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A new approach to the prospects of the oil and gas bearing of deep-seated Jurassic deposits in the Western Siberia

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Abstract. Complexly constructed low-permeability reservoirs are still poorly understood. This slows down the development of oil and gas resources of the Jurassic and deeply submerged pre-Jurassic deposits of the West Siberian oil and gas basin. There is also no consensus among the geological community on the prospects of these deposits from the perspective of the oil generation in them and subsequent emigration. There are many questions on the structure and oil and gas content of the deposits of the Bazhenov formation, whose oil resources amount to tens of billions of tons. The problems of oil and gas content and mapping of heterogeneous structure of massive rocks, including the basement formations, are considered in the article. In addition, the prospects of the oil and gas potential of the Jurassic and pre-Jurassic deposits of the northern regions of Western Siberia with geological and geochemical data were estimated. The revealed zones of highly transformed organic matter in the sediments of the Bazhenov formation and a number of other facts allow us to re-argue the prospects of the oil and gas bearing of the underlying deposits.

Keywords: pre-Jurassic deposits, reservoir rocks, oil and gas potential prospects, Bazhenov formation, hydrocarbons, oil, West Siberian oil and gas basin, microelements, vanadium, vanadylporphyrins

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Introduction

Currently, in the north of the Western Siberian oil and gas basin, over 220 prospecting and exploration wells have been drilled that have revealed Mesozoic terrigenous deposits in the stratigraphic range from the Upper Jurassic to the Triassic at depths of 2000 to 4000 m and more. All of them are located in Nadym-Pursky, Pur-Tazovsky and Gydansky oil and gas bearing areas. Significant progress in studying the structure and oil and gas potential of the deep horizons of the north of Western Siberia has been identified with regional and areal seismic surveys, drilling and exploration of super deep wells – SG-6 and SG-7, as a result of which a certain factual material has been accumulated (Khakhaev et al., 2008; Bochkarev et al., 2000; Skorobogatov, 2017; etc.).

However, the development of oil and gas resources in the Jurassic and especially in deeply buried pre-Jurassic deposits in Western Siberia is currently slowing down due to their insufficient knowledge and the difficulty in interpreting the results obtained. This particularly applies to geochemical and paleogeothermal estimates of the prospects for subsoil productivity at great depths exceeding 4.0-4.5 km. Among geologists, there is no unambiguous assessment of the prospects of oil and gas bearing deposits of great depths, significantly revised in the process of submerging them, from the point of view of identifying reservoirs. There remains much unexplored in the features of the structure and the oil and gas generation of the Bazhenov formation of the Titonian-Lower Berriasian age.

In the present article, we detail some of the concepts developed earlier by us, we consider in more depth the geochemical aspect of the oil and gas content of deep-lying sediments. In addition, data on the content of trace elements (ME), in particular vanadium (V), and metal-porphyrin complexes (MPC)-vanadylporphyrins (V_p) in OM of rocks from the Bazhenov formation and oils were used to evaluate their thermal transformation. We suggest a new angle of view to consider the geological structure of dense deposits of monolithic strata, their oil and gas content. A new perspective on the problem of the prospects of deposits under study has to be developed.

Low-permeability reservoir rocks

Necessary and sufficient conditions (geological factors) for the formation of oil and gas fields for deep horizons remain the same as for the formation of

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hydrocarbon (HC) accumulations in the Upper Jurassic-Cretaceous rock complex. They are the presence of a trap, reservoir rocks, fluids, favorable geochemical and hydrogeological characteristics of the section. However, the characteristics of these factors are changing (sometimes drastically) and, accordingly, the assessment of oil and gas prospects, the choice of directions and objects of geological exploration.

The reason for the significant, sometimes fundamental difference in the geological conditions of the Upper (Jurassic-Cretaceous) from the Lower Pre-Jurassic (Triassic-Paleozoic-basement) floor is, firstly, the substantial compaction of rocks at great depths under the influence of hydrostatic pressure, that leads to a change in the structure and texture of the rocks, the rupture of the seams and, in general, to a change in the structure. Increased tectonic activity at great depths, as compared to depths of 3-4 km, also causes a significant difference in the structure of reservoir rocks and fluid rocks. Secondly, the lithological composition of the rocks varies: from predominantly terrigenous and carbonate rocks in the upper floor, to the same but compacted rocks, as well as to effusive-terrigenous, effusive and crystalline (igneous) and metamorphic rocks (in the lower). As a result, the permeability decreases with depth, the character of voidness changes: from the porous type it transforms into a fractured-porous, fractured-cavern and at the same time its values are significantly reduced. The length of the seams varies considerably, they are broken into fragments, which can be easily traced in seismic sections: at the depth of the in-phase axis they are often broken. In deep horizons it is often difficult to relate the correlation of strata along the wells to seismic materials.

For a number of deposits, an extreme heterogeneity of the structure of deep-lying productive strata has been established, in particular, a chaotic distribution in the section of reservoir rocks and inflow zones. So, we (Shuster, 2003), on the well-studied Vietnamese oil field White Tiger in the basement, revealed an extremely uneven distribution of the reservoir rocks both in the area and in the section (based on GIS, 3D seismic data and the results of thermohydrodynamic studies). Moreover, when testing 500-800 m intervals of the open trunk in the wells, the main part of the oil inflow is fixed (according to the results of thermohydrodynamic studies in 20 wells) in 20-40 meter intervals. And, if in the Central arch of the White Tiger field, oil-saturated reservoir rocks lie immediately from the basement surface, then in the North arch the first reservoir rocks were found in a section at a depth of 500-600 m from the surface. The heterogeneity of the structure is also evidenced by a sharp difference in the filtration-capacity properties (reservoir properties) of reservoir rocks and, as a consequence, the values of oil rates. So, the received inflows of oil from wells, as a generalized index of the reservoir properties of rocks, in the basement deposits differ by three orders: from the first units to 2000 tons/day. These factors are difficult to explain from the standpoint of classical physics. The deposit is classified as massive.

The same picture in the structure of the basement is observed on two exploratory areas of Western Siberia: Ust-Balyksky and Severo-Danilovsky. At the Ust-Balykskу field, reservoir rocks identified by the seismic survey method using scattered waves are concentrated in the eastern part of the basement, and at the Severo-Danilovsky fields the reservoirs are detected directly below the basement surface, but are extremely unevenly distributed over the area. Not taking into account the complex heterogeneous structure of the basement, perhaps, is the reason that in Western Siberia large oil and gas reserves have not yet discovered in these deposits.

It is possible to consider hydrocarbon deposits in massive dense rocks from the position of the model of the "geophysical environment", nonlinear, hierarchically heterogeneous, energetically saturated and active (Nikolaev, 1991), i.e. from the position of transition to a new understanding of the properties of rocks, which requires serious additional research and confirmation.

A sharp heterogeneity is established in the structure of the Bazhenov formation of Western Siberia: a change in its lithological composition both in area and in section, the variability of alternation in the section of reservoir rocks and intervals of oil tributaries. The lack of reliable technologies for mapping the structure of the Bazhenov formation, along with technological problems, does not allow full-scale development of the resources and oil reserves of this unique stratum, a length of 1 million km, a width of 200 km.

