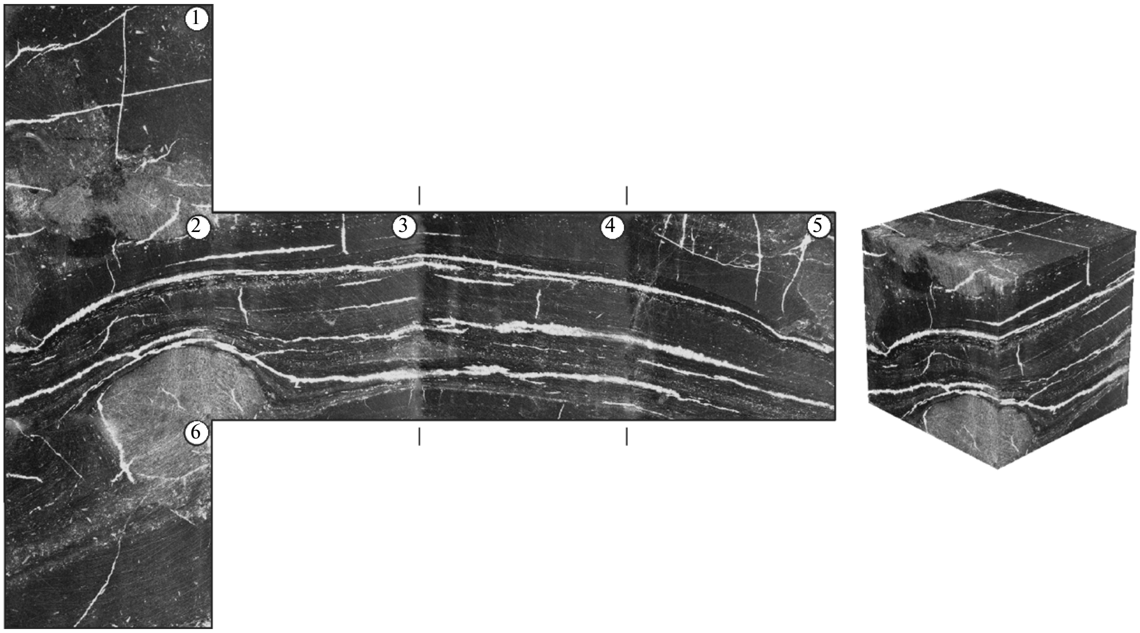

Fig. 3. A system of echelon-like transverse fractures. Section no. 2, depth is 1689.6 m. Capacity is 0.72%. Permeability along the directions (mD): I is 0.022; II is 1.088; III is 1.113. The surface density of the fractures over six sides of the cube (cm/cm^2): 1 is 0.68; 2 is 1.12; 3 is 1.12; 4 is 0.97; 5 is 1.24; 6 is 0.44 (the average is 0.93). Openness of the fractures (μm): 5 is the minimum; 150 is the maximum; 80 is the average.

tal permeability is 0.022 mD. The surface density of the horizontal fractures is high, viz., 1.1 cm/cm^2. The effective capacity of the rocks is 0.72%.

In sample no. 3, the stratum is represented by siliceous rock that is saturated nonuniformly with tentaculite bioclasts. The layering is unclear, discontinuous, and horizontal; in some segments it is gently oblique (5°–7°) and is emphasized by bioclasts of tentaculite shells. The size of the shells is up to 0.5–0.7 mm in transverse sections and up to 0.5 mm in longitudinal sections. The content of bioclasts varies from 5–10 to 15–20%.

