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Potential of High-Carbon Domanik (Upper Devonian) Shale Deposits: Timan-Pechora Oil and Gas Province Assessment

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ABSTRACT

The development of oil and gas production technologies has made it possible to take a new look at the prospects of increasing the raw material base of oil in areas with developed production infrastructure. The projects of exploration and preparation for development of high-carbon low-permeability strata, primarily shale formations, occupy a special position today, as the world experience has shown their potential for oil and gas production. High-carbon shale formations are widely spread in Russia. The most significant of them include the Bazhenov Formation of Western Siberia and the Domanik sediments of the Eastern European Platform, the hydrocarbon potential of which is estimated ambiguously. The ambiguity of hydrocarbon potential estimation is related to the uneven distribution of organic matter determined by the variability of sedimentation conditions. The paper presents the results of the study of Upper Devonian sediments, based on analytical geochemical data of well cores and extracts of bitumoids from them. The analysis of the confinement of zones of increased concentration of organic matter to certain sedimentary conditions and facies zones made it possible to estimate the volume of mobile hydrocarbons in the amount of 5.3 billion tonnes preserved in the high carbonaceous strata. The obtained data on HC volumes were compared with the reservoir properties, studied using X-ray tomography, of low-permeability hydrocarbon-bearing clay-siliceous strata, which allowed us to consider the Upper Devonian carbonaceous strata as an important reserve for maintaining oil production in the future in one of the developed oil-producing regions of the European part of Russia.

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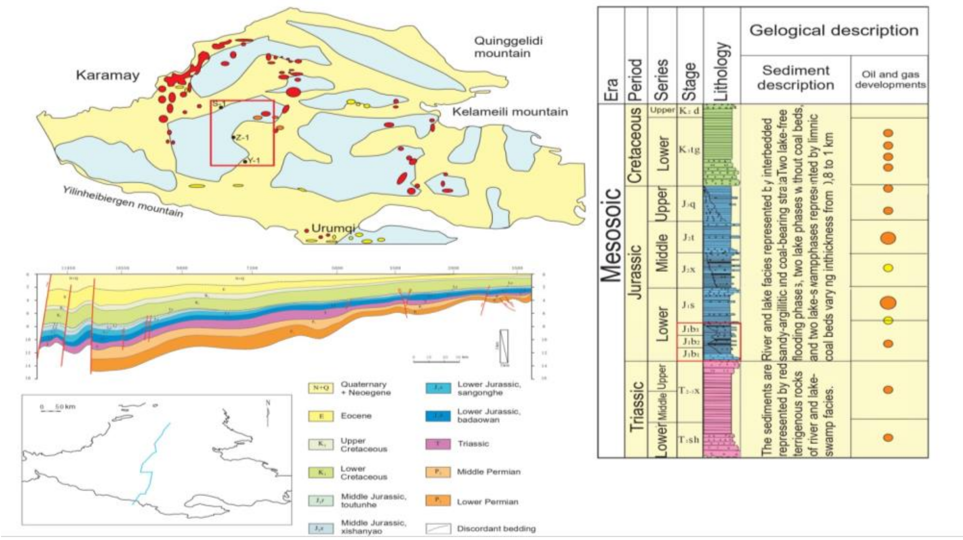
Graphical Abstract



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NOMENCLATURE

OM	Organic matter, %	OGB	Oil and gas bearing basin
TOC	Total organic carbon, %	SB	Sedimentary basin
PC	Protocatagenesis	S1	The content of free hydrocarbons, mgHC/g
MC	Mesocatagenesis	S2	Residual generative potential, mgHC/g
AC	Apocatagenesis	HI	Hydrogen index, mgHC/g

1. INTRODUCTION

Due to advances in technologies for developing unconventional reservoirs (characterized by low porosity and low permeability) in Russia, research interest has increased in the study of hydrocarbon accumulations in high-carbon shale formations, which are widely distributed and known as the most significant oil and gas source in Western Siberia (bazhenov and abalak formations), Timan-Pechora and Volga-Ural basins (domanik formation), in the North Caucasus (khadum formation) and on the Siberian platform (kuonam formation) (see Figure 1).

The primary object of scientific and industrial interest in accumulations of hydrocarbons in reservoirs characterized by low porosity (shale strata) on the territory of Russia is the Bazhenov formation of Western Siberia, whose huge hydrocarbon potential (estimated from 10 to 75 billion tons of recoverable oil reserves) is not in question today, and the main research areas are related to the development of technologies for localizing areas of the high concentration of hydrocarbons and creating acceptable technologies for their development (1). Searching and exploring new ways to increase the raw material base will also help diversify the state's oil sector to build a sustainable resource base (2).

The second most important high-carbon formation in Russia is domanik deposits and their formational analogs, which are widely distributed within the Eastern European platform (the territory of the Volga-Ural (3) and Timan-Pechora sedimentary basins) (see Figure 2) (4-7).

This formation is characterized by a high content of organic matter (OM) of marine genesis (TOC reaches 25%), the catagenetic maturity of which varies from proto (PC) - to apocatagenesis (AC) (7-11) depending on the paleogeological conditions.

Figure 1. Distribution map of the main high-carbon shale formations in Russia

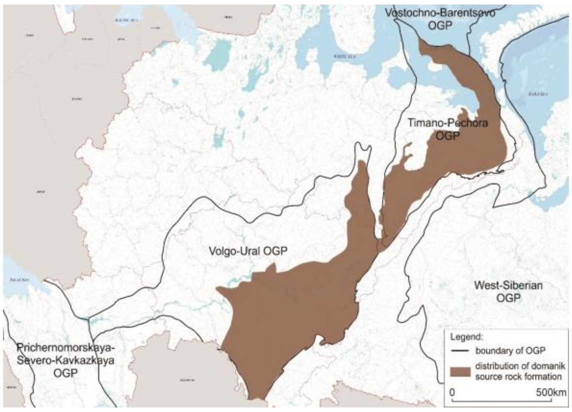

Figure 2. Distribution map of domanik source rock formation within the Timan-Pechora and Volga-Ural oil and gas province (OGP).

One of the important points that require clarification when discussing the issues raised in the article is the terminology used in parts of the stages of transformation of sediments enriched with dispersed organic matter and identified as oil and gas producing and oil and gas containing.

Active processes of transformation of organic matter under the influence of temperature and pressure are limited to the final stage of diagenesis. Such stage (an intensive transformation of organic matter) in some classifications (widely used, for example, in Russia) is allocated to a separate stage, which is called catagenesis.

Despite its wide distribution, commercial extraction of hydrocarbons from unconventional domanik collectors in Russia has not been conducted and is not being conducted. All the most frequently discussed examples and achievements in domanik development most often do not relate directly to shale (clay reservoirs), but are examples of the development of stratigraphic facies of the same age as domanik shale (deep-water) deposits of carbonate or siliceous-carbonate mainly of organogenic and shelf origin.

The experience of "shale" projects in the United States related to the industrial experience shows two possible and used in practice approaches to assessing the potential and identifying the so-called "tidbits" (9, 12-14).

The first is based on the search for the most significant areas identified by the results of seismic surveys using characteristics that determine the oil and gas potential obtained in wells during their testing. The second is based on the interpolation of properties and parameters obtained in real wells between them. In Russian conditions, such technologies may be in demand when evaluating license areas of square or rectangular shape with wells drilled in the corners and tested with more or less uniform properties between them, as well as traceable properties of the section based on seismic data.

Research of approaches to estimation of hydrocarbon resources and reserves in high-carbonaceous domanic strata and determination of the volume of "residual" mobile bitumoids by volumetric and volumetric-genetic methods on the basis of determination of pyrolytic parameters, kinetic activation spectra and X-ray tomographic researches of non-destructed core samples before and after extraction of bitumoids from them is one of the most important directions allowing to rely on their further industrial development.

2. MATERIALS AND METHODS

This research is aimed at clarifying individual parameters and methods for assessing hydrocarbon resources preserved in primarily enriched strata with OM related to oil and gas source in Timan-Pechora sedimentary basins on complex laboratory studies of natural outcrops samples and core wells. Also, based on interpretation of data from geophysical studies of wells and the results of seismic surveys on a network of regional profiles, which made it possible to refine and supplement data on the distribution by area and section of high-carbon rocks, distribution by lithotypes, geochemical characteristics of OM and extracts, filtration and reservoir properties of the section of the domanik-type sediments.

The methodology of the work involved a number of sequential steps, including clarification of the geological structure of the intervals of the section of the high-carbon strata of the Upper Devonian (Middle Frasnian-Famennian) and Tournaisian stage of carbon related to the main oil and gas producing on the territory of Timan-Pechora provinces, including their geochemical and petrophysical features.

Such sequential steps included:

1. Identification of characteristic features of high-carbon deposits of the “domanik type”.
2. Determination of the stratigraphic interval of the distribution of deposits primarily enriched with OM, related to the “domanik type”.
3. Determination of the area of development of each of the selected stratigraphic units related to the Domanik-type deposits.
4. Determination of the lithological composition (microscopic and petrographic studies of the sections) and lithotyping of the domanik-type deposits.
5. Assessment of geochemical features (laboratory research of bituminous extracts and pyrolytic studies of core samples), distribution and degree of transformation of OM of high-carbon deposits of the “domanik type”, confined to different lithotypes and zones differing in facies conditions of formation.
6. Assessment of the petrophysical parameters of the isolated lithotypes in the of the domanik-type sediments.
7. Identification of typical geochemical sections for all facies zones and stratigraphic intervals of the development of the Domanik-type deposits.
8. Mapmaking of the current concentration of organic carbon and the catagenetic maturity of OM by bituminological and pyrolytic studies.
9. Recalculation of the organic carbon content in the Domanik-type rocks at the beginning of catagenesis using balance equations for three types of OM.
10. Determination of the mobile part of bituminous (separation into residual kerogen and parautochthonous bituminous) preserved in oil and gas source deposits of the Domanik type after migration of generated hydrocarbons.
11. Clarification of the methodological approach to the assessment of oil and gas resources of high-carbon deposits of the Domanik type.
12. Assessment of the resource potential of the Upper Devonian-Tournaisian deposits of the domanik type of the Timan-Pechora OGP.