Numerous studies have established that the voidness of dense massive rocks is confined, mainly, to fractured and fractured-cavern reservoirs, which are the centers of accumulation of oil (gas). We (Shuster, 2003) was suggested that the formation of zones of unconsolidated fractured rocks in the basement formations occurs under the influence of static and dynamic internal and external stresses, with a relatively rapid decrease in pressure and temperature accompanied by a pulse of released energy, which is the primary cause of destruction. In the Bazhenov formation, fracturing ("decompression") is created artificially, by hydraulic fracturing.

Today, seismic exploration technologies using scattered waves have been developed that allow the sections and zones of development of reservoir rocks-potential oil and gas deposits-to be identified in the section of massive strata in prospective exploration areas even before the drilling stage. It should also be noted that the role of fluidisation for oil (gas) deposits in the basement formations can be played not only by regional but also by zonal and local fluidicides. Moreover, it can be not only clay or carbonate strata, but also effusive and crystalline rocks.

In the north of the Tyumen region, where deposits in the Cretaceous and Upper Jurassic fields, unique for the reserves of hydrocarbons, have been discovered, there has been a trend to reduce the increase in gas reserves in these deposits. Drilling was previously carried out only to a depth of 3-4 km with the thickness of the sedimentary cover according to geophysical data up to 9-11 km. Therefore, for today, the agenda is the question of a detailed study of the prospects for oil and gas potential of the Lower Middle Jurassic and pre-Jurassic sediments (the lower floor), including in the giant fields of the north of Western Siberia. According to a number of scientists (V.S. Bochkarev, A.M. Brekhuntsov, N.P. Zapivalov, I.A. Kleshchev, A.E. Kontorovich, I.A. Plesovskikh, V.A. Skorobogatov, V.S. Shein, V.L. Shuster, and others), the basal layers of the Middle and Lower Jurassic, sedimentary deposits of the Triassic and Paleozoic, the formation of the weathering crust and the zone of decompaction of the basement are referred to new promising objects.

Assessment of oil and gas potential prospects of Jurassic and pre-Jurassic deposits

The geochemical aspect of the prospects assessment of the oil and gas potential of the Jurassic and deep-lying pre-Jurassic deposits of Western Siberia is extremely important. Our studies on the composition of bitumen from Bazhenov deposits of the Western Siberian oil and gas basin not only clarified the features of the OM of the formation itself, but also provided additional information for assessing the possible generation capacity of pre-Jurassic and Paleozoic deposits from new positions.

Geochemical details of the genetic features of organic matter from the Bazhenov formation

The relevance of the study and the increased interest in the sediments of the Bazhenov formation is quite natural and is associated with its well-known uniqueness (oil resources) and the need to clarify the prospects for the oil and gas potential of the formation in most of the basin. The deposits of the Bazhenov formation, which are widely developed within the Western Siberian oil and gas basin, have been fairly well studied and described by OA. Arefiev et al.; V.I. Goncharov; M.V. Dakhnova et al.; A.E. Kontorovich et al.; D.V. Nemova et al.; I.I. Nesterov and I.N. Ushatinsky; G.S. Pevnevoy, etc. However, a relatively high degree of study of the formation did not lead to unambiguous judgments about the origin of the hydrocarbon series in it and the regularities of their spatial location. So one part of the researchers believes that the oil of the Bazhenov formation is syngenetic with its rocks (Lopatin, Emets, 1999; Kontorovich, Kostyreva, 2015; etc.). Other authors consider the oil in the formation to be epigenetic or mixed due to their secondary arrival from the underlying deposits in areas of high fracturing (Skorobogatov, 2017; Soboleva, 2017; etc.). The existence of different views on the source of oil has further increased the scientific and practical interest in the problem of the oil and gas potential of the Bazhenov formation, in particular, the geochemical aspects of the origin of hydrocarbons in them. The deposits of the formation are mainly black bituminous argillites with an admixture of siliceous and carbonate material, considerably enriched in Corg (up to 10-15% per rock) and chloroform extracted bitumen (CEB) (up to 2% per rock). A.E. Kontorovich et al. (2014) characterize these rocks as "carbonate-clay-kerogen-siliceous". To the outskirts of the sedimentation basin, an admixture of sandy material appears in the clays, and their bituminous content is significantly reduced.

Let us dwell in more detail on the features of the diagnostics of oil-producing sequences of the Bazhenov deposits, using the ME criteria for the genetic relationships "oil-scattered OM". A search in the section of the sedimentary strata of the oil source formations and their diagnostics is a necessary stage in assessing the prospects of the petroleum potential of sedimentary basins. The similarity of oils and syngenetic CEB rocks to the distribution of ME can be indicative of the participation of these strata in the processes of oil formation. Undoubtedly, the biogenic nature of most ME of oils provides a complete basis for such a correlation. For a more reasonable judgment on the presence in the sedimentary section of the oil deposits, it is necessary to clearly separate the bituminous components into syngenetic and epigenetic components.

The syngenetic bitumen from rocks with high organic carbon (C_{org}) and low bitumen content ($\beta = CBA/C_{org}$,%) is usually characterized by a high content of V, Ni, Co, Mo and other MEs associated with asphalt-resinous components, so-called "heavy". The concentrations of these ME can be two orders of magnitude higher than in oils or epibitumoids. The concentration of ME, associated with oil hydrocarbon components, the so-called "mobile" – Fe, Au, Pb, Cu, etc., in these bitumen is lower than the concentration of "heavy". The distribution of ME in epigenetic bitumen reflects their migratory nature, sometimes contaminated, they are more mobile, they have relatively lower concentrations of "heavy" MEs (in the same order as in oils) compared to syngenetic bitumen (Punanova, 2017; Punanova, Chakhmakhchev, 1992).

The study of the composition of the bitumen Bazhenov formatiion (by the method of atomic adsorption) and metal-porphyrin complexes (on the

Specord device) by the area of distribution, carried out by the authors, showed its considerable heterogeneity (Chakhmakhchev, Punanova, 1992; Punanova, 2017). As can be seen in Fig. 1, the content of V_p in the OM of rocks in the basin varies from their total absence to very high values. Thus, the CEB of rocks in the western regions is characterized by the absence or small values of the V_p content. The central regions (Surgutsky, Nizhne-Vartovsky, Aleksandrovsky swells and some areas to the north of them) are distinguished by substantial enrichment of the CEB with porphyrins. The peculiarity of the presented scheme is the zone of anomalously small values of V_p in the CEB, marked on the map by color, which has a northeasterly strike and covers areas of the areas of Salymsky, Kamenny, Dekabrsky, Verkhne-Lyaminsky, Vyngayakhinsky, Tarasovsky, etc. Spreading on Gubkinsky-Tarasovsky areas, this zone continues north-west towards New Port.