The rock has a developed system of fractures that was studied for the cubic sample and for the thin sections. Large colored thin sections with one cubic side are used not only for the lithological characteristics of rocks, but also to substantiate the development of the density of the natural fracturing (Figs. 4, 5). The openness of the vertical thin transverse fractures is 15–20 μm; a more detailed study revealed large cavities with sizes

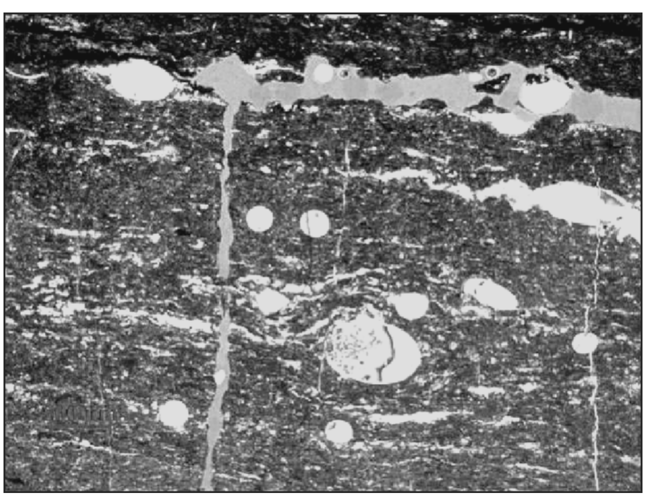

Fig. 4. Thin open vertical fractures that are interconnected with the horizontal fracture that is confined to the slot-like cavern with openness of up to 350 μm. The photo shows a thin section, sample no. 1.

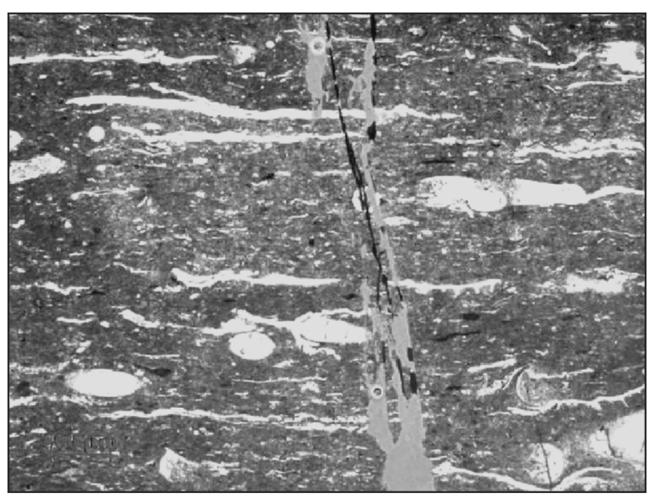

Fig. 5. System of open vertical joints partially filled with bitumen. The photo shows a thin section, sample no. 3.

