SHORT COMMUNICATION

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Study of the lithological characteristics of Domanic deposits of the Pervomayskoe field

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Abstract. The paper presents the results of studying rocks of the domanic horizon of the Pervomayskoe oil field represented by core material of the well 467D. In tectonic terms, this well, like the entire Pervomayskoe field, is confined to the axial part of the Kama-Kinel deflection system on the territory of the North-Tatar arch. Administratively, the Pervomayskoe deposit is located on the territories of the Elabuga, Mendeleevsky and Tukaevsky districts of the Republic of Tatarstan. To study the core material presented, different studies were conducted, including a macroscopic description of the core; comparison of the studied rocks with well logging data; optical microscopic analysis; X-ray analysis; determination of reservoir properties of rocks; study of organic matter by the Rock-Eval pyrolysis method.

Based on the analysis, it was found that the domanic horizon is composed of rocks containing carbonate and siliceous minerals to varying degrees, occasionally including minor mixtures of other minerals. The section of rocks is characterized by a sharp change in the lithological composition with a thickness of interlayers of several centimeters. According to Rock-Eval data, carbonate-siliceous interlayers have a high content of organic matter. Organic matter in Domanic deposits is characterized as immature and is found in rocks in the form of kerogen.

Keywords: hydrocarbons, Domanic deposits, domanicites, shale, shale oil, core, Pervomayskoe field; Republic of Tatarstan

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The potential of unconventional sources of oil and gas is currently one of the most pressing issues of the modern gas and oil industry. Nowadays, the main interests of exploration and production are hydrocarbon deposits confined to highly porous reservoirs of predominantly intergranular porosity. However, the reserves of "conventional" hydrocarbons are unfortunately gradually being depleted. This is why further prospects for the development of the oil and gas industry are increasingly associated with the prospection and exploration of objects associated with reservoirs with complex lithologic and petrophysical characteristics, also called "unconventional" reservoirs.

One of the best-known unconventional sources of hydrocarbons is shale oil and gas, produced mainly in the United States of America. It is considered that according to lithological and geochemical characteristics as well as reservoir potential, shale strata developed in the United States are analogous to the Bazhenov deposits of the West Siberian Plate and their analogues in other regions. For the territory of the Volga-Ural oil and gas region, domanic deposits offer the best perspectives for the production of "unconventional" hydrocarbons.

According to current research, the domanic deposits, or domanicits, are rocks of the domanic horizon of the Upper Frasnian Upper Devonian substage. Their distinctive feature is a high content of organic matter: from 5 to 20%. The overlying sediments from the Mendymsky to the Trans-Volga horizons of the Upper Devonian are called domanicoids (Korolyuk et al., 1984). They contain a lesser amount of organic matter: from 0.5 to 5%. Domanikits and domanicoids differ slightly in their lithologic composition: domanicoids are generally low-permeability, massive, layered carbonate rocks whereas Domanikits are massive, sometimes shaly, layered carbonate-siliceous and siliceous-carbonate rocks with very low permeability. Because of the type of organic matter, its maturity and thermodynamic conditions, domanic deposits in the territory of the oil and gas regions in Tatarstan are considered promising for oil generation.

According to the latest estimates, the resources of "unconventional" oil in the domanic sediments of Tatarstan range from 4.5 billion tons (Dyni J.R., 2005) to 14.6 billion tons (according to the data of the Academy

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of Sciences of the Republic of Tatarstan). They are currently being developed as a pilot by Tatneft PJSC. Oil production is also carried out in the Republic of Tatarstan from deposits of domanic sediments discovered many years ago during exploration campaigns for oil. The development of these deposits is carried out by methods used for conventional reservoirs, since these deposits are associated with linear zones of increased fracturing of rocks confined to regional faults (Khisamov et al., 2010). In other words, the type of porosity in the domanic rocks, to which these deposits are confined, is fractured, with a significant relationship between porosity and permeability, which is typical of «conventional» reservoirs. However, in most cases, fracturing of the domanic deposits in Tatarstan is rare, therefore they are usually referred to as "unconventional" reservoirs and require their own set of development methods. According to the world experience in developing such deposits, this set of methods used most often includes drilling horizontal wells and conducting multi-stage hydraulic fracturing to increase the permeability of rocks.