A specific feature of high-bituminous strata enriched with organic carbon the ability to generate and preserve generated hydrocarbons within single strata or in poorly permeable boundary strata associated with it above and below the section (15-17). In general, it can be noted that the unconventional oil and gas system differs from the traditional one primarily in that the object of industrial evaluation is hydrocarbons that have not been displaced from OGSS, after their generating (preservation) due to low permeability that does not provide further migration routes to traps or dispersion (18).

Geochemical methods play one of the most significant roles in the overall complex of studies aimed at predicting the oil and gas potential of the domanik-type deposits. Their use in conjunction with other geological and geophysical methods significantly increases the information-richness of the assessment (14, 19-21).

Also considered methodological approaches to identifying effective oil-saturated thicknesses when combining field geophysical data and Rock-Eval data to identify promising objects in the depth section.

The residual hydrocarbon potential of the oil and gas source shale strata is determined by the conditions of sedimentation and burial of high-carbon deposits, the history of their immersion, migration (expulsion) opportunities, the scale and speed of hydrocarbon generation, their redistribution, and preservation opportunities.

There are many approaches to estimating the resources of hydrocarbon accumulations confined to low porosity and low permeability strata of oil and gas source formations.

The basis of the research is the refinement of maps of the lithological-facies zonation and thickness of the domanik-tournaisian complex, the distribution of concentrations of OM and the assessment geochemical and lithological heterogeneities of a section for the allocation of the main types of organic carbon distribution in representative sections.

Based on the example of the Timan-Pechora sedimentary basin, it was revealed that the high-carbon strata were formed on the part of the basin area only in the Middle Frasnian, on the other part – in the Middle-Late Frasnian-Early Famennian period, in the limited eastern part – in the Middle Frasnian-Early Tournaisian period.

The methodology for assessing the generation, migration, and preservation of hydrocarbons in the generation column is based on a detailed dissection of the domanik-type deposits and its formation analogues with the allocation of basic lithotypes, that each has its own geochemical characteristic of OM. The reference is also related to sedimentation conditions from shallow-sea shelf to relatively deep-water scenarios. According to the results, three strata were typed in the age range from the Middle Frasnian to the Late Famennian-Tournaisian periods of the Upper Devonian.

The resources are estimated by the volumetric geochemical (genetic) method based on the capabilities of the rock to generate hydrocarbons. The generation potential of the oil and gas primary shale strata and the degree of its realization are estimated using this method.

A quantitative model of the generation of oil and gas in the process of transformations (catagenesis) for basic types of OM rocks are well developed in Russia regarding high-bituminous sources that was reflected in the works of Neruchev et al. (17), Halimov and Melik-Pashaev (22) These studies, along with other theoretical developments (23) allowed a better understanding of the hydrocarbon potential of these strata, which, of course, can be used in the debate around current issues.

Thus, one of the most well-known approaches to the quantitative model of oil and gas generating (24-26) based on the possibility of using systematic data on the composition of OM and bituminous media at different stages of catagenesis. However, this requires a huge amount of detailed geochemical studies of OM, which can be conducted in the presence of a representative selected core. In this regard, a method of quantitative modelling of oil and gas generation for the main genetic types of OMs was developed, which can be used as a basis for assessing oil and gas formation in any oil and gas basin (23).

One of the important points that require clarification when discussing the issues raised in the article is the terminology used in parts of the stages of transformation of sediments enriched with dispersed organic matter (DOM) and identified as oil and gas producing and oil and gas containing.

3. FACTUAL BASIS OF RESEARCH

Laboratory studies included:

- geochemical (pyrolytic by Rock-Eval method) studies of 310 samples;
- macro- and microlithological research and description of samples (400 pieces);
- bituminological (chromatographic) studies of bitumoid extracts (70 extracts).
- microtomographic studies of cores (120 primary undisturbed samples, 70 secondary samples after extraction of undisturbed samples); Determination of reservoir properties was performed on SkyScan 1173 tomograph with spatial resolution of 17-20 microns/pixel, rotation step - 0.15°. Samples were imaged using a brass filter.

The basis of this research is the executed works, including laboratory research of domanik samples obtained from 6 natural outcrops of the Eastern Timan frame (300 samples selected systematically and sequentially from all the presented lithological differences with a distance between the samples of no more than 0.5 m) from 10 wells with a domanik depth of 2-3.5 km (20 core samples) and 2 wells with a domanik depth of 3.8-4.3 km (100 core samples) (Figure 3).

The research used the data set on the organic carbon content in the domanik-tournaisian part of the section,

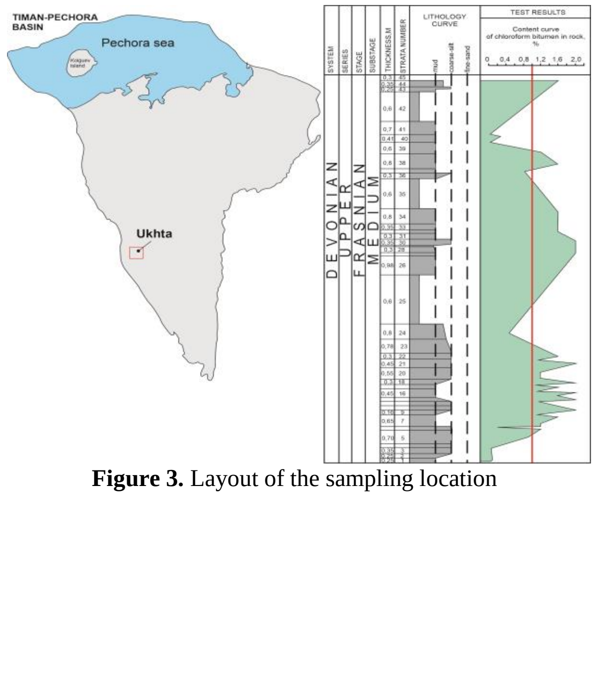

Figure 3. Layout of the sampling location

including more than 5000 determinations, compiled into the TPP database. The most significant contribution to the creation of the above database was obtained by summarizing the results of the studies carried out by the authors at the All-Russian Petroleum Research Geological Exploration Institute (VNIGRI) (Leningrad-St. Petersburg) on OM geochemistry, bituminology and lithology (11, 27).

In the present research, devoted to revealing the relationship between the conditions of sedimentation and the distribution of organic carbon over the area and section in the pre-domanik- (mid-Frasnian) lower tournaisian sediments of the TPP, we used previously constructed (27). and refined (as a result of reinterpretation of logs from 260 wells) lithological-facial schemes for 5 intervals of the domanik (Middle Terranean), Upper Terranean, Lower Terranean, Middle Upper Terranean, and Tournaisian sediments with a focus on establishing the areas and identifying the dependences of OM concentrations on the lithotypes of the section.

4. GEOLOGICAL POSITION OF THE REGION

The main tectonic event that determined the accumulation of the high-carbon formation was the intensive sinking (syneclise stage of development) that began in the late Devonian in the Timan-Pechora basin. The largest area of immersion in the late Devonian-early Carboniferous time existed on the site of the Ural paleobasin (Figures 4 and 5) (28).

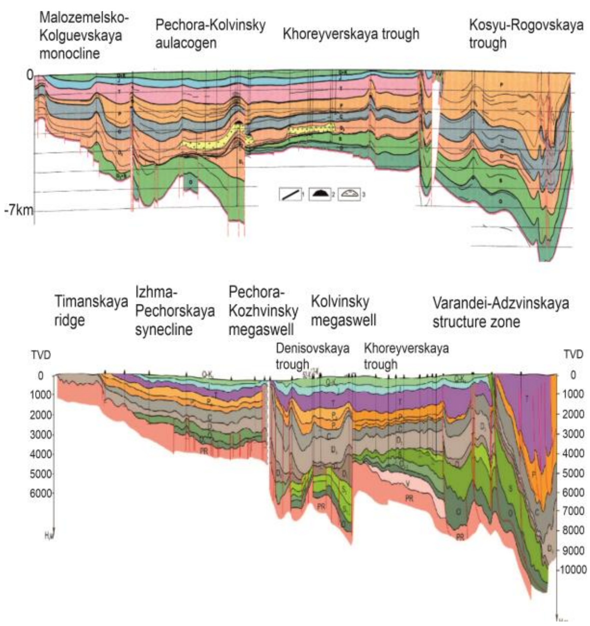

Figure 4. Geological sections through the Northern and Central part the Timan-Pechora region

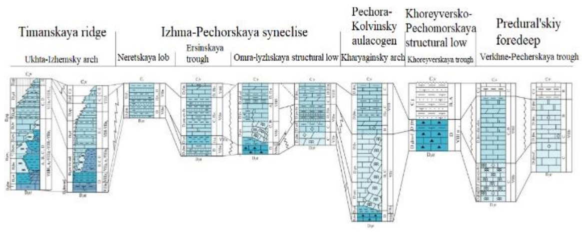

Figure 5. Typical sections of the middle frasnian - famennian-tournaisian deposits of the main tectonic zones of the Timan-Pechora province (28)

The Timan-Pechora basin developed from a maximum transgression in the domanik period - the beginning of the regression in the late Frasnian to a maximum regression by the end of the tournaisian age (29). The formation of domanik deposits is associated with active transgression of the sea basin from the Urals to the adjacent platform areas. In the middle of the Frasnian age delineated areas of relatively deep-water shelf, released at the southern part of the Pechora-Kolvinskoe aulacogen, Khoreiversky depression and Varandey-Adzvinskiy structural zone related to an outdoor sea basin located on the territory of the Ural-Pripaikhoisky paleobasin. This zone was characterized by a wide distribution of clay and especially carbonate silts formed in an open shelf sea basin with no detrital sediments in the early Frasnian period.