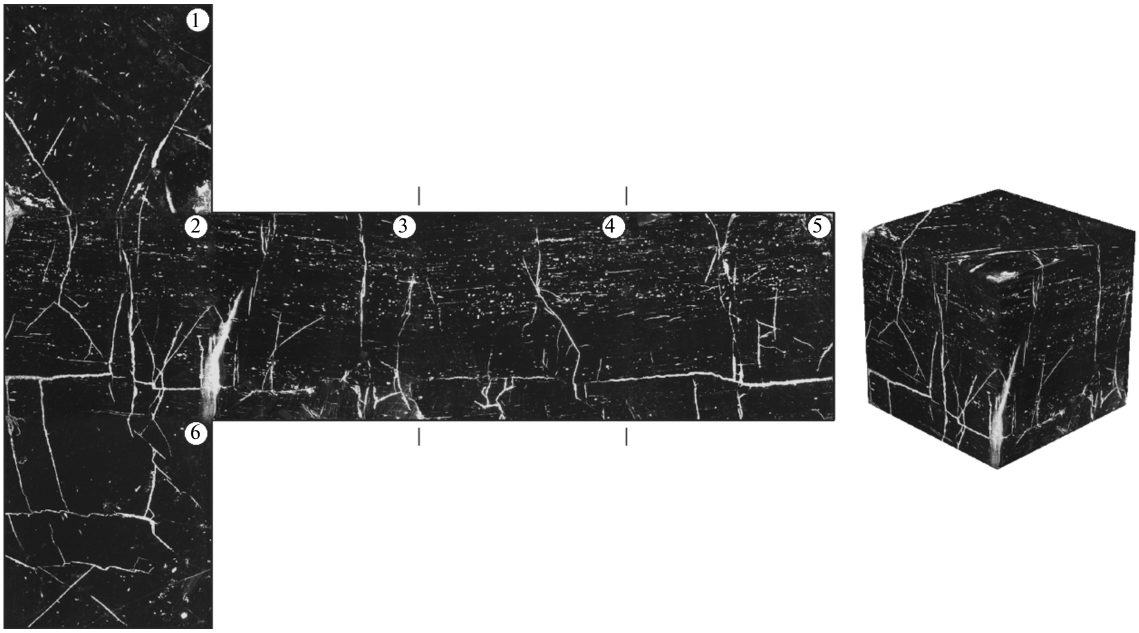

Fig. 6. System of vertical and horizontal fractures. Sample no. 3, depth is 1678.1 m. Capacity is 0.87. Permeability along the directions (mD): I is 0.518; II is 0.171; III is 0.275. The surface density of the fractures over six sides of the cube (cm/cm^2): 1 is 0.48; 2 is 1.19; 3 is 0.98; 4 is 0.56; 5 is 0.88; 6 is 1.08 (the average is 0.86). Openness of the fractures (μm): 5 is the minimum; 95 is the maximum; 17 is the average.

of up to a few millimeters along the fractures in the thin sections. The openness of the horizontal transverse fractures is not constant and ranges from 7 to 95 μm. The fractures are filled with bitumen and are partially calcitic. The surface density is high, viz., 0.86 cm/cm^2 (Fig. 6). The rock is isotropic, the permeability remains almost the same in three directions; the vertical permeability is 0.518, while the horizontal permeability is 0.171 and 0.275 mD.

The *high-carbon kerogenic–carbonate–siliceous stratum* is represented by oblique lens-shaped interlayering of bioclast brown–gray and dark-gray kerogenic–siliceous–carbonate limestones that are saturated with the bioclasts of tentaculites and black kerogenic–siliceous rocks.

The following interlayers were encountered from the bottom to the top in sample no. 4: a wedging out lens-shaped kerogenic–siliceous–carbonate interlayer that varies from dark gray to black in color and is uniformly saturated with bioclasts of tentaculite shells, which makes the rock look striated; the visible thickness is 1.2 cm. The bioclasts of tentaculates were confined to obliquely-oriented planes of stratification with an angle of straticules of up to 20°, a black siliceous carbonate interlayer that contains single tentaculite bioclasts with a visible thickness of 3 cm, and a dark-gray siliceous carbonate interlayer with a visible thickness of up to 3 cm that includes lenses of limestones that are located at an angle to the horizon of 5° to 20°. The lenses have an uneven shape and sizes of 0.5–2 × 6–7 cm. The limestones are bioclast (tentaculite) beige–gray, nonuniformly spotted, and fractured. Black kerogenic–siliceous rocks with an unclear poorly manifested oblique-lens-shaped texture (an angle of up to 20°) are found below 0.5–1.5 cm; these rarely contain tentaculite bioclasts of up to 0.2–0.5 mm in diameter on the planes of stratification.

We revealed that the sample has a system of transverse fractures with different orientations with lens-shaped limestones that were most developed in the interlayers (Fig. 7). The surface density of the fractures is high, viz., 1.11 cm/cm^2. The permeability anisotropy was determined. The horizontal permeability reaches 3.2 mD; the vertical permeability is lower by an order of magnitude due to the presence of a compact layer with a large number of tentaculites at the base of the sample. The effective capacity is 1.61%.