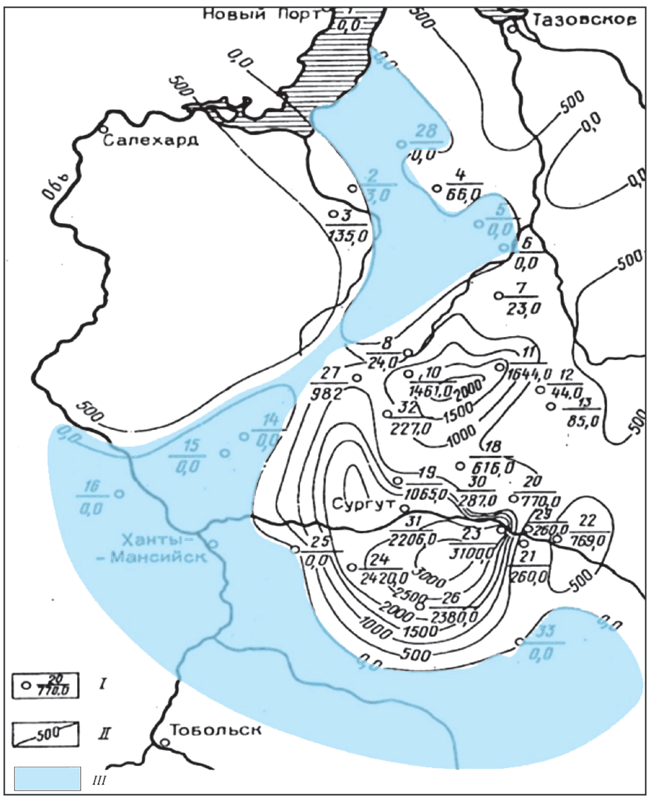

Fig. 1. Distribution scheme of the content of vanadium porphyrins (Vp) in OM from the Bazhenov Formation of Western Siberia (Chakhmakhchev, Punanova, 1992; Punanova, 2017). I – the core extraction area (numerator) indicating the content of Vp ($n\times10^{-3}$%) in OM (denominator). The core sampling areas are as follows: 1 – Novoportovsky, 2 – Nadymsky, 3 – Khaginsky, 4 – Yamovsky, 5 – Gubkinsky, 6 – Tarasovsky, 7 – Vengayakhinsky, 8 – Itursky, 9 – Kollektivny, 11 – Vyngapurovsky, 12 – Tagrinsky, 13 – Northern Erkalsky, 14 – Verkhnelyaminsky, 15 – Dekabrsky, 16 – Kamenny, 18 – Pokachevsky, 19 – Fedorovsky, 20 – Samotlorsky, 21 – Sosninsky, 22 – Medvedevsky, 23 – Megionsky, 24 – Ust-Balyksky, 25 – Salymsky, 26 – Ugutsky, 27 – Soimlorsky, 28 – Mezhvezhy, 29 – Strezhevy, 31 – Surgutsky, 32 – Kholmogorsky, 33 – Matyushinsky; II – isolines of the content of Vp in the OM of rocks; III – zone of anomalously low contents of Vp.

Fig. 2 shows the distribution of the contents of V in the CEB rocks of the Bazhenov Formation of Western Siberia. Based on the values of this parameter, the entire basin area is significantly dissected. The V content in the CEB varies from 0.83×10^{-2}% (Ugutsky district) to 30×10^{-2}% in the western regions of the basin (Kamenny area, Khaginsky and Nadymsky districts). An anomalous zone of low contents of V, tracing from the south-western direction to the northeast, also shown on the map by color, is clearly traced. This zone repeats in its orientation the areas highlighted in Fig. 1 on the anomalously low content of V_p (Chakhmakhchev, Punanova, 1992; Punanova, 2017). As we know, we also noted earlier, in the conditions of high paleotemperatures, V_p are destroyed, forming pyrroles and short chains of hydrocarbons of different structures. In the catalytic conversion zones, oil and OM also lose a significant share of ME, in particular V (T.V. Karaseva, O.V. Serebrennikova, S.A. Punanova, et al.).

A detailed study at the regional level of the OM composition of the formation made it possible to distinguish two of its genetic varieties. The first one, slightly transformed, is characterized by low values (not

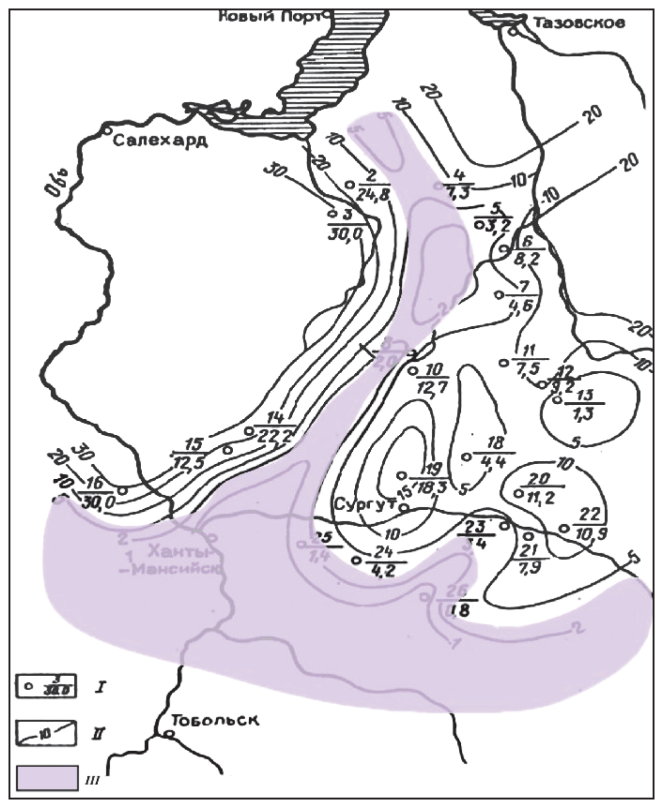

Fig. 2. Scheme of distribution of vanadium content in OM of the rocks from the Bazhenov Formation of Western Siberia (Chakhmakhchev, Punanova, 1992; Punanova, 2017). I – the core extraction area (numerator) with the content V ($n\times10^{-2}$%) in the OM (denominator), the core selection area – see Fig. 1; II – isolines of the content of V in the OM of rocks; III – zone of anomalously low contents of V.

more than 7-8%) of the bituminous coefficient (β) and relatively high values of the metamorphism coefficient $k_i = (P+F)/(n\text{-}C_{17} + n\text{-}C_{18})$ to 0,8, and also a relatively high concentration and diversity of different oxygen-containing structures with increased total aroma. This type of bitumen is developed in the deposits of the Latitudinal Ob Region. The second type of bitumen is characterized by increased β (up to 30%), low values of k_i (0.1-0.3), low relative concentration of oxygen-containing compounds and total aromaticity of CEB with respect to CH_2 groups of *n*-alkanes. In the CEB of this type, practically no porphyrins are found and vanadium concentrations are negligible. Such indicators, as noted earlier, are characteristic of high conversion stage of OM. This geochemical zone coincides with the zone of industrial oil content, and in the regional plan it was reflected in the form of a wide strip having a northeastern strike. It covers part of the Yugansky depression, the Koltogorsky trough, the Salym uplift and extends further to the northwest.

Thus, the revealed heterogeneity of OM rocks of the Bazhenov formation can be explained from our point of view by their different nature – syngenetic and epigenetic. Such dismemberment of bitumen in the oil and gas basin is a necessary condition for further comparison of OM of rocks and oil for detection in the section of oil source formations.

In order to compare the composition of the oils and OM of the rocks of the Bazhenov formation, the well No. 554 of the Salymsky field, which is part of the so-called Great Salym, was studied in detail. The layer Yu_0, confined to the clays of the Bazhenov Formation J_3v^1-K_1b^1, is oil-bearing in a considerable area. Well No. 554 is located within the oil-bearing contour on the central dome of the structure. Based on the results of the study of the rocks of the Bazhenov formation, a close similarity in the composition of oil in the formation and in the composition of the bitumen rocks was revealed. It was expressed in the absence of porphyrins, disproportionately low concentrations V, close to the quantitative distribution of ME and oxygen-containing groups. Due to the fact that the comparison of oils is likely to be carried out with epigenetic bitumen (in the oil-bearing contour), this similarity is not genetically developed and does not prove, but on the contrary it refutes the idea of the connection between the industrial oil bearing capacity of the formation and the generation capacity of its OM, and the revealed proximity – this is the result of contamination of OM rocks by naftides of other sources of generation.