Having this information in mind, the domanic deposits of Tatarstan are undoubtedly a current topic for research. The object of the study was the core material from well 467D of the Pervomayskoe field, which is located on the territory of the Republic of Tatarstan and tectonically located in the axial zone of the Kama-Kinel deflection system on the territory of the North-Tatar arch. This territory is characterized by an average thickness of mendym-domanikovy deposits from 60 to 80 meters (Fig. 1).

The set of studies carried out included: macroscopic core description, comparison of the core with well logging data, optical microscopic analysis, X-ray analysis, determination of reservoir properties, rock pyrolysis using the Rock-Eval method.

The aim of the work conducted was to prepare a preliminary assessment of the domanic deposits of the Pervomayskoe field as an "unconventional" reservoir with a possibility of containing hydrocarbons.

The core material from well 467D was selected at depths of 1662.2-1684.4 m. This interval represents the rocks of the lower part of the domanic horizon, which lies in this well at depths of 1644.5-1682.4 m (Fig. 2) and the top of the Sargayevsky horizon, present at depths of 1682.4-1691.4 m. The choice of the interval for sampling was justified with a more intense saturation of the organic content of the core samples from this part of the section. According to well logging data, this part of the domanic horizon is characterized by increased radioactivity, which is associated with a high content of organic matter, adsorption of uranium salts, as well as lower resistance values, which indicates the absence of oil in these rocks.