At first, the sea basin covered all the depressions inherited from the earlier aulacogenic stage of the region's development, and by the beginning of the middle Frasnian time of the late Devonian, a regime of uncompensated sedimentation was established in most of the Timan-Pechora basin. Thus, the formed clay and clay-siliceous domanik deposits are the same-age analogs of the reef shelf deposits of the carbonate platform. They are represented by thinly layered dark-colored siliceous shales, limestones and marls with calcareous, siliceous, phosphate and pyrite nodules. There are different points of view about the depth of domanik deposits at a depth of 100-200 m (rarely 400 m) under low sedimentation rates and high sea level conditions. The thickness of the actual domanik deposits varies between 30-60 m and rarely exceeds 100 m. At the same time, the thickness of the relatively rich OM of the middle-upper- Frasnian -lower-Famennian deposits has large thicknesses, is distributed above the domanik deposits in the section and reaches 500 m. Facies variability and thickness changes are noted, confirming the presence of irregularities in the basin bottom (grabens and protrusions) during deposition.

The monoclinic slope of the platform in the Eastern direction towards the Paleocene that existed on the site of the Urals led to the fact that the Western edge of the shelf moved eastward during sea regression and the area filled with shale strata decreased (30). Even within the same search area of the well, both a purely carbonate (riphogenic) type of section and clastic plumes, reef facies and fill strata are revealed.

This pattern is emphasized when tracing the age of reef formation at the edge of the shelf, which is consistently rejuvenated from West to East of the basin.

The Precambrian edge of the East European craton is considered as the Western limit of the domanik tournaisian carbonate platform formed on a shallow shelf (31, 32).

The upper Devonian deep-water shale, shale-siliceous, and shale-carbonate strata in the TP region are characterized by a significant content of organic carbon (on average more than 5 wt. %), which, based on the analysis of geological history, allowed to conclude that starting from the late Paleozoic-early Mesozoic time, domanik deposits provided the generation of hydrocarbons that migrated through the transit strata both laterally and vertically into reservoirs from the middle Devonian to lower Triassic, with the highest concentration directly in Devonian and Carboniferous-early Permian rocks-reservoirs. The oil and gas system formed by the domanik strata provided more than 70% of the oil reserves and resources and more than 50% of the gas reserves and resources of the sedimentary basin.

Both intensive deflection and inversion rearrangements, starting from the early Carboniferous time in the Pechora-Kolvenckiy aulacogen of the Riphean formation (Figure 2) continued in the Hercynian (Permian), early Cimmerian (late Triassic - early Jurassic) time during the orogenic uplift of the Urals, which resulted in tangential compression of all structures located along the paleouralian, as well as those associated with them.

5. DISTRIBUTION OF HIGH-CARBON DOMANIK DEPOSITS

The complex is characterized by facies variability caused by successive changes in depositional settings under uncompensated deflection. There is a sharp facies variability and thickness change, confirming the presence of basin floor irregularities (grabens and ledges) during deposition. This pattern is emphasized by tracing the age of reef formation at the shelf edge, which consistently rejuvenates from west to east of the basin. The Precambrian edge of the East European craton is considered as the western limit of the Domanik-Tournaisian age carbonate platform formed on the shallow shelf (14, 33).

The complex of rocks rich in OM (attributable to domanikoides) combines the deposits of Domanik, Vetlasyansky, Syrachoisky and Ukhta horizons of Frasnian layer, Zadonsky, Yeletsky, Ust-Pechora, Zelenetsky, and Numilgsky horizons of the Famennian of the upper Devonian layer, and terrigenous-carbonate deposits of the Tournaisian tier of the lower Carboniferous (Figure 6). Domanikoid deposits are the strata of cross layers of the section intervals and carbonate rock layers enriched with OM. High-carbon intervals of the section are distinguished up the section from the domanik in the overlying horizons, but they have a local distribution due to the facies conditions of the marginal part of the carbonate platform (Figure 4) (34).

The lithological composition of rocks of Domanik deposits is very diverse. These are limestones (pteropodic with abundant goniatites; polydetrite; fine-grained with radiolarians; siliceous), siliceous marls and siliceous mudstones, silicites (35). A feature of the lithological composition of Domanik deposits is a large amount of free silica, which is also characteristic of deposits in the marginal part of the Timan and the Urals. The excess of silica is probably associated with the introduction of material from the East Ural basin, which was an area of active volcanism during this period (36). The enrichment of the basin waters with silica contributed to the development of organisms with a flint skeleton, in particular, radiolarians.

The formation is divided into two parts: the lower Semiluksky (Domanik) horizon, a thin, but highly enriched and upper from upper- Frasnian, Famennian to

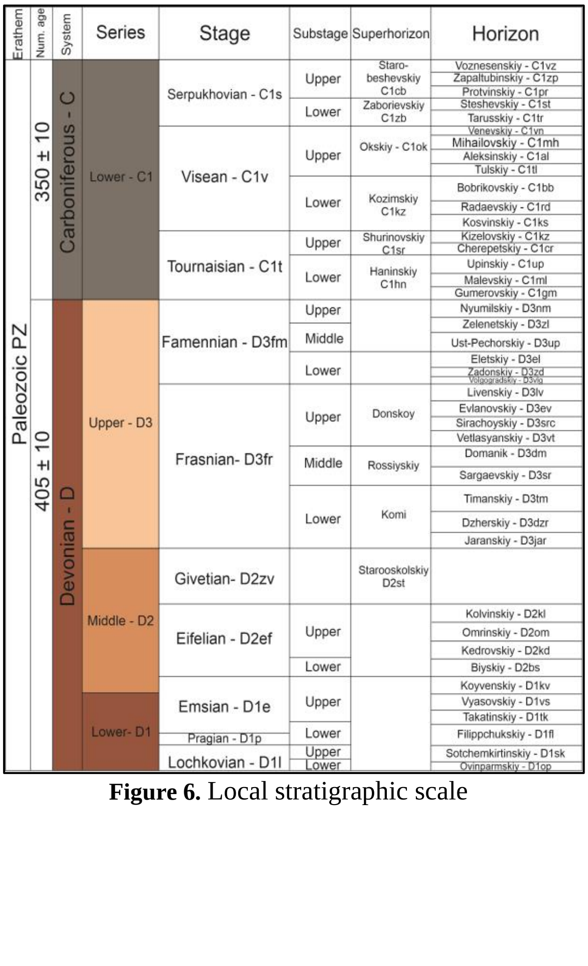

Figure 6. Local stratigraphic scale

Tournaisian tier, more thick but less common and less enriched in OM. A feature of the upper part of the Domanik formation of the Timan-Pechora OGP is a gradual stepwise increase in its stratigraphic range and, accordingly, its thickness from West to East in accordance with the shift towards the basin that limits its distribution by the reef barrier (37).

6. RESULTS

6. 1. Characteristics of Domanik Source Rock

There are a huge number of works devoted to the description of domanik deposits, their stratigraphy, lithology, paleogeography, and geochemistry. Currently, the expression “Domanik deposits” has lost its regional significance and has become a household name. Conventionally, all sedimentary rocks enriched with planktonogenic sapropelic OM were classified as Domanik deposits (6).

The content of organic carbon – TOC in domanik rocks, as a rule, varies from 1.4 to 13.5%. However, there are layers of typical oil shale with a sorghum content of up to 27 %. Domanik sediments of the Ukhta region contain more than 20% of TOC.

Domanik rocks contain sapropelic OM of type I and type II with the content of TOC (total organic carbon) in the range of 1-30 wt %. The average content per formation is about 5 wt.%. The hydrogen indices (HI) range from 500-700 mg/g, documenting the oil-prone nature of the OM. It is also characteristic that almost all areas where HC accumulations are detected contain domanik oil and gas source strata with a high level of its maturity.

6. 2. Geothermal Gradient and Thermal Maturity of the Oil and Gas Source Rock

The existing temperature gradients in the TP region are standard and moderate: from 19 to 35°C/km, but the heat flux was probably higher in the early and middle Mesozoic time, as evidenced by the presence of active Triassic volcanism. High temperature gradients characterize the region along the boundary parts of the Timan ridge and the rift zone of the ancient Pechora-Kolvinskoe aulacogen and areas of depressions of the pre-Ural and Prepaikhoi edge deflections - Kosyu-Rogovskaya and Korotaikhinskaya, as well as the Northern sea part of the Timan-Pechora province.

Organic matter of domanik deposits of the largest part of the Timan-Pechora basin is characterized by medium and high maturity. But there is considerable disagreement as to when exactly thermal maturity reached oil and gas formation conditions in various parts of the province. In areas with the greatest depth (history of sinking), for example, in the Western part of the Pechora-Kolvinsky aulakogen - Pechora-Kozhvinsky megabank, oil formation began a little earlier than in other areas (Figure 4).

According to Ulmishek (38) and Martirosyan et al. (39), the earliest time of the beginning of oil formation belongs to the late Frasnian time (Figure 6), considers it slightly earlier – early Carboniferous, and according to kinetic studies by Espitalie et al. (40) it is assumed that the earliest stage of oil generation can still be considered the middle-late Carboniferous time. New data provided in the research where the period of oil generation from the breeds of domanik defined as the beginning of the early Mesozoic, with a fairly active period, which lasted until the Jurassic time, it is difficult to accept based on perceptions about the absence of any tectonic or sedimentary activity at this time, when the region was characterized by the absence of active tectonic processes, and especially bending.