The features of the formation, its shale nature and the frequent alternation of denser and less dense rocks – reservoirs and hydrocarbon producers, lead to difficulties in deciphering the actual oil-material interlayers in its structure. This uncertainty is caused by the fact that the methods of studying conventional hydrocarbon accumulations are not applicable to non-conventional objects, which are both oil source and oil-containing objects. Any movement of fluids within such strata results in a change in their composition, in particular, enrichment with more mobile components and depletion with resin-asphaltene components, to which ME and MPC are associated.

Based on these considerations, for a more correct interpretation of the results obtained, ie. to clarify the nature of the epigenetic bitumen and the role of the OM of rocks from the Bazhenov formation in the processes of oil formation, and, taking into account the noted difficulty in identifying the syngenetic component and sources of oil formation in the Bazhenov formation, we carried out experimental studies on the soft thermolysis (up to 300 °C) of deeply de-bituminous OM for the production of kerogen. The similarity of the ME composition of the released products (during thermolysis) to the trace element composition of oil of the formation will indicate the syngenetic nature of the OM of the enclosing rocks. In the case of reverse results, the idea of the secondary nature of oil relative to the rocks of the formation becomes more convincing, which is illustrated graphically (Fig. 3) (Chakhmakhchev, Punanova, 1992; Punanova, 2017): after heating, there is no similarity of ME between oils and syngenetic bitumen, like it was observed before heating. Thus, as a result of the analytical work carried out, it can be concluded that the similarity of oil and OM of rocks from the Bazhenov formation is not genetic, but manifests itself at the expense of secondary oil content. The bitumen obtained after heating (out of oil-bearing contour), as in the case of bitumen of the wells No. 554 (inside the oil-bearing contour), differs in ME composition from the oils of the Bazhenov formation of the Salymsky field: in V/Ni value, concentration series of the ME distribution, and also in magnitude of ME ratio. All this testifies to the epigenetic character of highly transformed bitumen, migrating probably from the lower high-heated horizons of the basin to higher and unrelated to the syngenetic, poorly catagenetically transformed bitumen of the Bazhenov deposits. The involvement of data on the bitumen characterization and hydrocarbon composition of rock formations also indicates the presence of highly transformed OM in abnormal zones (Chakhmakhchev, Punanova, 1992). The complex comparison of HC biomarkers and ME in the system “kerogen-bitumen-oil” made it possible to call into question of oil-generating role of OM of the Bazhenov formation within the boundaries of the Salymsky field.

Proceeding from this, it can be assumed that within the zones with anomalously low V_p and V contents or their complete absence in bitumen, a mixture of

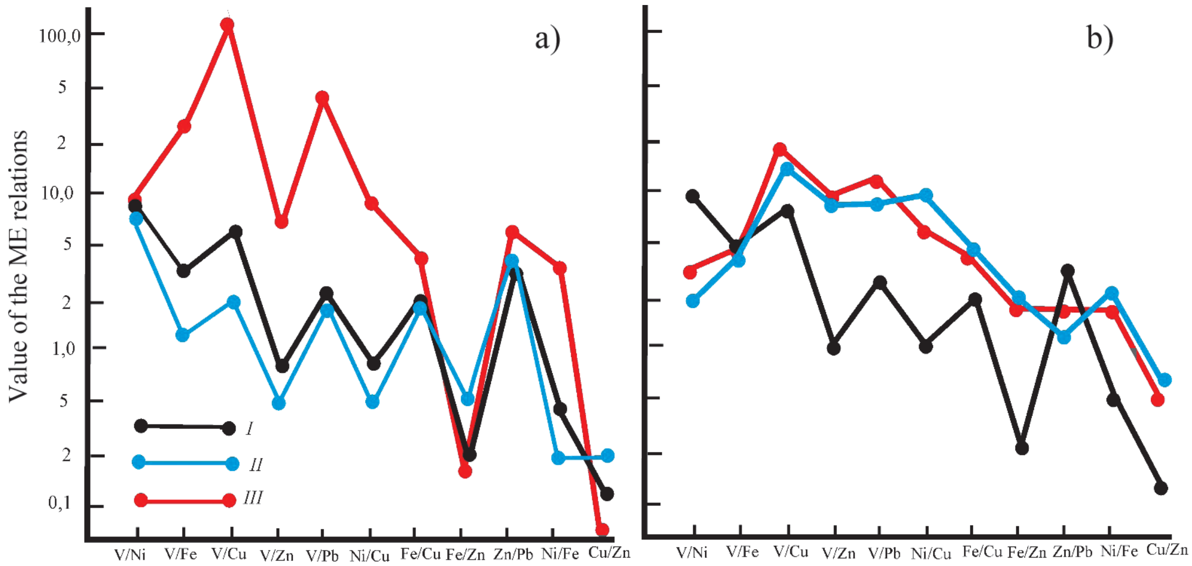

Fig. 3. Comparison of ME ratios in OM of rocks and oils before heating (a) and after heating (b) (Chakhmakhchev, Punanova, 1992; Punanova, 2017). Relations of the ME: I – in oils, II – in the CEB of rocks of the Bazhenov formation inside the oil-bearing contour, III – in the CEB of rocks of the Bazhenov formation outside the oil-bearing contour.

bitumen of the Bazhenov formation with bitumen formed in deeper horizons at higher paleotemperatures occurred. The Bazhenov formation is characterized by the transformation stages of end of MK_1-MK_2 (R° = 0.45 – 0.85%), which corresponds to the second half of the main zone of oil formation (main zone of oil generation) (Kontorovich et al., 2014; Neruchev et al., 1986). These data confirm the possible flow of liquid hydrocarbons from the underlying deposits of the Jurassic (Vasyugan and Tyumen formations), the Triassic and the Paleozoic, capable of generating a high productivity of the entire Jurassic and underlying section. A zone extends through the Yugansky depression, the Koltogorsky basin, the Salymsky uplift and further north-west to the Yamal Peninsula. The territory of highly transformed OM corresponds to the spread of Triassic rifts, granitoid massifs and fluid-conducting faults in the basement (Kontorovich et al., 2008; Fomin, 2011). According to basin modeling (Stoupakova et al., 2015), Triassic rifting and subsequent development of the basin resulted in deep regional faults favorable for vertical fluid migration. According to the results of mathematical modeling (Shuster, Punanova, 2014) this zone practically coincides with the prospective oil-bearing zone of pre-Jurassic deposits and the existing oil bearing capacity of the Khanty-Mansi and Nyurol regions.

Some researchers have a different view on the genesis of oil in the Bazhenov formation, considering it a syngenetic OM of the formation itself, refuting the epigenetic or mixed nature of it. Thus, N.P. Fadeeva, A.V. Stoupakova et al. believe that in this region the deposits of the Bazhenov formation are in the oil window (mid-second half of the main zone of oil generation); the original OM is phytogenic, and can generate oil itself; and the bitumen that we take for epigenetic, are parautochthonous, displaced in the most oil-bearing stratum. A number of researchers (Fomin, 2011; Kontorovich, Kostyreva, 2015; etc.) recognize the presence of zones of highly transformed organic matter of the Bazhenov deposits themselves, for example, at the Chupal and Malobalyksk deposits, confirming this by pyrolytic and charcoal characteristics, and also by an elevated temperature gradient. Additional heating of sediments and an increase in catagenesis in comparison with closely spaced areas, where the deposits of the Bazhenov formation are on gradations of the catagenesis MK_1-MK_2, were also facilitated by the faults fixed in these territories.