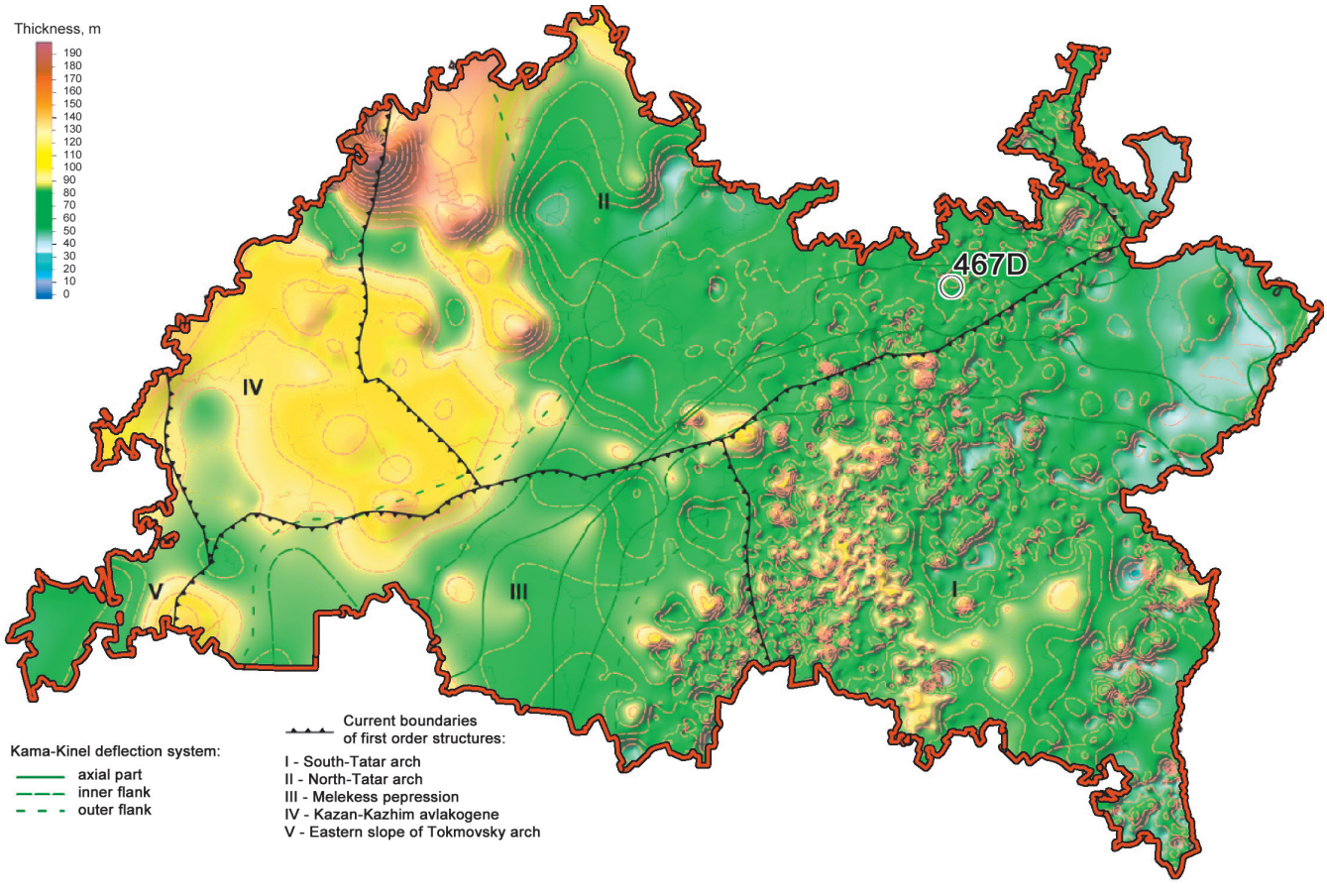

Fig. 1. Map of Mendym-domanic deposits of the Upper Devonian according to deep drilling data on the territory of the Republic of Tatarstan