Gas generation began according to research from the late Permian period and continued until the early Triassic in areas of intense deflection. In more stable tectonic regions, it may have started from the late Triassic to the early Jurassic, when the gas formation process temporarily stopped during the general uplift of the territory. Most authors believe that the formation of hydrocarbons from domanik strata occurs later or simultaneously with the formation of traps as a result of Carboniferous and Triassic structural inversions and orogenic uplift of the Urals. At the same time, suggests a much earlier formation of HC from domanik - at least partially preceding the formation of large traps. The main stage of the formation of oil accumulations in the accumulation zones probably reached its peak by the middle of the Jurassic period. According to Prischepa et al. (41) the formation of high-amplitude inversion shafts (Kolvinsky, Pechora-Kozhvinsky) was preceded by the beginning of oil formation from rocks of the middle Devonian and domanik, which led to widespread oil saturation of almost all natural reservoirs located on large high-amplitude shafts starting from the middle Devonian part of the section.

6. 3. Approaches and Estimates of the Potential of High-carbon Domanik Shale Strata

Estimates of the volume of generation and emigration from the organic matter of the domanik oil and gas source strata of the Timan-Pechora and Volga-Ural provinces vary very widely from 10-12 billion tons to more than 1 trillion tons (6).

The scale of HC emigration from the domanik formation was first estimated in the 80-ies of the 20-th century in the works of Neruchev, Kontorovich, Bazhenova and amounted to more than 410 billion tons of liquid and 114.8 trillion m^3 of gases; 2/3 of which fall on the upper, nadsemilukskaya part of the formation due to its greater thickness (42).

According to literature, the non-emigrated part of the generated hydrocarbons is estimated at 176.5 billion tons (58.6 billion tons). t - D3sm; 117.9 billion tons for the D3f3-C1t subformation).

According to the research (MSU, completed in 2015, 277 samples of domanik rocks from 9 wells and 4 outcrops in the Timan-Pechora basin were studied and the residual generation potential of the domanik formation of the Timan-Pechora Province (TPP) was determined, which is estimated from 135.2 billion tons of o.e. (oil potential – 59.63 billion tons, gas potential – 88.88 trillion m^3) to 171.2 billion tons of o.e.. (oil potential – 66.14 billion tons, gas potential – 123.88 trillion m^3) (24, 43).

The most relevant research is based on the description of the core of deep wells with a depth of domanik 2733-4416 m – 80 samples; core of 5 structural wells drilled in the Ukhta region of South Timan with a depth of 50-300 m – 357 samples and 12 samples from natural outcrops of domanik horizon rocks in the Ukhta region of South Timan, according to which the resources of the siliceous-carbonate high-carbon domanik formation were estimated using the volume-genetic method and alternatively using the volume method.

According to these studies, the density of hydrocarbon resources per 1 km^2 was 0.3-0.5 million tons/ km^2 for areas in the initial oil formation zone; 1.0 – 1.5 million tons/ km^2 for areas where oil-source deposits are in the active phase of oil formation or at the stage of its completion. According to the volume method, the resource density per 1 km^2 of high-carbon strata is estimated in the shelf zone-0.2 million tons/ km^2; on the slopes of the carbonate platform (side parts of the depression) - 2.1 million tons/ km^2 and in depressions-1.4 million thousand tons/ km^2.

Thus, according to modern research, taking into account the revealed zoning of catagenesis and the identified facies zones, the volume of oil and gas resources in the domanik thickness of the Timan-Pechora sedimentary basin is estimated at 150-225 billion tons.

6. 4. Oil and Gas Potential of the Domanik Complex of Timan-Pechora Sedimentary Basin

The domanik formation is the base of the late Devonian-tournaisian and middle Vizeyko-Kungursky hydrocarbon system where it plays the role of the dominant oil and gas source strata that provides hydrocarbon reservoirs in the Timan-Pechora region.

The main "consumers" of UVS generated by domanik NMT are collectors of the domanik-tournaisian carbonate complex as well as overlying carbonate reservoirs of the middle-upper visean-lower Permian age.

Cut one of the richest and represented by numerous deposits of domanik-tournaisian carbonate oil and gas complex of the Timan-Pechora basin is characterized by four main (generalized) facies types of sediments: the shallow shelf, reef (facies margin of the shallow shelf and single buildings on consideration raising relatively deep depressions), the rocks of the strata filling and relatively deep-water ("domanikites"). Currently, commercial hydrocarbon deposits in the Timan-Pechora basin are discovered in deposits of shallow-water shelf genesis, in reef deposits and rocks of an uncompensated depression – "domanikites".

The reservoir properties of the shelf layers and the reef bodies themselves are significantly higher than those of the host rocks due to postsedimentation leaching and dolomitization processes. The porosity of reefed secondary Dolomites and dolomitized limestones can reach 22-25%, and the permeability can reach Darsi units (for example, at the Pashorskoye field it is more than 2.0 D, at the Zapadno-Tebukskoye field-4.0 D).

The main deposits in domanik and overlying domanikoid sediments of the same age with high-bituminous clay and clay-carbonate strata in the TP SB are concentrated along the strip of barrier reef structures, the boundary part of the carbonate platform, limiting the zone of uncompensated sedimentation of the deep-water basin and in organogenic single structures bordering shoals on the shelf. Such deposits are known in the Izhma-Pechora and khoreyverskaya depressions.

The productivity of the depression, the clay or clay-carbonate sediments of domanik and domanikoids installed at several areas of the Timan-Pechora province (the field name of the Roman Trebs in fractured reservoirs of domanik horizon, Bagan field in domanik-zadonskiy thicker depression, characterized by a fissure reservoirs with a permeability of 140 mD on Kolvinskoe field in the domanik interval in fractured-porous type reservoirs with a carbonate component, at West Yareyyagiskoe field in clay-carbonate deposits of the domanik horizon, at the Verkhnevozeyskoye field in the deep-water analogs of the Ukhta reef, at the Zapadno-Khatayakhskoye field in the domanik fractured-pore reservoirs with core porosity – 3-14%, in the South-Osh field depression in the sediments of Zadonsk age.

The oil flows from the domanikits received on Povarnitskaya area in Kosyu-Rogow depression, Cherpauskay of born place of the bank of Gamburtseva in Varandey-Adzvinskaya structural-tectonic zone, Adakskaya area of the ridge Chernyshev, Suborskaya field in the Eastern part of the Bolshesyninskaya depression, Hatayachskaya and Verhnetagilskaya areas of Khoreiverskaya depression. Gas inflows were obtained from the Zapadno-Soplesskoye field of the Srednepechorsky transverse uplift and the Vuktylskoe field in the Northern part of the Verkhnepechorskaya depression.

However, the identified deposits in the clay facies of domanik and its overlying analogs in the TP SB are difficult to attribute to typically unconventional ones, since they are controlled by a combination of structural and lithological factors, are often supported by plantar water, and are associated with fractured reservoirs.

6. 5. Results of OM Distribution and their Confinement to Different Facies Zones and Lithotypes The potential of a high-carbon domanik formation is determined by the initial concentration of OM in the rock and its catagenetic maturity, and the formation of effective reservoirs in rocks is associated with both sedimentation, diagenesis, and subsequent epigenesis, including the formation of biological voids and the reservoir space formed by the OM itself, which determines the need to use geochemical studies in assessing resources and reserves.

To substantiate the parameters for estimating the hydrocarbon resources of “residual oil”, a series of geological field works and laboratory studies were carried out, which made it possible to significantly refine and supplement the data on the distribution, distribution in the section, lithotypes, geochemistry of OM, filtration and reservoir properties of domanik deposits and its analogs within the Timan Pechora SB.

Total sample of 745 TOC analyses, 228 samples were obtained from natural outcrops of the Ukhta region (the rivers Chut, Ukhta, Domanik and the Shudayag outcrop, Vetlosyan quarry, №№ 1, 7, 16, 21 and 28) , where the average content of organic matter per rock from the stratigraphic domanik was 9.9% with a distribution in the lower part of the section from 11.1% to 8.4% and in the upper part of the domanik section from 9.7% to 5.6% (according to 4 intervals presented in the section of outcrops) (Figures 7 and 8). At the same time, in the wells that opened the deep-water facies of domanik, according to analyzed 182 core samples, represented by clays, mudstones and marls, the average content of TOC was 5.6%.

As part of the TP SB high carbon thickness was formed only in the middle frasnian, part - middle-late-frasnian-early famennian time, on a limited East in middle Frasnian -early Tournaisian time, the thickness of oil source strata varies from 10-20 m up to 140-150 m.