On the other hand, studies published in recent years sufficiently substantiate the mixed nature of bitumen in the Bazhenov deposits and the possibility of formation of the oil bearing capacity at the expense of other sources of generation. So, in the work (Soboleva, 2017), when interpreting the results of the detailed hydrocarbon composition of a large sample of oils (more than 80 oil samples from the West Siberian oil and gas basin), it was assumed that in addition to the “own OM of the Bazhenov oil and gas source formation, hydrocarbon fluids from Vasyugan, Tyumen formations and possibly Paleozoic rocks took part in the generation of oil content. The flow of light liquid hydrocarbons and gases occurred along fault zones of different genesis and duration of existence”.

Of course, the identification of oil deposits in the shale formations of bazhenites, domanicites, melinites is quite a difficult task. Since the time of I.M. Gubkin, and to this day, there are heated debates about the oil-generating capabilities of the Upper Devonian Domanic formation of the Volga-Urals. Its oil source properties are not in doubt, but the scale of the possible separation of micronized oil from the stratum is subject to discussion. However, in the depositions of the Domanic formation, residual micro-oil (now called shale oil) is found in the decompressed fractured interlayer reservoirs, and from the bituminous siliceous-carbonate rock formations inflows of hydrocarbons are produced of semi-industrial and industrial nature (Dakhnova, Mozhegova, 2015; Stoupakova et al., 2015; Mukhametshin, Punanova, 2016). I.N. Plotnikova et al. (2017), on the basis of in-depth studies of the geochemical characteristics of the bitumen from Semilukskian horizon and the oil of the Eifelian-Frasnian terrigenous complex, it was concluded that, along with the syngenetic scattered matter, mobile bitumen identical to the oil of the underlying terrigenous deposits of Pashian and the Timanian horizons. In this regard, the authors consider bitumen in the Domanic stratum as migratory, and the deposits of the Domanic facies themselves should be regarded as "accumulative or accumulative-generation system, oil deposits of which were formed due to oil systems generated in other sources."

Similar conclusions were obtained by a detailed study of the composition of the CEB of clayey deposits from the menilite formation of the Oligocene age (Upper Paleogene) of the Ciscarpathian marginal trough of the North-Ciscarpathian oil and gas basin. Investigation of the relationship between oil and Om of rocks allowed us to distinguish two varieties of bitumen – syngenetic and epigenetic, significantly differing in the MPC content. The syngenetic type was revealed in samples from the areas of Tanyavsky, Pasechnyansky and Shodnitsky. It is characterized by a low value of β (up to 7-8%) and high concentrations of vanadylporphyrins (V_p) (up to 1.6% on the CEB), which indicates a low stage of the transformation of OM. In epigenetic bitumen obtained from sediments from the areas of Rozhnyatovsky, Dolinsky, as well as in the oil from the Dolinsky, Tanyavsky, Rozhnyatovsky, Shodnitsky, Bitkovsky, Lopushnyansky deposits, there are no V_p from the depths from 2513 to 4712 m.

This circumstance, as well as the features of hydrocarbon composition and the distribution of oxygen-containing groups, indicate a higher catagenic transformation. Based on the revealed genetic differences in the composition of the oils and OM of rocks, and also the different degrees of their catagenetic transformation, menilite clay black shales probably were not the only generating sources for hydrocarbon systems from the Cenozoic section of Ciscarpathian. The formation of oil deposits may have been due to mixing, or due to the migration of liquid hydrocarbons from the more deeply submerged zones of the development of the Meso-Paleozoic sedimentary complex (Maevsky et al, 1992).

Summarizing the above rather extensive material on the features of the distribution of OM in the sediments of the Bazhenov Formation of the Western Siberian oil and gas basin and other regions with the spread of such a black shale formation, we can state the presence of zones with the introduction of highly transformed epigenetic bitumen catastrophically altered by deep processes, which, in our view, increases the prospects of the oil and gas potential of the region due to the additional source of hydrocarbons, besides the OM of the Bazhenov deposits. These sources can be associated with oil-producing Jurassic (Vasyugan and Tyumen formations) and deep-buried pre-Jurassic sedimentary deposits – Triassic and Paleozoic.

Assessment of oil and gas potential prospects of Lower-Middle Jurassic and pre-Jurassic deposits

By 2016, 902 hydrocarbon fields have been discovered within the Western Siberian oil and gas basin, including 350 with deposits in the Jurassic complex. The largest number of deposits (624 deposits at 210 fields) was found in the Tyumen formation; in the Bazhenov formation there were 80 deposits. The largest initial open oil reserves are concentrated in the Lower-Middle Jurassic oil and gas bearing complex of the central and northern regions of the basin (17.6 billion tons, geological reserves), The smallest are in the Bazhenov formation (0.6 billion tons, extracted reserves) (Skorobogatov, 2017). In our previous studies, the issues of assessing the prospects of oil and gas potential of the Jurassic and pre-Jurassic deposits were thoroughly worked out (Vinogradova, Punanova, 2006; Chakhmakhchev et al., 2003; Punanova, Shuster, 2012; Dmitrievsky et al., 2012; Shuster, Punanova, 2016). Let us briefly discuss the main points.

According to the representations (Shemin et al., 2001) the most informative indicators of prospect evaluation in relation to the Jurassic deposits of the Nadym-Taz interfluve are tectonic and lithologic-facies, since they control the development of the largest hydrocarbon accumulations here. Yu.N. Karogodin (2004) attaches great importance to the role of geodynamic processes in the formation of unique fields in the northern and arctic regions of Western Siberia. It was here, in contrast to other regions of Western Siberia, during the Neogene-Quaternary period, intensive structural-formational movements with the formation of uplifts with amplitudes of more than 200 m were manifested. Skorobogatov (2003), who believes that, depending on the tectonic structure of the sedimentary basin, the lithological and facial characteristics of the sedimentary cover and the geothermal regime, the conditions of ontogenesis of hydrocarbons are significantly different and lead to the formation of differently large and phase states of deposits.

Based on the above considerations, we paid special attention to the lithologic-facies situation of sedimentation, the staginess of the catagenetic transformation of OM sediments, and the structural features of the region in connection with the scale of the fields. The material is illustrated by schematic diagrams (Fig. 4, 5).

An analysis of the relationship between the scale of fields and structural elements has revealed the confluence of unique and large fields to large positive structural elements – mega and meso swells. When allocating the tectonic zones, the materials of V.A. Kontorovich et al, G.G. Shemin et al. were used (Fig. 5). In the Jurassic deposits, the largest fields are confined to positive structures of the first order (megaswells) and second order (meso swells), as well as to positive structures that complicate the megamonoclinal sides. The Bovanenkovo field (large in terms of reserves in J_{1-2}) is located on the Bovanenko-Nurminsky megaswell; Novoportovsk field (unique in reserves in J_{1-2}) – at the South Yamal meso-swell; Novogodny field (large in terms of reserves in J_3) – at Vyngapurovsky megaswell, Urengoysky field (average in reserves in J_{1-2} and J_3) – at the Central Urengoy meso-swell. The Kharampursky field (large in reserves in J_3) is located in the East-Pur megamonocline. Small fields tend to arches and hollows (megatroughs and deflections). For example, in the North arch, deposits are found exclusively with small reserves. However, this relationship does not exclude the possibility of discovering on the same structures fields with other categories of reserves.