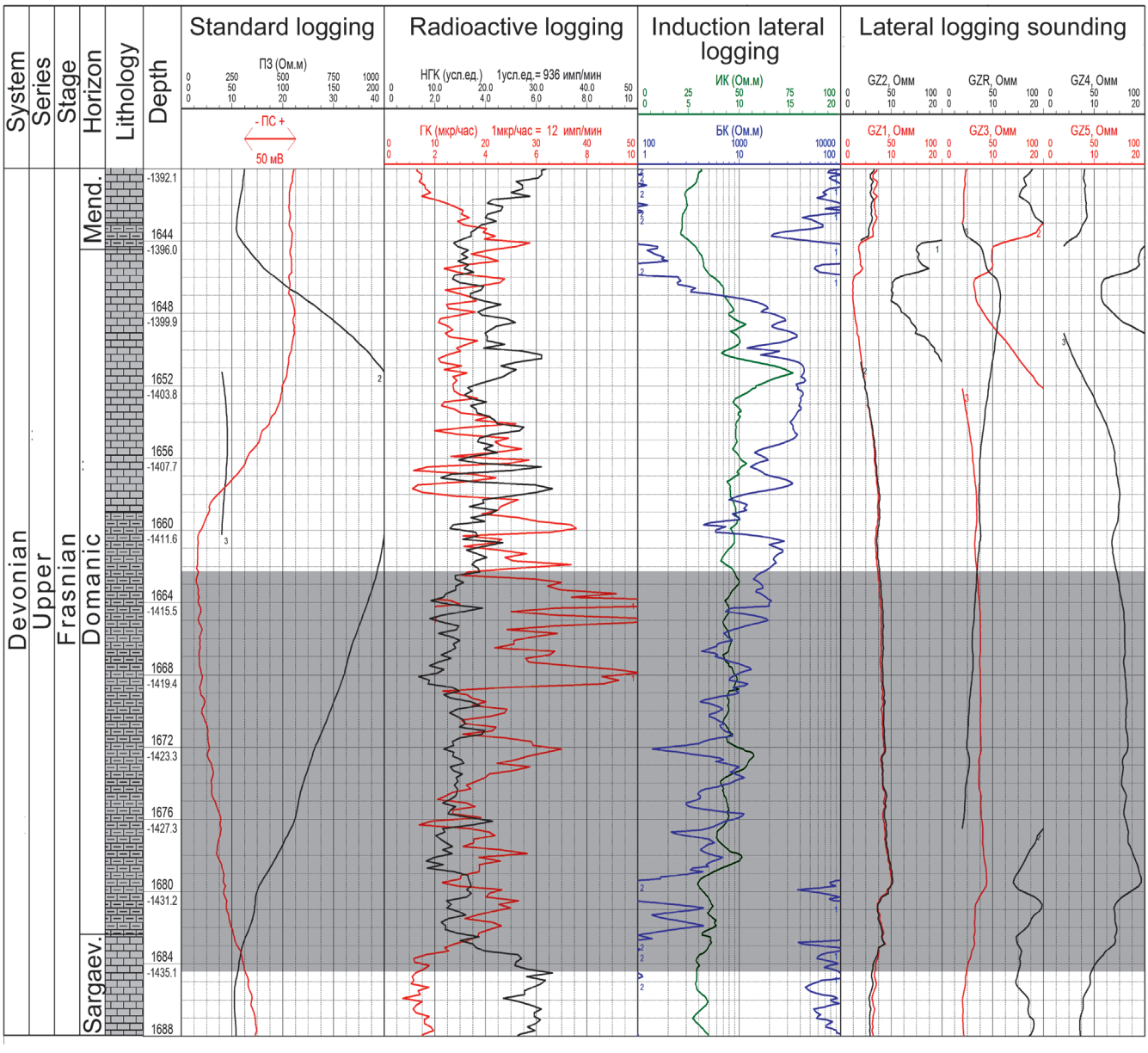

Fig. 2. Well logging data in the interval of occurrence of the domanic horizon in the 467D well (The selection of core material for the study is shown in color)

Based on the macroscopic description of the core of the domanic horizon, the rocks are predominantly carbonate-siliceous and siliceous-carbonate, sometimes carbonate, with a cryptocrystalline structure, laminated, shaly and sometimes with a massive texture, intensely saturated with organic matter. Carbonates are chemogenic and organogenic. In the samples, horizontal and wavy layering are found, as well as rewashing and redeposition of sediments. Horizontal stratification is characteristic of carbonate-siliceous rocks (Fig. 3a), non-horizontal, and wavy - of siliceous-carbonate rocks (Fig. 3b).

Optical microscopic and X-ray analyses made it possible to clarify the mineralogical composition of the domanic rocks: silica, calcite, rarely dolomite, clay minerals are rarely found and are in minor proportions.

The study of petrographic thin sections in transmitted light was carried out using a Polam L-211M microscope with a USB2.0 YW500 digital camera.

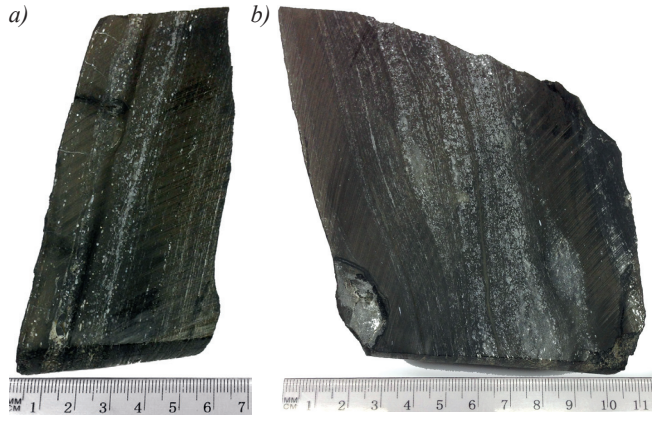

Fig. 3. Stratification of rocks: a) horizontal layering of carbonate-siliceous rock; well 467D, Pervomayskoe field, sample no.20, depth – 1679.4 m; b) wavy layering of siliceous-carbonate rock; well 467D, Pervomayskoe field, sample no.11, depth – 1672.5 m

Studying thin sections, it was discovered that the texture of the rocks is predominantly thin and medium-layered, sometimes shaly, massive, patchy, breccia-like. The interlacing of fine-grained limestone with a carbonate-siliceous rock is quite common. The thickness of the interlayers varies from tenths to several millimetres. Remains of radiolarians and phytoplankton were found.

X-ray analysis was performed on a D2 Phaser diffractometer (Bruker, Germany) for measuring powder preparations in Brega-Brentano geometry (3-40°) using monochromatic CuK α-radiation, in scan mode with a step of 0.02° with a speed of 1°/min. The voltage of the X-ray tube was 30 kV, and the current strength was 30 mA. Diffraction patterns were identified by comparing with reference diffractograms from the international PDF-2 ICDD database. On each diffractogram, the diffraction reflections of the minerals present in the sample are shown in a determined colour in a bar-graph.

Confronting macroscopic, optical microscopic and X-ray data, the following lithogenetic types of rocks can be distinguished: organogenic-detrital limestone, granular limestone, siliceous-carbonate and carbonate-siliceous rocks, silicites. These rocks are interbedded, the thickness of the interlayers ranges from several to tens of centimetres.