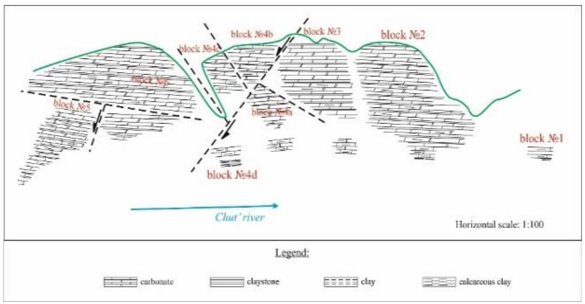

Figure 7. Diagram of the domanik deposits of the river Chut. The first ledge

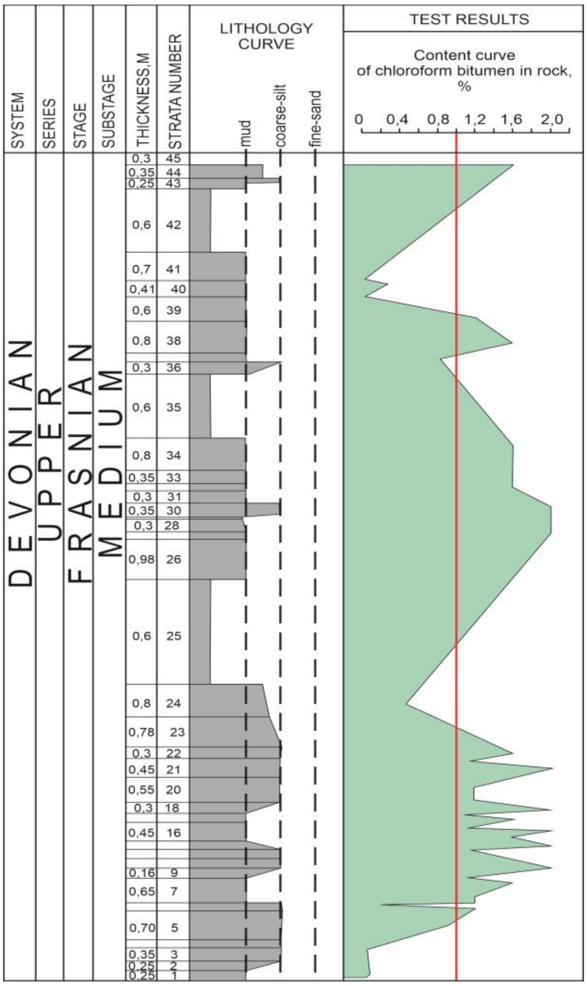

Figure 8. Basic structure of domanik deposits in the Ukhta region.

Noted more thick sections (up to 140 and even up to 300 m) accumulated in the carbonate platform offshore, and more calcareous part of the section of the complex, source rocks are often characterized by low organic carbon content, or its complete absence. In most large tectonic zones characterized by uncompensated deflection (ancient rift structures depressions) conditions favorable for the accumulation of high-carbon formation were maintained for a long time. In these structures, the thickness of the high-carbon formation also sometimes reaches 200 meters or more. At the same time, the capacity of the oil-producing layer can be up to 60-80 meters. On the slopes of the shelf, where domanikoids were formed during the middle-late Frasnian and Famennian times, the thickness of the high-carbon strata can reach 100 meters or more, while the thickness of the oil-producing strata is about 30 m (Figures 9, 10 and 11).

In order to clarify the areal and stratigraphic boundaries of the high-carbon formation, as well as the distribution of TOC over the domanik section and its

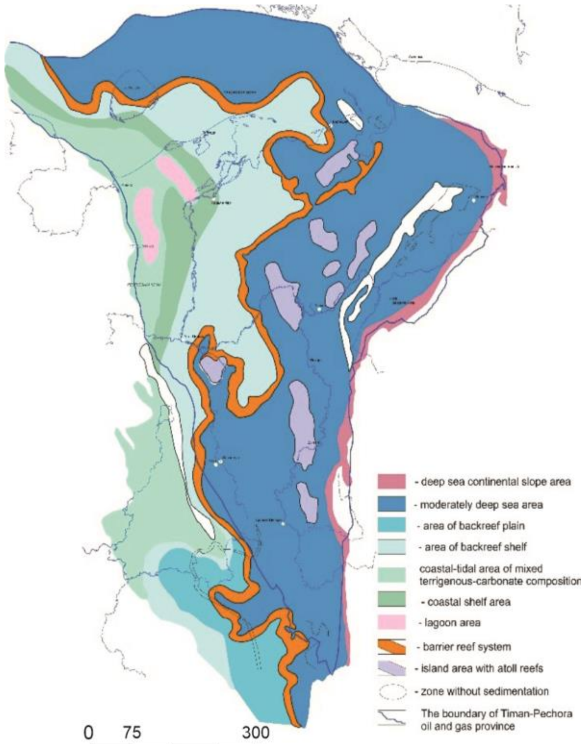

Figure 9. Distribution of deep-water high-carbon deposits in the middle Frasnian (domanik) time

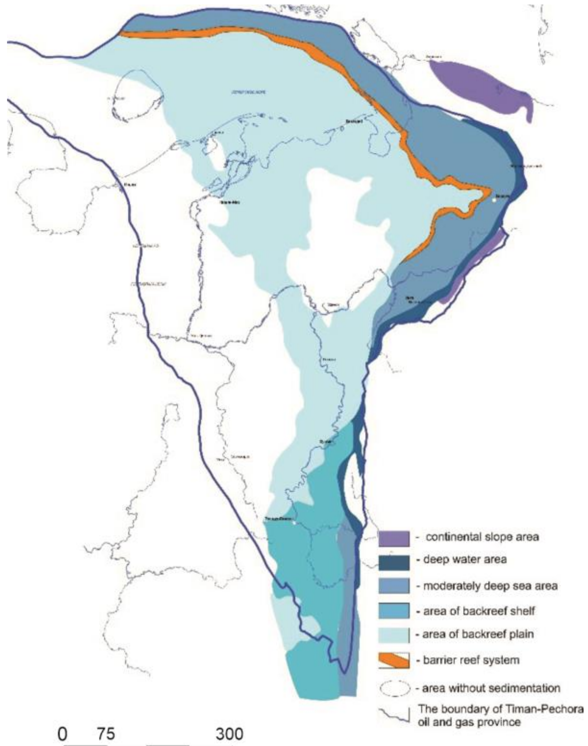

Figure 11. Distribution of deep-water high-carbon deposits in the Famennian-Tournaisian age within the TP region

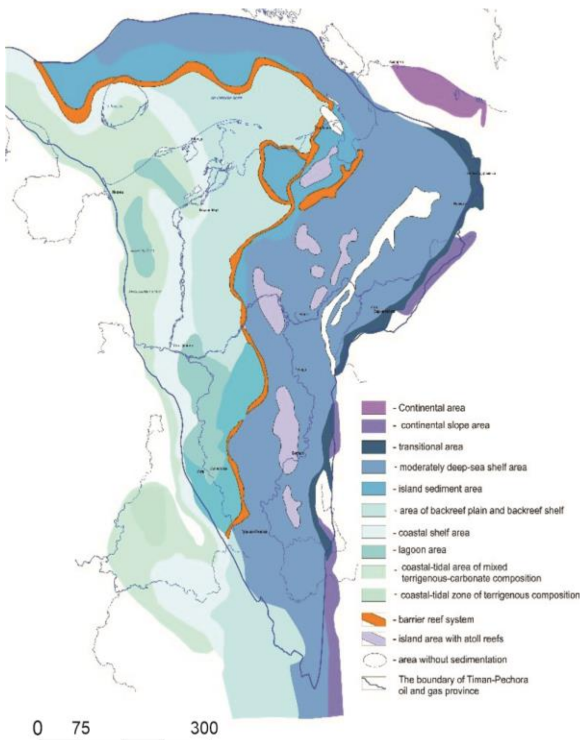

Figure 10. Distribution of deep-water high-carbon deposits in the late Frasnian and early Famennian age

overlying facies, lithological facies maps were used as the basis for the research, the geophysical data of the wells that have penetrated these sediments in Timan Pechora SB (more than 350 wells) with reference to the primary selected lithotypes in the range of domanik-tournaisian deposits (separately for domanik, upper Frasnian - lower famennian and famennian - tournaisian parts of the section) (Figures 9, 10 and 11) .

The sole of the high-carbon formation within the Timan-Pechora SB is most often carried out at the base of the depressive high-carbon deposits of the domanik horizon. The roof of a high-carbon formation is carried out, as a rule, on the sole of overlapping carbonate or clay rocks for the corresponding interval.

In the North-West of the basin, there is an area where there are no domanik deposits. In the well sections and in the Northern-Timan outcrops, the complex is represented by terrigenous strata of inter layers siltstones, mudstones, and clays with rare layers of coarser-grained rocks. Layers of marls and carbonates appear in the Eastern direction, and lithofacies of transition zones to the shallow-sea shelf are observed (Figures 9, 10 and 11).

Within most of the sedimentary basin, domanik-type deposits with different stratigraphic ranges are distinguished. Actually, domanik horizon is the most widespread in the basin in sediments of the upper Frasnian area of distribution of deposits of domanik type, it narrows, its outer boundary coincides with the boundary of strata which filling vetlasyanskaya suite. In a famennian layer the bituminous shales are developed in the side parts of paleo cavities. The area of their development is controlled by the boundary slopes of barrier reef systems of the late-upper Frasnian age. The stratigraphic range of their development increases from the outer to inner sides of the depressions from the zadonsky to the lower-upper famennian. Sections where domanikoids are also developed in deposits of the tournaisian stage of the lower Carboniferous are confined to the axial parts of the paleo cavities. The area of their distribution is observed in the easternmost and North-Eastern parts of the Timan-Pechora OGP and occupies a fairly large area.

Since the method for estimating the generation, emigration, and preservation of hydrocarbons in the generation column is based on a detailed dissection of domanik deposits and formation analogs, the first stage identifies basic lithotypes, each of which has its own geochemical characteristic of organic matter. The reference is also made to sedimentation conditions from shallow-sea shelf to relatively deep-water.

The main results of typing are as follows. Within the selected facies zones, the most significant is the domanik (semiluksky) horizon of deep-water sedimentation, which occupies an area of 12 thousand km sq. (in the zone of PC3-MC1 catagenesis) with TOC concentrations in the lower part (at a thickness of 10-16m) – 15% and in the upper part at a thickness of 12-15m - 12%, in the zone of MC2 catagenesis, which occupies an area of about 20 thousand km^2 with a total thickness of the high-carbon part of the section up to 20 m and TOC concentrations. 5%, in the zone of catagenesis of MC3, which covers an area of about 35 thousand km^2 with a total thickness of the high-carbon part of the section up to 20 m and concentrations of TOC 4.5% (Figures 12 and 13).