Analyzed by us (Punanova, Vinogradova, 2006; 2008), the thicknesses, the distribution of formations, the size of hydrocarbon reserves and their phase state

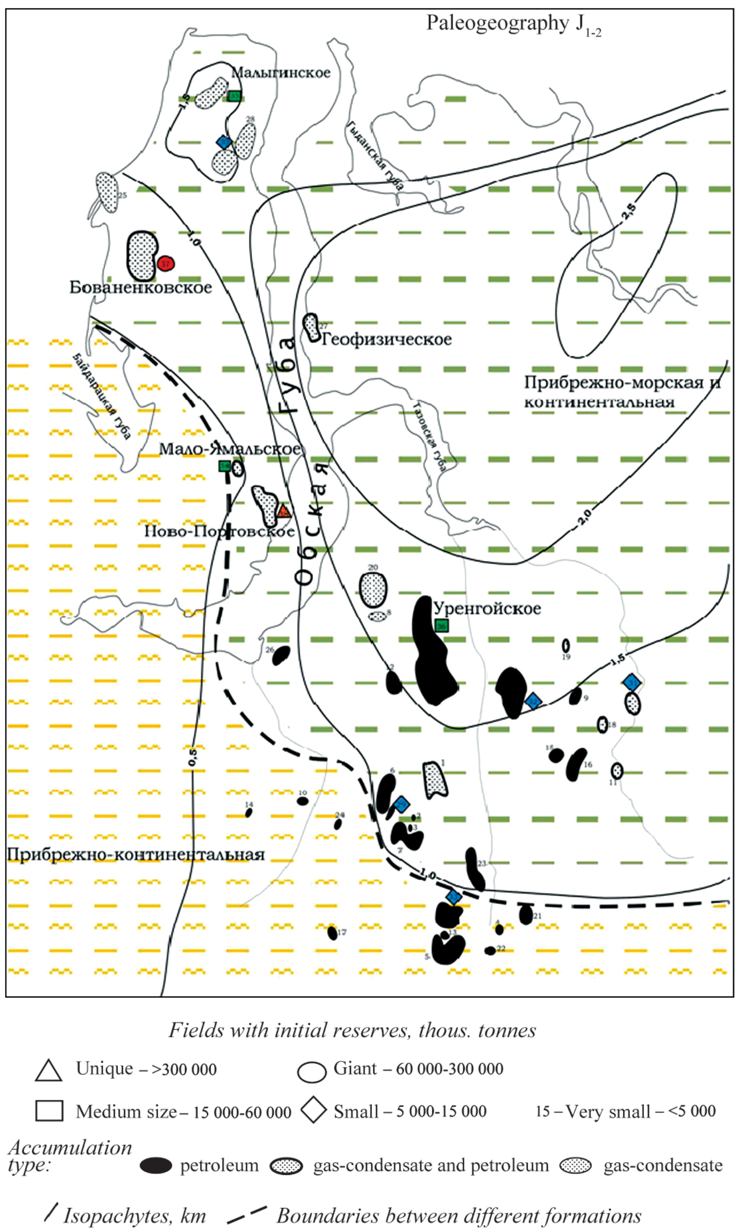

Fig. 4 Schematic map of the distribution of hydrocarbon accumulations of different phase states in the Lower-Middle Jurassic oil and gas bearing complex in connection with facies features of sediments

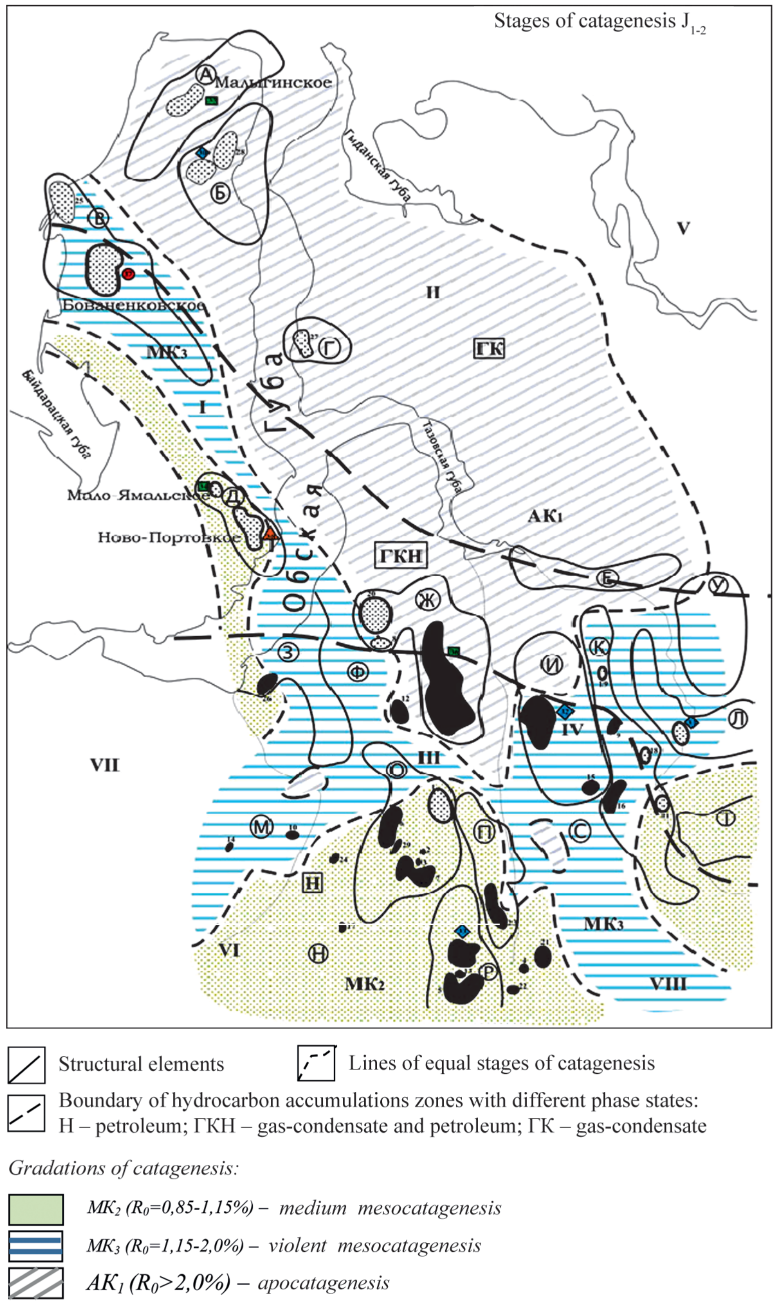

Fig. 5 Schematic map of hydrocarbon accumulations of different phase states in the Lower-Middle Jurassic oil and gas bearing complex in connection with the catagenesis of the Jurassic basal horizons. Conventional designations: fields by initial reserves and type of deposit – see Fig. 4. Oil and gas bearing areas: I – Yamal; II – Gydansky; III – Nadym-Pursky; IV – Pur-Tazovsky; V – Yenisei-Khatanga (Ust-Yenisei); VI – Sredneobsky; VII – Frolovsky; VIII – Vasyugansky. Structural elements: A – North Yamal megaval; Б – Middle-Yamal megaval; В – Bovanenkovo-Nurminsky inclined megaval; Г – Geophysical mezoval; Д – South Yamal mezoval; Е – Tazovsky megaval; Ж – Central-Urengoi mezoval; З – Medvezhye-Nuginsky inclined megaval; И – Srednepursky oblique megaprogib; К – Russian-Chasel megaval; Л – Thermokarst high; М – Nadym hemisyneclise; Н – South-Nadym megamonoclysis; О – North arch; П – Etypurovsky megaval; Р – Vyngapurovsky megaval; С – East-Pursky megamonoclinal; Т – Upper Tolkinsky arch; У – Mangazeya zone of uplifts; Ф – Nerutinsky depression.