Some interlayers consist of almost completely siliceous rocks with an insignificant content of calcite and microcline (Fig. 4). In these rocks, there is a higher

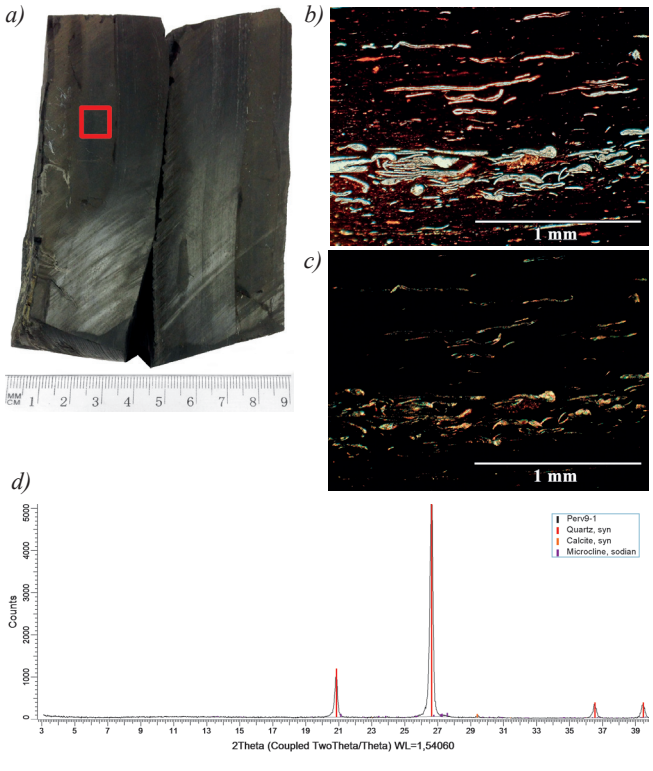

Fig. 4. The carbonate-siliceous rock sample studied: a) photograph of the sample; well 467D, Pervomayskoe field, sample no.9, depth – 1670.4 m; b) photograph of a thin section in parallel nicols; c) a photo of a thin section in crossed nicols; d) diffractogram

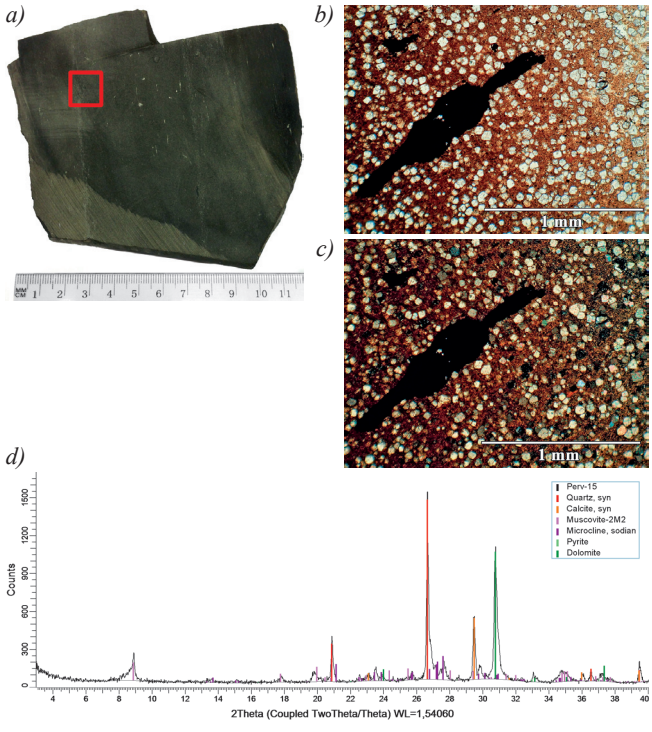

Fig. 5. The carbonate-siliceous rock sample studied: a) photograph of the sample; well 467D, Pervomayskoe field, sample no.15, depth – 1675.5 m; b) photograph of a thin section in parallel nicols; c) a photo of a thin section in crossed nicols; d) diffractogram

content of organic matter (kerogen). In thin section remains of ostracod and tentaculite are observed, which are mainly deposited in thin interlayers parallel to the stratification of the rock.