Sample no. 5 is represented by a lens-shaped alteration of limestones and siliceous–carbonate rocks. The boundaries between the rocks are uneven with the traces of intrusion and perhaps sliding. From the bottom to the top, there are the following interlayers: 0.5–0.8 cm is a wedging out siliceous–carbonate lens-shaped interlayer that contains a 0.5 × 2 cm slide carbonate interlayer that is located at an angle of 20° to the horizon, as well as a 1 × 2–2.2 cm pocket-shaped cut that is filled mainly with carbonate material; 1–1.5 cm is a lens-shaped wedging out carbonate interlayer with a very uneven pocket-shaped lower boundary; 0.4–0.8 is a lens-shaped carbonate–siliceous interlayer with a variable thickness that contains a 0.1–0.2 × 3 cm

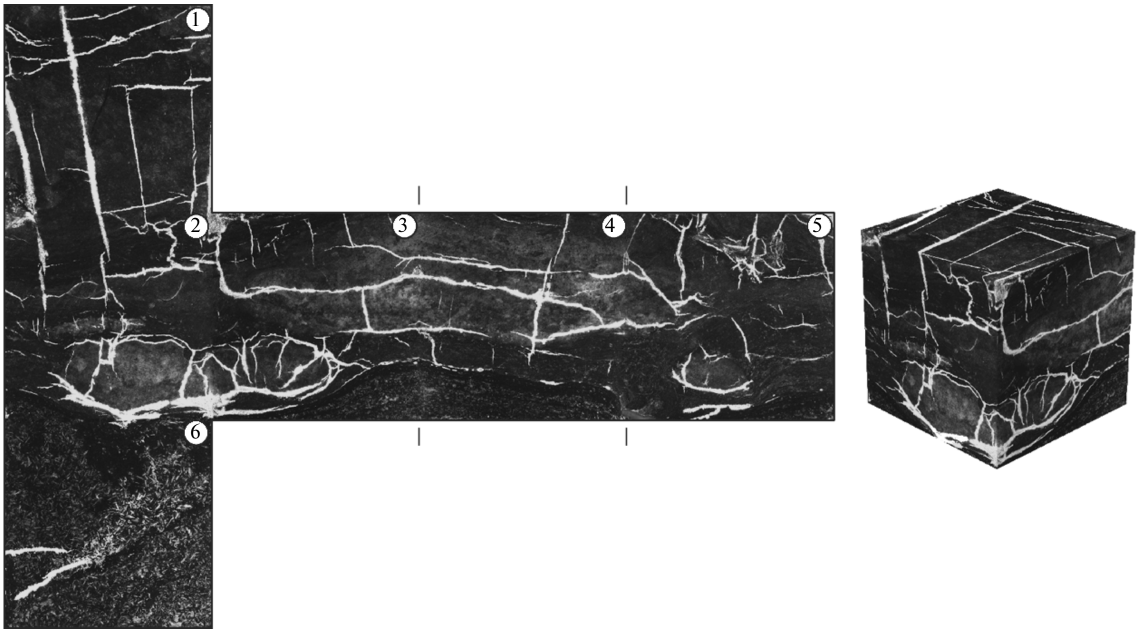

Fig. 7. System of differently oriented transverse fractures, Sample no. 4, depth is 1674.23 m. Capacity is 1.61%. Permeability along the directions (mD): I is 0.124; II is 3.200; III is 1.352. The surface density of the fractures over six sides of the cube (cm/cm^2): 1 is 1.32; 2 is 1.25; 3 is 1.43; 4 is 1.16; 5 is 1.28; 6 is 0.16 (the average is 1.11). Openness of the fractures (μm): 5 is the minimum; 200 is the maximum; 65 is the average.