are shown in Fig. 4. The Lower-Middle Jurassic oil and gas bearing complex in the northern regions of the West Siberian oil and gas basin is represented (Nemchenko, 2000; Rudkevich et al., 1988) by two formation series – two sandy-silty-clay formations:

- coastal-marine and continental, rhythmically-horizontal-layered;
- coastal-continental lenticular-layered.

The differences in formations are manifested in the more marine nature of the former and the continentality of the latter. Both formations are gray-colored and dark-colored, sub-carboniferous. They contain OM of humus and sapropel-humus type. The amount of C_{org} in clay and argillic varieties ranges from 2 to 3%. If the thicknesses of the first formation vary from 0.5 km in the south-west to 2.5 km in the northeast, then the thickness of the deposits of the second formation, distributed in the south-western and southern parts of the region, varies from 0.5 to 1 km. O.I. Bostrikov et al. (2012), on the Leontievskian horizon of the Tyumen formation of the Jurassic, most widely developed in the region under investigation (covering more than 80% of the territory of the Western Siberian oil and gas basin), shows the next range of changes in C_{org}: in the deposits of the deep shelf in the central part of the Yamal-Gydan region the C_{org} content reaches its maximum values (up to 3%), decreasing to the south and south-west to 1%. The type of OM is expressed by the proportion of aquatic (sapropel) components (the rest of the OM is represented by the humus terrigenous constituent of mostly higher plants). This share varies from 75% to 25%. Within the Yamal-Gydan region, the deep-sea shelf sea prevailed. Clay and clayey-aleuritic sediments with a content of aquatic components in the range of 50-75% were accumulated here. The southwestern frame of the Yamal-Gydan region is characterized at this time by sediments of the shallow shelf with a smaller content of aquatic components up to 25-50%.

An analysis of the material concerning the stage-by-stage transformation of the region's OM reveals a significant diversity of viewpoints of the researchers (Nemchenko, 2000; Fomin et al., 2001) and various patterns on the maps of the catagenetic transformation zones of OM. When constructing schematic maps of catagenesis of the Lower-Middle Jurassic and Upper Jurassic oil and gas bearing complexes, we used a map of A.N. Fomin et al. (2001) as the basis of the constructions, as the most representative, based on large factual material.

The degree of catagenetic transformation of the OM of the basal horizons of the Jurassic varies considerably over the territory and is represented by the entire catagenesis scale – from grades PC_3 to AC_{1-3}. The least transformed OM (PC_3) is observed on the western peripheral outer side of the basin. The zone of weak mesocatagenesis of OM (R_0 = 0.5 – 0.85%) is adjoined by a thin strip from the east to this region. The largest areas of the northern part of the West Siberian oil and gas basin are represented by three gradations of catagenesis (Fomin et al, 2001): the stages of MC_2, MC_3 and AC_1, i.e. moderate, severe mesocatagenesis and apocatagenesis. The schematic map (Fig. 5) shows the boundaries of the distribution zones of the three stages of the transformation of OM and associated HC fields with different reserves. Here, too, the boundaries of the zones with hydrocarbon accumulations of different phase composition are given (Vinogradova, Punanova, 2006).

Considered three stages of the catagenetic transformation of OM in the Jurassic basal horizons relate to the types of hydrocarbon accumulations corresponding to the phase state: zone of moderate catagenesis is oil deposits area; gas-condensate-oil deposits prevail in the zone of strong mesocatagenesis, the zone of apocatagenesis is a region of gas condensate deposits with a low condensate factor. The allocated zones are most likely continued in the southern waters of the Kara Sea.

Comparison of the staged catagenetic transformation of Jurassic OM with the value of the initial hydrocarbon reserves did not reveal a direct relationship between them. As was noted by many geochemists and confirmed by the study, the degree of catagenesis of OM determines the type of hydrocarbon fluid: with increasing gradations of catagenesis, the type of deposit varies from oil to gas-condensate-oil and gas-condensate.

Thus, the analysis of the spatial distribution of fields in terms of geological reserves in the Lower-Middle Jurassic oil and gas bearing complex showed a fairly clear connection with the structural features of the region. Dependence of reserve values on the paleofacial environment of sedimentation and sediment thickness, as well as on the catagenetic transformation of the initial OM, was outlined (Vinogradova, Punanova, 2006; Punanova, Vinogradova, 2006; 2008).

The common point for characterizing the oil and gas bearing complexes under investigation is the presence of sufficiently thick oil and gas source strata in each complex, which due to the catagenetic conditions (the "oil and gas window") became oil and gas producing, capable of generating large amounts of bitumen and gases. The presence of traps and low-permeability screens-tires contributed to the accumulation of hydrocarbons formed and their safety. The observed nature of propagation over the area and the section of hydrocarbon accumulations of different phase states corresponds to the evolutionary development of the strata and their original OM, i.e. stages of their catagenetic transformation: from deep pure gas deposits through transitional and oil to accumulations of protocatalogenetic gases and naphthenic condensates and oils of early generation. The established and predicted boundaries of hydrocarbon distribution zones of accumulations of different phase states in the studied oil and gas bearing complexes in the north of Western Siberia correspond to the gradations of the catagenetic transformation of the initial OM and its facies-genetic composition (Vinogradova, Punanova, 2006). The deposits of the Lower- Middle Jurassic age, containing mainly OM of humic nature (carbonaceous and sub-glacial continental formations), are classified as gas-producing, which led to the concentration of large gas and gas-condensate deposits in these sediments. The type of OM in sediments of the Upper Jurassic age is characterized as mixed, humus-sapropelic, which is a source of predominantly oil accumulations.

Thus, by the size of geological reserves, statistical regularities in the distribution of resources, their spatial distribution and the phase state of the clusters, each investigated oil and gas bearing complex of Mesozoic deposits in the northern regions of Western Siberia is independent, and the scale of accumulations is controlled by factors inherent in each complex individually. It is the tectonic, lithologic-facies and catagenetic features of the processes of oil and gas generation that control both the phase state of the deposits and the differentiation of accumulations in terms of geological resources (Punanova, Vinogradova, 2008).

The estimation of the oil-generation potential, carried out by pyrolytic methods based on drilling Tyumensky SG-6 and Yen-Yakhinsky SG-7, and also the study of samples from Paleozoic deposits of the northern frame of the Western Siberian oil and gas basin significantly changed the negative views of many researchers on the possibility of oil generation of Paleozoic OM sediments (Belokon et al., 1994; Gorbachev et al., 1996; Dmitrievsky et al., 2012; Ekhlakov et al., 2000; Kontorovich et al., 2001; Lopatin et al., 1997, 1999; Prasolov et al., 2000; Khakhaev et al., 2008; Chakhmakhchev et al., 2004; etc.).