Next, importance is predominantly clay and shale rocks high frans divided into two types with thickness in the zone of catagenesis MC2, occupying an area of distribution about 25 thousand km^2 with a total capacity of high-carbon part of the section up to 12-20 m and concentrations of TOC 3%, in the zone of catagenesis MC3, occupying an area of distribution about 40 thousand km^2 with a total capacity of high-carbon part of the section up to 20 m and concentrations of TOC 1.5%.

And the least significant, but also important for the most Eastern regions of the sedimentary basin is mainly clay and carbonate-clay strata, which can also be attributed to the high-carbon part of the Famennian and lower Tournaisian formation, divided into two types in the catagenesis zone MC2, which occupies an area of about 15 thousand km^2 with a total thickness of the high-carbon part of the section up to 20 to 30 m and concentrations of TOC 2%, in the catagenesis zone MC3, which occupies an area of about 60 thousand km^2 with a total capacity of the high-carbon part of the section up to 30 m and TOC concentrations of 1.0% (Figure 14).

Overlying deposits of relatively deep-water facies of domanik analogs have been studied in both shallow and deep wells. The most important conclusions should include the established significantly lower content of TOC per rock than discussed in the literature [5,10,39].

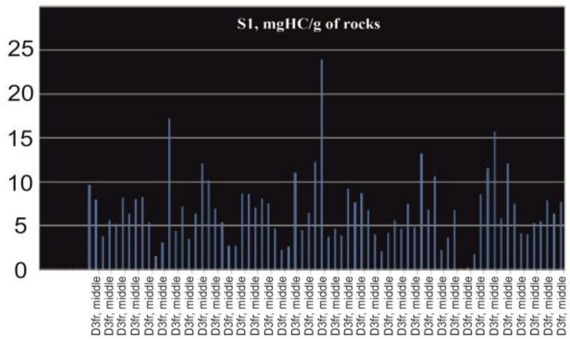

Figure 12. Distribution of the S1 indicator in the Ukhta domanik section

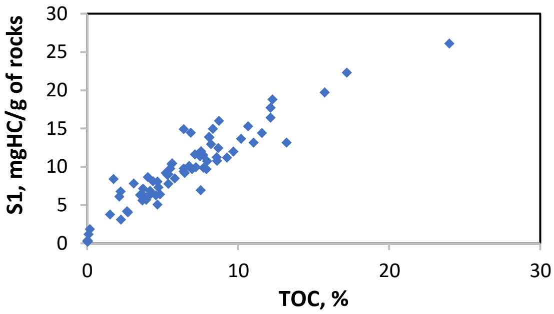

Figure 13. Correlation of the S1 parameter with the TOC content in the domanik formation deposits in the shallow well Komi-1 (according to Fortunatova et al. [53])

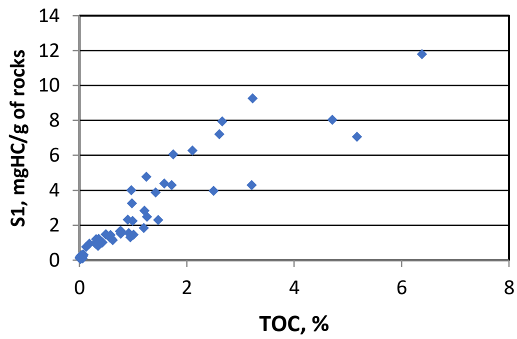

Figure 14. Correlation of parameter S1 with TOC content in middle Frasnian (domanik horizon) deposits and upper Frasnian deposits from wells with a depth of 3148-4260m

So, for 88 samples of the upper Frasnian tier, the average content of TOC was only 0.4%: 22 samples of marl and clay of Eletskaya, Zadonskaya and Evlanovsko-Livensky deposits and 0.27%, respectively, for 35 samples of marl and claystone from wells of the low famennian part of the section and 0.43%, 70 samples of marl and claystone of the high famennian part of the section - 0.15% for 135 samples of claystone and marl of the tournaisian relatively deep-water deposits was 0.76%.

Of course, in each of these stratigraphic intervals of the domanikoid formation, separate intervals with a higher content of organic carbon are found. The highest values were recorded for the tournaisian deposits of the Jebol stage - up to 4.9%. The average content of TOC clays and mudstones of the filling thickness was 0.34% for 22 samples, which, in general, does not differ much from its content in the deep-water deposits of famen.

Despite the fact that layers of high-bituminous carbonate-siliceous and clayey rocks are present in almost all the studied sections, their oil and gas source potential is significantly lower than is assumed in the calculations of the volume-genetic method according to the TP SB.

In the section of natural outcrops, there is a clear relationship between the content of TOC and the carbonate content of rocks.

The most enriched TOC (10-15 %), and in some samples up to 20-30 %, rocks are depleted of carbonate material. In carbonate layers - lithotypes of limestones and clay limestones on the contrary, in most cases, characterized by a low content of TOC (from tenths to the first units of percent) and low values of the S1 index (Figures 15 and 16).

Shale mudstones and clay-siliceous limestones with the thinnest layers of sapropelites are characterized by the highest concentration of OM in the domanik formation. The content of TOC in them reaches 15-25 %, and in sapropelites exceeds 30%. The hydrogen index (HI) of kerogen contained in rocks of this type is 560-717 mgHC/g TOC, and the oxygen index (OI) varies from 7 to 23 mg of $CO+CO_2$/g TOC. The OM of TOC - enriched with domanik bundles is characterized by a high generation potential (S2 – 50-100 mgHC/g of rock and higher, HI-600-650 mgHC/g TOC), a low oxygen index (OI), and an increased content of free HC (S1) relative to carbonate bundles.

Based on reported data previously performed works (5, 44), it was found that samples of domanik deposits from outcrops contain type II OM and are located at the beginning of the "oil window" (T_{max} 409-424°C). Current studies have proved close values of catagenesis - T_{max} from 411 to 423°C, with average values of 420°C.

Generation potential of domanik rocks is high and range from 36 to 170 mgHC/g of rocks (according to Sannikova et al. (45)) and in the range 48-137 mgHC/g (according to current research) to the bottom of domanik and in the range 25-124 mgHC/g (current research) at the top of domanik. Table 1 represented samples' parameters for the river Chut, there is also a correlation of the content of OM with the lithotypes of rocks (Table 1).

Mainly siliceous rocks or silicites are characterized by a lower content of OM (up to 6-8 %) than clay differences, but have a high generation potential.

The lowest TOC content is mainly characterized by carbonate rocks. In them, the content of TOC rarely exceeds 1%. At the same time, they show a slight increase in HI at lower values of T_{max}, which may indicate the presence of displaced HC in these intervals.

Samples of domanik deposits from shallow wells contain types I and II of OM, the degree of its maturity is slightly higher (T_{max} 413-429°C), than on outcrops (gradation of catagenesis MC1-2) (33, 46). The content of TOC in them varies from 2 to 15 %, and in sapropelites exceeds 20%. The hydrogen index (HI) of kerogen contained in rocks of this type is 360-800 mg of HC/g TOC.

The description of core samples of domanik deposits in deep wells showed that all of them belong to types I or

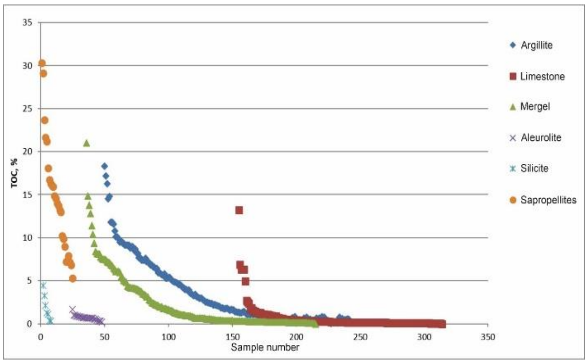

Figure 15. TOC content is confined to the selected domanik lithotypes. Lithotypes: 1- clay shales, 2-limestone, 3--marls, 4- siltstones, 5-silicites, 6- sapropellite

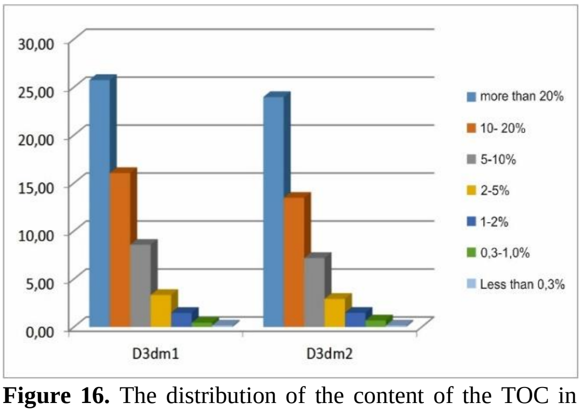

Figure 16. The distribution of the content of the TOC in accordance with the age in the domanik-famennian part of the TP SB section

TABLE 1. Pyrolitic test results for domanik sediments from natural outcrops of TP SB (author's material)

Age	Lithology	S1, mgHC/g of rocks	S2, mgHC/g of rocks	Tmax, °C	TOC, %	HI, mgHC/g TOC
D3 vt	clay, marl, clay limestone	0,02	0,14	418	0,3	47,6
D3 f2 (dm2)	dark calcareous mudstone	10,19	91,29	417	14,18	637,83
D3 f2 (dm2)	clay shale	9,39	86,52	419	13,22	655,29
D3 f2 (dm2)	marl	7,26	70,68	420	10,75	630,9
D3 f2 (dm2)	limestone and clay limestone	3,81	42,6	420	6,82	553,6
D3f2 (sr)	clay	0,14	4,62	426	1,53	289
D3 f2 dm1	clay limestone, calcareous mudstone	7,44	73,15	420	10,64	676
D3 f2-f3	Average of 5 outcrops (without pure limestones)	6,22	59,69	419,97	9,35	586,94

II of OM with a degree of maturity from MC 2 to M 3-4 maturity (T_{max} 439-463°C), which is significantly higher than in outcrop rocks and than in shallow wells. The content of TOC in them varies from 0.2 to 11.8 % (on average 2.3%). The hydrogen index (HI) of kerogen contained in rocks of this type is 350-660 mg of HC/g TOC (on average 260 mg of HC/g TOC).