In other layers, a decrease in the silica content and an increase in the carbonate minerals content (calcite, dolomite) is observed (Fig. 5). These rocks contain a higher percentage of impurities of other minerals (pyrite, microcline, muscovite, etc.) and a significantly smaller amount of organic residues and, consequently, a smaller amount of organic matter.

There are interlayers in which silica is found in much smaller quantities than carbonates (calcite) (Fig. 6). Calcite in these rocks is predominantly organogenic. A large amount of organic residues occurring parallel to the layering is observed. The content of organic matter (kerogen) in these interlayers is rather high.

Carbonate interlayers were also present with a complete absence or very low content of silica (Fig. 7). A large amount of organic residues is observed even if organic matter in carbonates is practically absent, or is present in small amounts in layers with a mixture of silica.

All the distinguished lithogenetic types of rocks are deposited by interbedding, and no regularities were observed in the sequence of their intercalation. A characteristic feature of this section is a sharp change in the lithological composition and content of organic matter (Fig. 8), while the thickness of the layers is

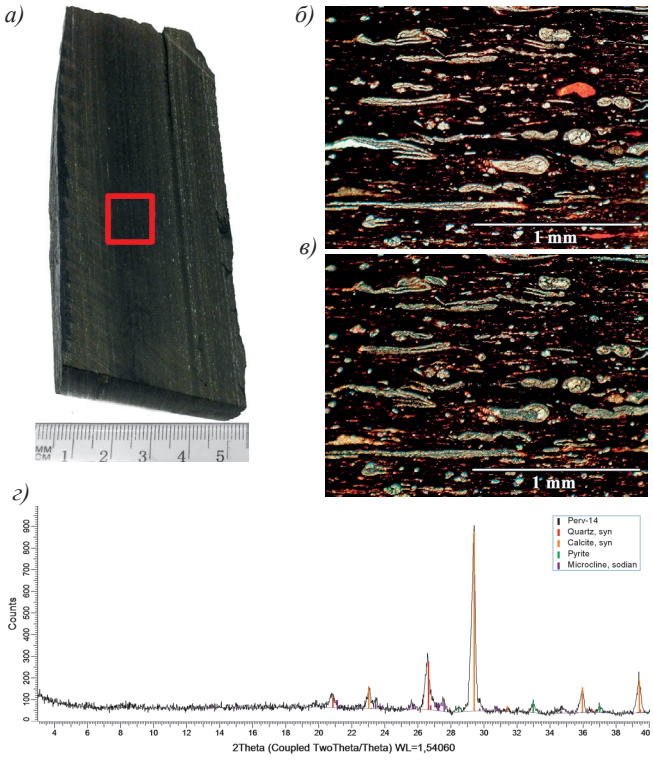

Fig. 6. The carbonate-siliceous rock sample studied: a) photograph of the sample; well 467D, Pervomayskoe field, sample no.14, depth – 1674.4 m; b) photograph of a thin section in parallel nicols; c) a photo of a thin section in crossed nicols; d) diffractogram

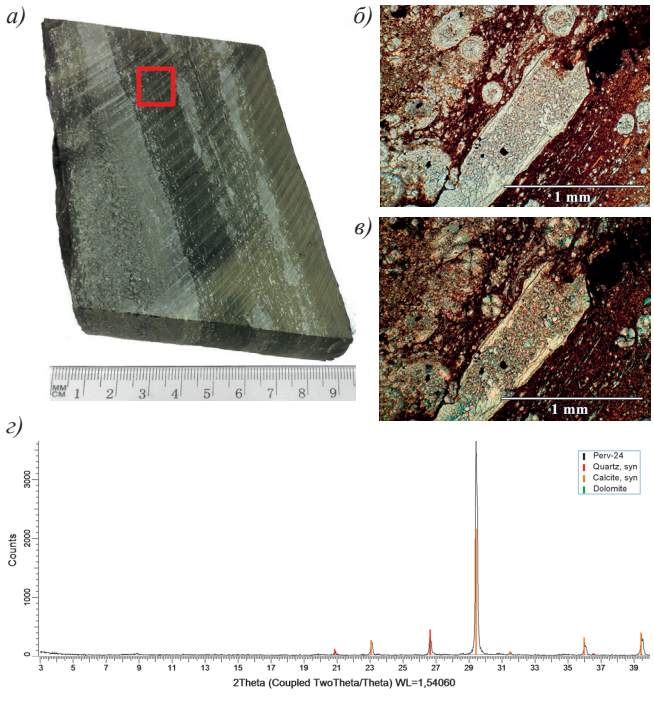

Fig. 7. The carbonate-siliceous rock sample studied: a) photograph of the sample; well 467D, Pervomayskoe field, sample no.24, depth – 1683.9 m; b) photograph of a thin section in parallel nicols; c) a photo of a thin section in crossed nicols; d) diffractogram

only a few centimetres. The content of organic matter is directly related to the presence of silica in the rock. The exceptions are the interlayers with a low content