According to the analysis of core from SG-6 within the Tyumen, Kotukhtinsky, Yagelny, Novy Urengoy and Varengayakhinsky formations, productive, medium-productive and highly productive oil and gas source rocks with increased contents of sapropel-humus type OM and bitumen are widely developed. In the Paleozoic deposits underlying the effusive-sedimentary stratum of the Triassic, the oil and gas source rocks are developed, which, in terms of productivity, are classified as productive and highly productive oil and gas reservoirs.

Studies of the core and sludge from the well SG-7 indicate that increased values of the generation potential of rocks are recorded in the deposits of the Pokursky, Tangalov, Bazhenov and Tyumen formations. The main zone of oil formation is fixed in the depth interval 2850-4700 m, in which the concentration of free and sorbed hydrocarbons (up to 1.6 mg HC/g of rock) sharply increases, the values of the productivity index and Tmax increase. The gas generation properties of the rocks are preserved up to the bottom of the sedimentary strata (6921 m). Almost throughout the entire well section, including the effusive rock complex, there is intensive migration of hydrocarbon fluids. In the Paleozoic sections of the northern frame of the Western Siberian oil and gas basin (outcrops of the Polar Urals on the Shchuch'insky outburst, the Western Taimyr and the Nizhne-Pursky swell), based on pyrolysis data on the characterization of the oil- and the distribution of HC biomarkers, strata are identified that have favorable oil-production parameters. The HC accumulation zones can be expected within structures similar to the Nizhne-Pursky swell, where these rocks are located in the main zone of oil generation, as well as in other regions where these deposits lie at considerable depths and are covered by good impermeable beds (Kostyreva et al., 2008; Boldushevskaya et al., 2008; Kiryukhina et al., 2012).

Based on the significant differences in the intensity of paleoheating of sedimentary strata in the entire territory of the West Siberian oil and gas basin with depth depending on the age of the basement consolidation (Kontorovich et al., 2008; Fomin, 2011), we predict the depths of HC generation processes in accordance with R^o and paleotemperatures. The highest generation indices of oil and gas producing sequences and greater depths of detection of oil accumulations (up to 4,200 m) can be expected in areas of Pre-Baikal basement, and Jurassic strata will be the main oil-producing strata in the areas of rigid paleo-heating. The depths of the discovery of oil accumulations here are limited to 3200 m (Table 1) (Dmitrievsky et al., 2012).

Based on the analysis of geochemical indicators, most researchers believe that the oil of the Jurassic and pre-Jurassic complex (the contact zone of the basement and the cover) form a group with a single fluid dynamic system and a common source of oil and gas formation, close in physicochemical characteristics and hydrocarbon composition. Both Lower Jurassic and Upper Jurassic deposits are recognized as petroleum deposits (Moskvin et al., 2001; etc.). However, the comparison of the contents of the biophilic elements V,

Cycle of basement consolidation (Kontorovich et al, 2008; Fomin, 2011)	**Main areas of accumulation (Kontorovich et al, 2008; Fomin, 2011)**	**Temperature gradient**	**Probable lower boundaries of HC generation, m**	
			of oil	of light oil and GC
Pre-Baikal	Prienisesky, part of the Mansiysky syneclise, Surgutsky and Nizhnevartovsky arches	Low	4200	5200
Gercinsky, Caledonsky	Central and South-East parts of West Siberia	Medium	3650	4400
Triassic reefs, granitoid massif and fluid-conducting faults in basement	Shaimsky, Krasnoleninsky and others arches	Intense	3200	4050

Table 1. Estimated depths of oil and gas generation processes

Ni, Fe, Mo, Cu in oil and bitumen of the Shaim region with the data on rare-earth elements (REE) (Fedorov et al., 2010) on the Khanty-Mansiysk, Danilovsky, Lovinsky, Martymya-Teterivsky, etc., attests to the essential difference between the Paleozoic naphthids and the weathering crust from the Jurassic ones. Also, sharp differences in the oils of the Jurassic, Triassic and Paleozoic complexes according to ME indicators are evident in the Nyurol region (Punanova, 2002). All these facts are probably connected with the presence of local foci of oil formation in the Paleozoic and pre-Jurassic deposits. These data confirmed the conclusions made by us on the basis of thermolysis of Bazhenov deposits. Thus, when comparing the hydrocarbons and ME compositions of naphthys of the Jurassic and Paleozoic complexes, it is concluded that there are two possible sources of oil generation. This syngenetic OM of the sedimentary Paleozoic and OM, generated by Jurassic sedimentary and Triassic volcanic-sedimentary deposits.

Conclusion

In connection with the sharp heterogeneity of the structure in exploration areas and fields in dense massive rocks, expressed in a "chaotic" distribution of reservoir rocks with different filtration-capacity properties and oil and gas inflow zones, it is necessary to take a new approach to choosing the location and depth of the designed wells on promising areas. At the stage of preliminary drilling of exploratory wells, it is necessary to conduct seismic operations using scattered waves, which allow detecting in the zones and areas of increased energy of scattered waves, i.e. reservoir rocks. Moreover, zones with the maximum energy values correspond to the section intervals with the best reservoir properties of the reservoir rocks and the maximum oil rates in the wells. This technology can be used in the low-permeability strata of the Bazhenov formation.

By the features of the OM distribution in the sediments of the Bazhenov formation of the Western Siberian oil and gas basin and in the black shale formations of other regions, the zones of introduction of highly transformed epigenetic bitumen, catagenically altered by deep processes, have been identified. In our opinion, it improves the prospects of the oil and gas potential of the region under study at the expense of the additional source of hydrocarbons, besides the OM of the Bazhenov formation itself. These sources can be associated with oil-producing Jurassic (Vasyugan and Tyumen formations) and deep-buried pre-Jurassic sedimentary deposits – Triassic and Paleozoic.

Summarizing the rather extensive material, it can be stated that a number of the facts revealed that it is possible to assess the prospects of the Jurassic and deeply buried pre-Jurassic deposits of the Western Siberian oil and gas basin from a new perspective. Such new arguments include traced zones of highly transformed OM in the bitumen of the Bazhenov formation, indicating the presence of generation foci in the underlying sedimentary strata, geochemical data on in situ oil formation processes in the Paleozoic complex, favorable geochemical conditions of pre-Jurassic deposits, which is expressed in relatively high Corg content and bitumen, in moderate and sufficient catagenetic heating of subsoil, high realized generation potential. In combination with other geological prerequisites – reservoirs and impermeable beds, the studied sediments can be considered as a promising object for the discovery of oil and gas fields in it. Moreover, the most promising areas are the epigenetic migratory bitumen zone that extends through the Yugansky depression, the Koltogorsky basin, the Salymsky uplift and further north-west to the Yamal Peninsula and possibly to the Kara Sea. The new arguments give an additional impetus to the wide deployment of scientifically grounded work on the Jurassic and deep pre-Jurassic horizons of the West Siberian oil and gas basin – the lower floor of the oil and gas bearing both within its northern part (Ob, Taz and Gydan Gulfs) and in marine areas that will confirm the predictions the founder of oil geology acad. A.A. Trofimuk, that Paleozoic oil in Western Siberia really is the "gold substrate" of its Mesozoic wealth.

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