The estimation of resources by the volume and geochemical (genetic) method is based on the ability of the rock itself to generate hydrocarbons. This method evaluates the generation potential of the oil and gas source shale layer and the degree of its implementation.

In recent years, the pyrolytic method in the Rock-Eval variant has been widely used to determine the hydrocarbon potential of OM and rocks and assess potential resources. At the French Institute of petroleum, the results of open pyrolysis were used to determine the kinetic parameters of maturation reactions for three types of kerogen that are widely distributed in nature: type I (sapropel), type II (mixed), and type III (humus). The same work was carried out with reference to domanik in the published research of Sannikova et al. (45). and in the 80 years were performed by VNIGRI using the technology of combining a step of thermal decomposition and chromatography.

The estimation technology proposed by Fortunatova et al. (46) involves the identification of the oil source rock, its distribution area, and the estimation of its capacity. Then the total amount of organic carbon contained in the volume of the source rock is calculated, and respectively the amount of HC generated. The volume method for estimating HC generation is based on the fact that part of the initial kerogen is converted to HC which amount can be calculated by the hydrogen index (HI=S2•100/TOC, mg of HC/g of TOC). This parameter characterizes the hydrocarbon potential of the oil-source of OM and depends on its type. The difference between the initial potential (HIout), i.e. before the beginning of catagenesis (generation), and the potential at the final stage of catagenesis (HIcat) means a decrease in the generation potential and corresponds to the number of generated hydrocarbons.

Oil-saturated intervals in the section of the thickness differ from the deposits containing them by an abnormally high content of free hydrocarbons (indicator S1), relative to the concentration of organic carbon (TOC or CBT) (Figures 13, 14 and 15). The coefficients proposed by Neruchev et al. (47) were used for recalculation (Table 2).

To restore the original value (by the beginning of mesocatagenesis, grading PC3/MC1), it is necessary to multiply the current value of TOCad (analytically determined) by the corresponding coefficient. This coefficient shows how many times the mass of OM has decreased as a result of the generation of volatile products (water, gases, liquid hydrocarbons).

The kerogen maturity in the Central regions of the Khoreyverskaya depression corresponds to the gradation of MC1 (T_{max} ~ 440ºC), and in the Northern, North-Western and Eastern directions increases to MC3 (T_{max} – 455-465ºC).

TABLE 2. Conversion factors residual concentrations of TOC in the source at the beginning of catagenesis [57]

Gradation of catagenesis	Concentration of TOC ^{out} at the beginning of catagenesis	
Catagenesis	Sapropel OM	Humus OM
PC_3	1,03 • TOC_{ad} *	1,08 • TOC_{ad}
MC_1	1,14 -1,3 • TOC_{ad}	1,09 • TOC_{ad}
MC_2	1,43 • TOC_{ad}	1,10 • TOC_{ad}
MC_3	2,32 • TOC_{ad}	1,19 • TOC_{ad}
MC_4	2,66 • TOC_{ad}	1,21 • TOC_{ad}
MC_5	3,01 • TOC_{ad}	1,22 • TOC_{ad}
AC_1	3,16 • TOC_{ad}	1,23 • TOC_{ad}
AC_2	3,23 • TOC_{ad}	1,26 • TOC_{ad}
AC_3	3,26 • TOC_{ad}	1,31 • TOC_{ad}
AC_4	3,27 • TOC_{ad}	1,33 • TOC_{ad}
Graphite		1,43 • TOC_{ad}

Domanikites in the Khoreyverskaya depression alternate with less TOC layers (1-4 %), which are represented by more carbonate rocks. In this case, TOC most often does not exceed tenths of a percent. Separate layers of TOC rocks are recorded in the lower part of the Famennian deposits. However, the content of TOC in them does not exceed 3-4 %, and in the upper mainly carbonate part of the section is reduced to tenths of a percent (48).

To achieve these goals, computer x-ray microtomography, chloroform extraction, and bituminological analysis of extracts were used.

The chloroform extraction method was performed using a Soxlet extractor. Whole core samples were placed in the apparatus and subjected to chloroform saturation. The soluble part of the bitumoids was then extracted with a solvent. Dried samples with residual kerogen were re-investigated by x-ray tomography to compare the results before and after extraction (49, 50).

Outside the scope of this research, bituminological analysis of extracts and pyrolytic studies of fragments of core samples before extraction (with soluble bitumoids and kerogen) and after extraction (only with kerogen) were carried out to solve the problems of reconstruction of conditions for the formation of mobile oil in domanik deposits of the TPP. Significant discrepancies were found between the results obtained on unresolved samples and pyrolytic studies of destroyed samples, which should be taken into account both when evaluating reservoir properties and when developing approaches to extraction technology.

Domanik deposits contain a significant amount of non-emigrated hydrocarbons.

In most of the Timan-Pechora basin, the producing strata of the domanik high-carbon formation are at the stage of catagenesis (MC 2-3) and have fully entered the main zone of oil and gas formation. Only in the Western part of the province (the Malozemelsko-Kolguevskaya monocline, the Central and Western parts of the Izhma-Pechora depression, and the East Timan complex shaft) catagenesis gradations correspond to the early (PC3-MC1) stage of oil formation, while in the pre-Ural regional trough and most of the Pechora-Kolva aulakogen, domanik deposits are located in the main gas formation zone (Figures 17 and 18).

7. DISCUSSION OF RESULTS

Assessment of the resource potential of domanik-tournaisian deposits by the volumetric method.

The estimation of liquid hydrocarbon resources in the free pore space of the domanik horizon was performed by using the volumetric method. For this purpose, the most important thing was to determine the volume of the pore space (45).

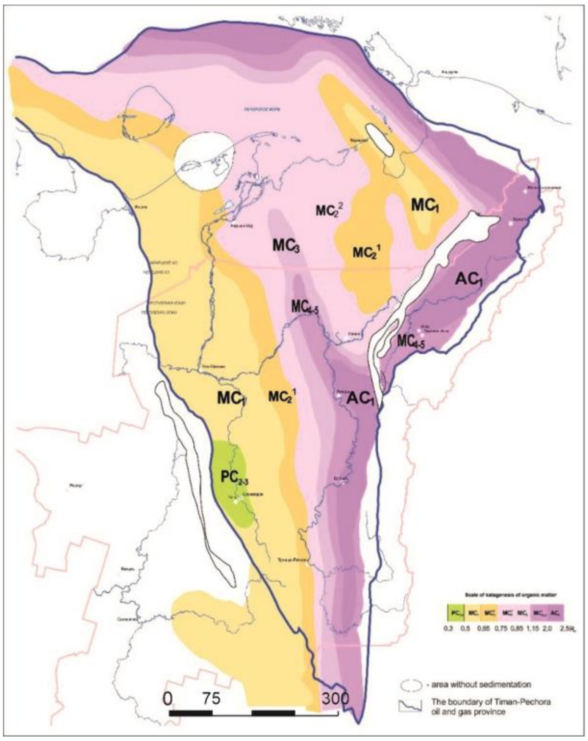

Figure 17. Scheme of catagenesis of deposits of the domanik horizon of the TP SB ((11) with author's additions)

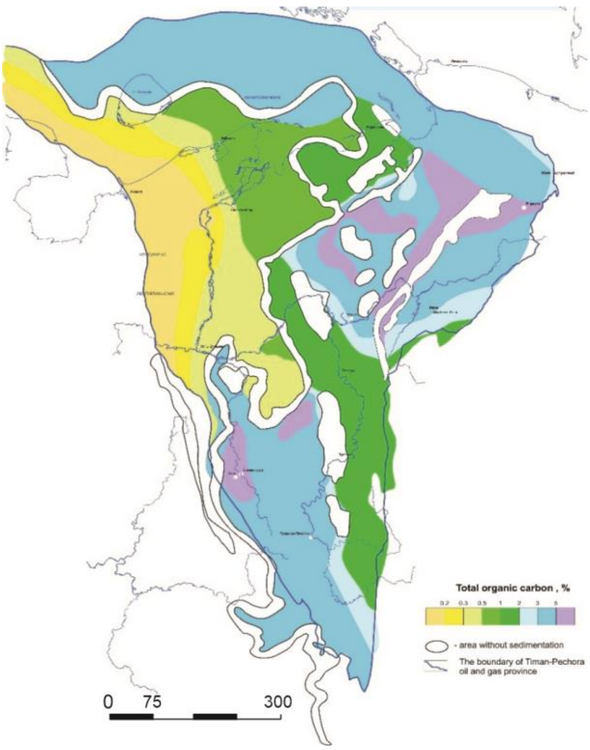

Figure 18. Distribution of non-carbonate carbon in the section of the Dominic-lower Frasnian TP SB, scale of SNC concentrations, (in % per thickness) ((11) with author's additions)

Taking into account the obtained data and significantly updated maps of the distribution of organic carbon throughout the section and the area of the Timan-Pechora sedimentary basin. According to the present researches (Table 1), the generation potential of the domanik formation with the estimated density of hydrocarbons of 0.9 – 1.2 million t/km^2 for the areas of formation, in the initial zone of oil generation (oil window); 2.0-2.2 million t/km^2 for the areas in the main zone of oil generation and of 1.4-1.6 million t/km^2 for the areas of the main completed oil formation zone and in the main zone of gas formation is estimated at 336 billion tons (oil potential – 210 billion tons, gas potential - 126 trillion m^3), the residual potential of hydrocarbons preserved in the reservoir is estimated at 42-63 billion tons of oil and 12.6 -18.9 trillion m^3 of gas (10, 11, 51).