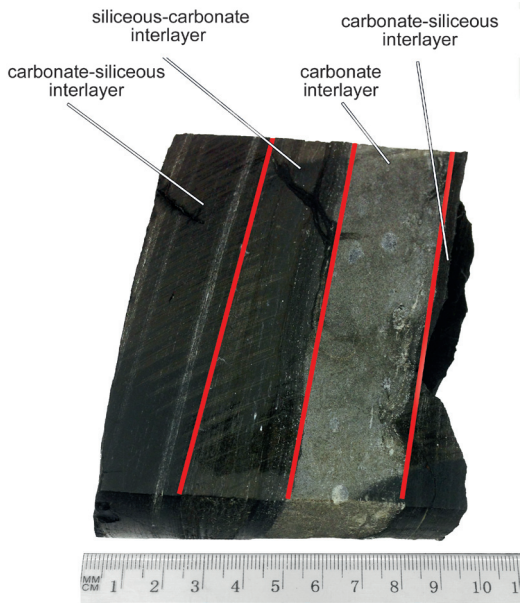

Fig. 8. Interbedding of different lithological types of rocks; well 467D, Pervomayskoe field, sample no.5, depth – 1666.5 m

of organic residues and a high content of impurities of other minerals, such as dolomite, pyrite, muscovite, microcline. In these interlayers, the organic content is characterized by lower values.

Subsequently, the reservoir properties of rocks were investigated. The open porosity was determined by saturating the samples under vacuum with a model of produced water (NaCl solution with a density of 1.16 g/cm^3) and their weighing before and after saturation (Preobrazhensky Method).

The permeability of rocks was determined by testing samples of cylindrical shape for gas permeability to nitrogen on the GK-5 device.

As a result of measurements, it was determined that the rocks of the domanic horizon have very low porosity and permeability (Table 1). The permeability value was only obtained for sample no.1, granular limestone.

No. of sample	Depth, m	Open porosity, %	Permeability to gas, 10^{-3} μm^2
1	1662,20	0,68	0,46
2	1663,40	0,38	0
3	1664,70	0,40	0
7	1668,30	0,10	0
9	1670,40	0,88	-
14	1674,40	0,34	0
15	1675,50	0,26	0
16	1676,60	0,55	-
17	1677,20	0,59	-
18	1677,80	0,65	-
19	1678,70	1,20	-
20	1679,40	0,73	-

Table 1. Reservoir properties of rocks

In other samples, the permeability value was so small that it could not be measured and assumed to be zero. The presence of increased permeability in limestones relative to other rocks indicates a better communication between the pores, which is characteristic of traditional reservoirs, but most of the section studied is practically impermeable. Low values of open porosity also allow us to consider the studied rocks as "unconventional" reservoirs, which are characterized by closed porosity.

To determine the type as well as the amount of organic matter in the rocks, the Rock-Eval pyrolysis method was used. For the analysis, a HAWK Resource Workstation pyrolyzer manufactured by WildCat Technologies was used.

The results of Rock-Eval confirmed the dependence of the content of organic matter on the silica content (Table 2): in high-silica rocks (samples 3, 4, 8, 9, 14) the organic content is from 16.43 to 26.22%; in limestone (samples 1, 18, 24) – from 1.15 to 2.58%; in siliceous-carbonate dolomitic rocks with a low content of organic residues (samples 15, 16, 21, 22) the content of dispersed organic matter varies from 1.40 to 4.89; in the remaining interlayers, predominantly represented by carbonate-siliceous rocks, the organic content varies from 4.09 to 10.70%. Organic matter in the studied rocks is in the form of kerogen (parameter S2>S1) and is immature (Tmax <435 ° C). Kerogen is considered to be type II (HI value varies from 300 to 600), which is characterized by predominant generation of oil.