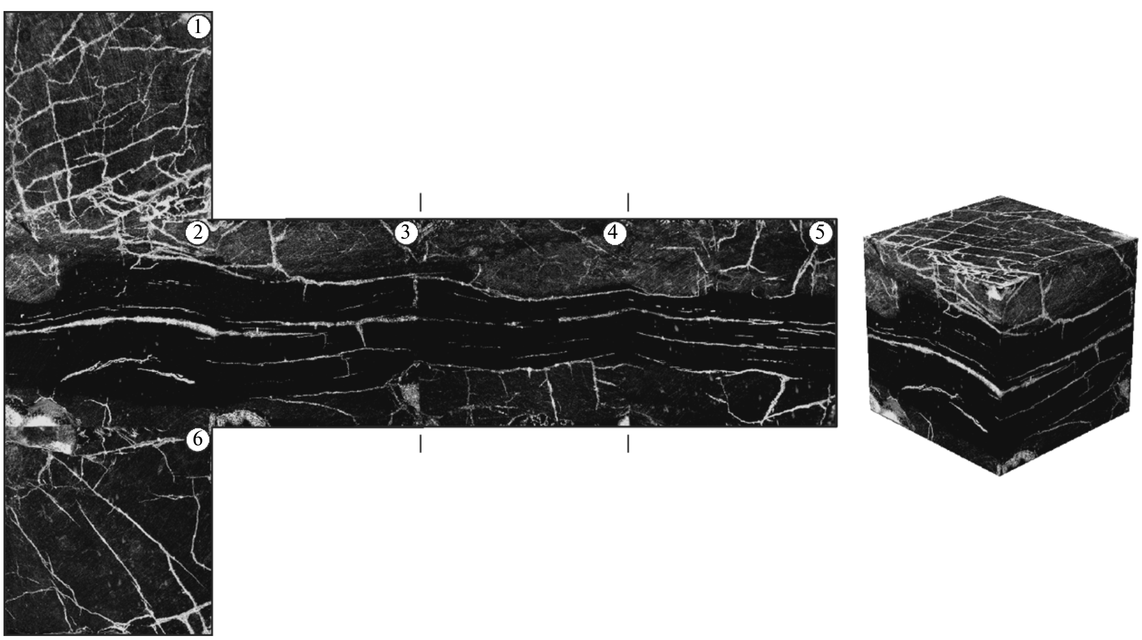

Fig. 8. Lens-shaped alternation of limestones and siliceous–carbonate rocks with different systems of fractures. Sample no. 5, depth is 1673.4 m, capacity is 1.93%. Permeability along the directions (mD): I is 0.028; II is 3.526; III is 11.642. The surface density of the fractures over six sides of the cube (cm/cm^2): 1 is 2.21; 2 is 1.19; 3 is 1.44; 4 is 1.45; 5 is 1.68; 6 is 1.56 (the average is 1.59). Openness of the fractures (μm): 5 is the minimum; 180 is the maximum; 100 is the average.

uneven wedging out lens in the lower segment; 0.9–2 cm is a lens-shaped carbonate interlayer that is pyrytized nonuniformly and that has an uneven lower boundary.

A system of horizontal transverse fractures with an openness of 7–95 μm that provide a lateral permeability of up to 11 mD was found in the limestone interlayer. The siliceous–carbonate interlayer exhibits a system of vertical fractures with a surface density of up to 2.2 cm/cm^2. The vertical fractures feather the horizontal ones that are located at the rock boundary (Fig. 8). The rock is characterized by permeability anisotropy due to the absence of vertical fractures in the limestone; however the vertical fractures participate in the reservoir properties (RPs) as they feather the horizontal fractures. The effective capacity is 1.93%.

CONCLUSIONS

1. The high-carbon kerogenic–carbonate–siliceous stratum that is characterized by the development of systems of fractures with different-orientation is of outstanding interest. Their surface density reaches 2.2 cm/cm^2 at average values of 1–1.5 cm/cm^2. The stratum permeability is relatively high; it can be 11 mD or greater at the capacity of 1.5–2% or more.

2. The kerogenic–carbonate deposits contain interlayers of compact carbonates and are characterized by the development of a horizontal system of fractures with rare thin vertical feathering small fractures. The surface density of the fractures varies from 0.8 to 1 cm/cm^2. The permeability does not usually exceed 1 mD; the capacity is 0.5%.

3. The classification of the identified fracturing with respect to lithotypes and accurate reference to geophysical well logging, as well as testing of the established intervals, will make it possible to develop a procedure for determining the intervals that can deliver hydrocarbons.

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