At the same time, the total amount of oil in the free pore space of the domanik horizon using kinetic spectra amounted to 10.5 billion tons of oil and 6.3 trillion m^3 of gas, and taking into account the reservoir space defined with the division into the shelf zone, the slopes of the carbonate platform (side parts of the depression) and in the de-pressions is 5.2 billion tons of o.e. in the areas of high concentration, which is comparable to the volume of accumulated HC in traditional reservoirs, estimated in TP about (6 billion tons) and allows to consider the high-carbon domanik strata as an important reserve for oil production in the conditions of high prices for hydrocarbons in the well-developed regions of the European part of Russia (8, 11).

Based on the conducted research and considered approaches to potential assessment, the most significant directions for further explorations and development of unconventional hydrocarbon accumulations in the high-carboniferous Domanik Formation in the territory (including the offshore area) have been determined. The Timan-Pechora is primarily associated with areas of low and medium mesocatagenesis (MC1-MC2), spread over more than 80 thousand km^2 for the middle-upper Frasnian and Famennian-Tournaisian deposits. They can be considered as priority areas for developing technologies for extracting oil from shale reservoirs.

Reservoir properties analysis, combined with research into bituminous extractions, enables the localisation of areas suitable for extraction when hydrocarbon prices rise or new technologies were developed (52, 53).

The estimation of the proportion of syngenetic and epigenetic bituminous in the generation thickness was compared with the effective porosity, i.e. a combined volume method and an improved volume-genetic method were used (Table 3, Figure 19) (8).

TABLE 3. Characteristics of the domanik formation of the Timan-Pechora OGP and assessment of unconventional accumulations of hydrocarbons in the domanik shale strata (according to the authors research using the balance equations (8, 17, 47))

Basin/total area		**Timan-Pechora (with marine part) / 450 thousand km^2**			
Shale formation		Domanik (South-Western, Central, Northern and Eastern parts of the basin)		Domanikoid (Upper-Frasnian, Famennian, Tournaisian) (Central, North-Eastern and Eastern parts of the basin)	
Geological age		Middle Frasnian		Upper Frasnian, Lower Famennian	Upper Famennian, Tournaisian
Sedimentation		Marine (relatively deep water)		marine	marine
Proposed area (km^2)		25 000	140 000	155 000	58 000
Formation thickness (m)	including enriched OM /average	0-50/20	10-30/15	10-100/20	10-60/20
	Effective thickness average	10	8	10	6
Depth (m)	interval	0-2000	2000-4600	1600-4400	1400-4400
	average	1200	3200	3000	2800
Reservoir properties					
Layer pressure		abnormally high	abnormally high	normal	normal
Middle TOC (%)		8.0	4.0	2.0	1.5
Thermal maturity by vitrinite reflectivity (% Ro)		6.0-8.0	8.0-11.0	7.8-11.0	7.8-10.0
Shaliness		Low and middle	Low and middle	low	low
Capacitive space* (the porosity + fracture)		4%	3%	2,5%	1,5%
Recourses					

Oil phase	oil	oil	oil-low condensate	oil-low condensate	Summed by D3dm-C1t
Geological resources total (generated), trillion m^3	40.0	84.0	62.0	17.4	203.4
Geological oil resources total (generated), billion tons	36.0	56.4	41.2	10.0	143.6
Geological gas resources (generated), trillion m^3	4.0	27.6	20.8	7.4	59.8
Geological resources of oil “residual” (dispersed in the thickness)	28.8	33.6	28.0	7.8	98.2
Geological resources of gas “residual”, (trillion m^3)	1.0	9.1	10.4	3.7	24.2

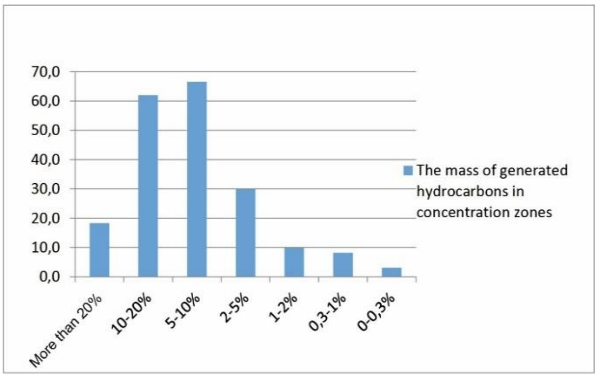

Figure 19. Diagram the mass of generated hydrocarbons in concentration zones of the domanik formation of the Timan-Pechora OGP

7. CONCLUSION

The study revealed the relationship between primary sedimentation conditions and organic carbon concentrations, the authors developed a methodology based on the results of pyrolytic and bituminological analyses of organic matter and extracts of bitumoids, which makes it possible to divide the generated hydrocarbons into emigrated from the oil and gas maternal strata and those preserved in it. A sequence of studies is also proposed that enables the residual hydrocarbon potential to be estimated. The latter, i.e. residual hydrocarbon (not emigrated part) potential is the most debatable issue and requires experimental confirmation in the future. The methodology based on the balance equations is developed. Recalculation of the OM content at the beginning of catagenesis for sediments taking into account the type of organic matter (sapropelic according to type II).

For a more objective assessment we used maps of distribution of organic carbon concentrations presented in this work for three stratigraphic intervals characterised by the highest OM contents with different facies affiliation.

For calculations of the residual potential we used the organic carbon distribution maps linked to specific facies and sedimentary conditions, which significantly distinguishes them from the known maps for the region, which were constructed using thickness-weighted average values of TOC content obtained from laboratory studies.

As an important feature of the proposed methodology the necessity to compare the obtained values of the residual volume of mobile oil with the volume of free pore space determined by X-ray tomography after sample extraction is noted.

The research methodology and calculations presented in this study can be applied to the evaluation of similar low-permeability high-bituminous sediments both in Russia and abroad.

The volumes of hydrocarbons dispersed and concentrated in generation sites were found to be similar on the basis of OM composition and georeferencing to catagenesis zones. Therefore, in the Timan-Pechora sedimentary basin, the potential of the Domanik high-carbon formation, previously estimated at 5.3 billion tons of oil, according to this research, ranged from 4.91 to 6.39 billion tons. For gas, estimates reached 4.8 trillion m^3, according to this research, from 2.4 to 1,67 trillion m^3, which is explained by a decrease in the accepted share of gas preservation at a level some half of that estimated previously in gas-concentration zones.

The research results will become the basis of quantitative assessment of hydrocarbon resources of non-conventional high-carbon formations of the Russian Federation, conducted under the leadership of the Federal Agency for subsoil use (leading Institute VNIGNI with involvement at the site of the TP with VNIGRI research and consultation, the laboratory of St. Petersburg Mining University).

8. AUTHOR CONTRIBUTIONS

Prischepa O.M. - study concept, development of a geochemical complex to study hydrocarbons in sediments of domanik type; Xu Ruiming - processing of analytics, development of methodology for evaluation of unconventional HC of shale strata.

Martynov A.V. - construction of lithological and facies models.

Ibatullin A.Kh. - formation of a database on the content of Sorghum in pre-domanik sediments.

Krykova T.N. - processing data of PGI wells in domanik part of the section.

Sinitsa N.V. - analysis of unconventional HC estimation methodology, review of views on structure of high-carboniferous strata of the Russian Federation.

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Persian Abstract

چکیده

توسعه فناوری های تولید نفت و گاز این امکان را فراهم کرده است که نگاهی نو به چشم انداز افزایش پایه مواد خام نفت در مناطقی با زیرساخت های توسعه یافته تولید داشته باشیم. پروژه های اکتشاف و آماده سازی برای توسعه اقشار کم نفوذپذیری با کربن بالا، در درجه اول سازندهای شیل، امروزه جایگاه ویژه ای را به خود اختصاص داده اند، زیرا تجربه جهانی پتانسیل آنها را برای تولید نفت و گاز نشان داده است. تشکیلات شیل با کربن بالا به طور گسترده در روسیه گسترش یافته است. مهمترین آنها شامل سازند باژنوف سیبری غربی و رسوبات دومانیک در بستر اروپای شرقی است که پتانسیل هیدروکربنی آنها به طور مبهم تخمین زده می شود. ابهام تخمین پتانسیل هیدروکربنی مربوط به توزیع ناهموار مواد آلی است که توسط تغییرپذیری شرایط رسوب تعیین می شود. این مقاله نتایج مطالعه رسوبات دونین بالایی را بر اساس داده های ژئوشیمیایی تحلیلی هسته چاه ها و استخراج بیتوموئیدها از آنها ارائه می کند. تجزیه و تحلیل محصور شدن مناطق افزایش غلظت مواد آلی به شرایط رسوبی خاص و مناطق رخساره ای امکان برآورد حجم هیدروکربن های متحرک را در مقدار ۵.۳ میلیارد تن حفظ شده در لایه های کربن دار بالا فراهم کرد. داده‌های به‌دست‌آمده در مورد حجم HC با خواص مخزن مورد مطالعه با استفاده از توموگرافی اشعه ایکس، لایه‌های خاک رس سیلیسی حاوی هیدروکربن با نفوذپذیری کم، که به ما امکان می‌دهد لایه‌های کربنی دونین بالایی را به عنوان یک ذخیره مهم برای حفظ تولید نفت در نظر بگیریم، مقایسه شد. در آینده در یکی از مناطق توسعه یافته تولید نفت بخش اروپایی روسیه.