Conclusion and Discussion

Based on the analysis of the lithological composition and organic matter of the domanic sediments of the 467D well of the Pervomayskoe field, the following conclusions can be noted:

1) The studied rocks are composed of carbonate and siliceous minerals with minor mixtures of pyrite and microcline.

Sample	Depth	S0	S1	S2	S3	TOC	Tmax	HI
	m		*«Free oil» mg HC/g of rock*	*Kerogen, mg HC/g of rock*	*mg CO_2/g of rock*	*Total Organic Carbon, wt %*	*Maturity °C*	*Index of hydrogen, mg HC/g TOC*
1	1662,2		0,06	1,47	0,17	1,15	432	127
2	1663,4		0,24	29,93	0,30	5,79	432	517
3	1664,7		0,73	115,83	0,56	20,49	433	565
4	1665,8		0,74	87,40	0,39	16,43	429	531
5	1666,6		0,47	56,83	0,33	10,70	432	531
6	1667,5		0,20	23,39	0,17	4,48	431	522
7	1668,3		0,31	39,93	0,23	7,81	431	511
8	1669,5		0,73	98,43	0,47	17,84	432	551
9	1670,4		0,85	101,10	0,53	18,46	432	547
10	1671,6		0,34	43,29	0,24	8,00	431	540
11	1672,5		0,30	30,27	0,36	5,80	431	522
12	1673,3	0,17	0,20	19,58	0,31	4,95	430	395
13	1673,4		0,29	32,36	0,25	6,09	431	531
14	1674,4		0,89	171,72	0,73	26,22	430	654
15	1675,5		0,14	4,52	0,45	1,40	437	322
16	1676,6		0,20	24,89	0,56	4,89	436	508
17	1677,2		0,37	43,33	0,33	7,63	433	567
18	1677,8		0,12	10,75	0,17	2,29	431	469
19	1678,7		0,19	21,39	0,20	4,09	431	523
20	1679,4		0,47	54,79	0,35	9,62	430	569
21	1680,5		0,13	12,50	0,09	2,58	431	484
22	1681,6	0,11	0,12	7,07	0,25	1,87	431	377
23	1682,4		0,19	24,23	0,26	4,39	430	552
24	1683,9		0,12	10,86	0,37	2,43	436	445
25	1684,4		0,16	20,56	0,32	3,51	429	585

- high-silica rocks, silicite
- siliceous-carbonate dolomite rocks
- limestone
- carbonate-siliceous rocks

Table 2. The results of pyrolysis using the Rock-Eval method for the core of well 467D

2) Lithogenetic types of rocks were identified: limestones, organogenic-detrital, granular limestones, siliceous-carbonate and carbonate-siliceous rocks, silicites.

3) In the section is observed an interbedding of rocks without a definite dependence with interbedding thickness of several centimetres, which indicates sharp changes in the conditions of sedimentation.

4) It was established that the content of organic matter is higher in carbonate-siliceous rocks, smaller in siliceous-carbonate rocks, and practically absent in carbonate rocks. Thus, there is a direct dependence of the organic content on the silica content in the rock.

5) Organic matter in the Domanic sediments is characterized as immature and is found in the rocks in the form of kerogen. Kerogen is of type II.

According to preliminary estimates, based on studies of the 467D well, it can be said that the deposits of the domanic horizon of the Pervomayskoe field are extremely heterogeneous in terms of lithological composition and organic matter content. Domanicites are dense, mostly silicified rocks, with no fractures and porosity visible under the microscope. The porosity values do not exceed 1.2%, the permeability values in the majority of the section are close to zero. The average content of organic matter in the section of rocks is rather high and amounts to 7.96%, which is typical of the domanicites of the Volga-Ural oil and gas region. The data obtained indicate that the Pervomayskoe domanic deposits are reservoirs of «unconventional» type. In case of their development, it is necessary to use the methods used to develop shale deposits ("shale oil") and deposits in low-permeability reservoirs ("tight oil") – drilling horizontal wells and carrying out multi-stage hydraulic fracturing. It is also necessary to use a technology that allows the development of immature organic matter ("oil shale"). Such technologies exist nowadays, but are at the stage of experimental research (ICP Shell, Chevron CRUSH, ExxonMobil ElectroFrac).

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