JUSTIFICATION OF OIL AND GAS POTENTIAL OF THE JURASSIC-PALEOZOIC DEPOSITS AND THE BASEMENT FORMATIONS OF WESTERN SIBERIA

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Abstract. In terms of perceived decline trend of oil production and reserves increment from the 'conventional' Cretaceous and Upper Jurassic deposits of the main region of Russian hydrocarbon production – Western Siberia, the paper considers oil and gas potential of the Jurassic-Paleozoic sediments and, mainly, the basement formations. It is the basement, along with deposits of the Bazhenov Formation, which is associated with a possible significant increase in resources of oil (gas) in Western Siberia.

In assessing the prospects for the oil and gas potential of the basement, the focus in the research was paid to the study of the structure, including reservoir properties of reservoir rocks and geochemical conditions of oil (gas) deposits formation. According to the assessment we suggested the most favorable directions of exploration, separate forecast for hydrocarbons is made.

Keywords: Western Siberia, basement, pre-Jurassic deposits, deposits of oil and gas, oil and gas potential, reservoir rocks, geochemical conditions, microelements, oil generating potential

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Russia's economic security has been based in recent years on the oil and gas industry, at the expense of which more than half of the country's budget is formed. This trend will probably continue in the coming decades.

Oil production is increasing year by year, at that increasing exports of oil (together with petroleum products), which in 2015 increased by 27 million tons and reached 416 million tons. The growth of oil and gas production makes it necessary to increase oil and gas resources and reserves.

Western Siberia is one of the main regions of Russia for oil and gas production. Replenishment of oil and gas production by increment of reserves and resources in Western Siberia is one of the main tasks of the country's oil and gas industry in the near future for 20-30 years.

In Western Siberia, the main oil reserves are concentrated in the Cretaceous and Upper Jurassic deposits. The promising new objects (areas of exploration works) include basal layers of the Lower and Middle Jurassic and thinning areas of Jurassic horizons (in the north of the territory), sedimentary and volcano-sedimentary rocks of Triassic filling graben-like depressions (here a large Rogozhnikovsky oil field has been discovered), formation of the weathering crust and areas of decompressed basement rocks.

Petroleum potential of the pre-Jurassic complex of Western Siberia has been enlightened in a significant number of publications, including (Schuster, 2003; 2008; Schuster, Punanova, 2011; 2013; 2014; Schuster et al., 2011;. 2014; Punanova, Schuster, 2012; Dmitrievsky et al., 2012; Schuster, Dzyublo, 2012).

Pre-Jurassic complex of Western Siberia has three subcomplexes (Table 1).

Subcomplexes	Age	Lithology	Type of cavernosity	Occurrence depth (km)
Transition subcomplex	Trias, Upper Permian	volcanic-clastic rocks (turin series), limestone and dolomite	porous-vuggy	1,5-2,5
Folded basement	Palaeozoic	metamorphic, magmatic dislocated rocks	fractured-cavernous	1,6-3,0
Consolidated basement	Archean-Proterozoic, in the middle of the basin – suboceanic (Triassic)	magmatic (with predominance of granitoid)	fractured-cavernous	5-6

Table 1. Schematic section of the pre-Jurassic complex of West Siberia.

In the transition complex on Krasnoleninsk swell, a number of oil fields was discovered in Nurolsky trough, including secondary reserves in the Triassic (Permian-Triassic) deposits in volcanic-clastic, carbonate rocks. The band of Triassic deposits stretches 1000 km long from Krasnoleninsky arch by a wide strip to the northwest of Western Siberia, the area of which is promising for oil and gas.

In the north of Western Siberia in the context of deep horizons, oil and gas potential is associated with sandy-silty sediments in Lower and Middle Jurassic and weathering crust at a depth of 3-4 km (Schuster, 2014).

Oxford and Bathonian rocks have the best reservoir properties. Carbonate deposits of Malyshev complex (J_{2-3} formation) at a depth of 3950 m (absolute elevation), apparently have regional oil and gas bearing.

On Nurminsky, Obruchevskt and Rusanivsky megaswells, in the waters of the Gulf of Ob significant prospects of finding hydrocarbon deposits are associated with both Lower-Middle Jurassic and Paleozoic sediments.

On the border of sedimentary cover and the basement in Western Siberia more than 50 deposits of oil (gas) have been discovered and, in addition, about 50 signs of oil have been obtained.

A significant contribution to the study of geological structure and oil and gas potential of the basement was introduced by a number of Russian (Soviet) and foreign researchers, in the first place, the French geologist Ragen (1979), R.Kh. Muslimov (1996, 2014) and the geologists of his school; M.N. Osipov (1982) and others.

With a relative degree of certainty about the oil and gas potential in the basement, the following is known to date (although a number of provisions are still being debated)

- Global oil-bearing of the basement;
- Complex heterogeneous geological structure;
- Sharp variation in area and section of reservoir properties and oil saturation of rocks;
- On a number of oilfields reservoir properties of rocks (and oil saturation) are preserved in the section of wells in the basement rocks at great depths from the surface (up to 2 km on the field White Tiger, Vietnam);
- We have proposed a possible mechanism for the formation of petroleum accumulations in the basement: due to the migration of petroleum hydrocarbons from the adjacent to the basement sedimentary source strata, enriched in dispersed organic matter; on an alternative version – oil fields in the basement are formed by deep fluids;
- Confining beds for hydrocarbon deposits in the basement can be both regional clay-argillic and carbonate rocks (as in Western Siberia), and zonal or local low-permeable granitoids (White Tiger field) and/or volcanic rocks;

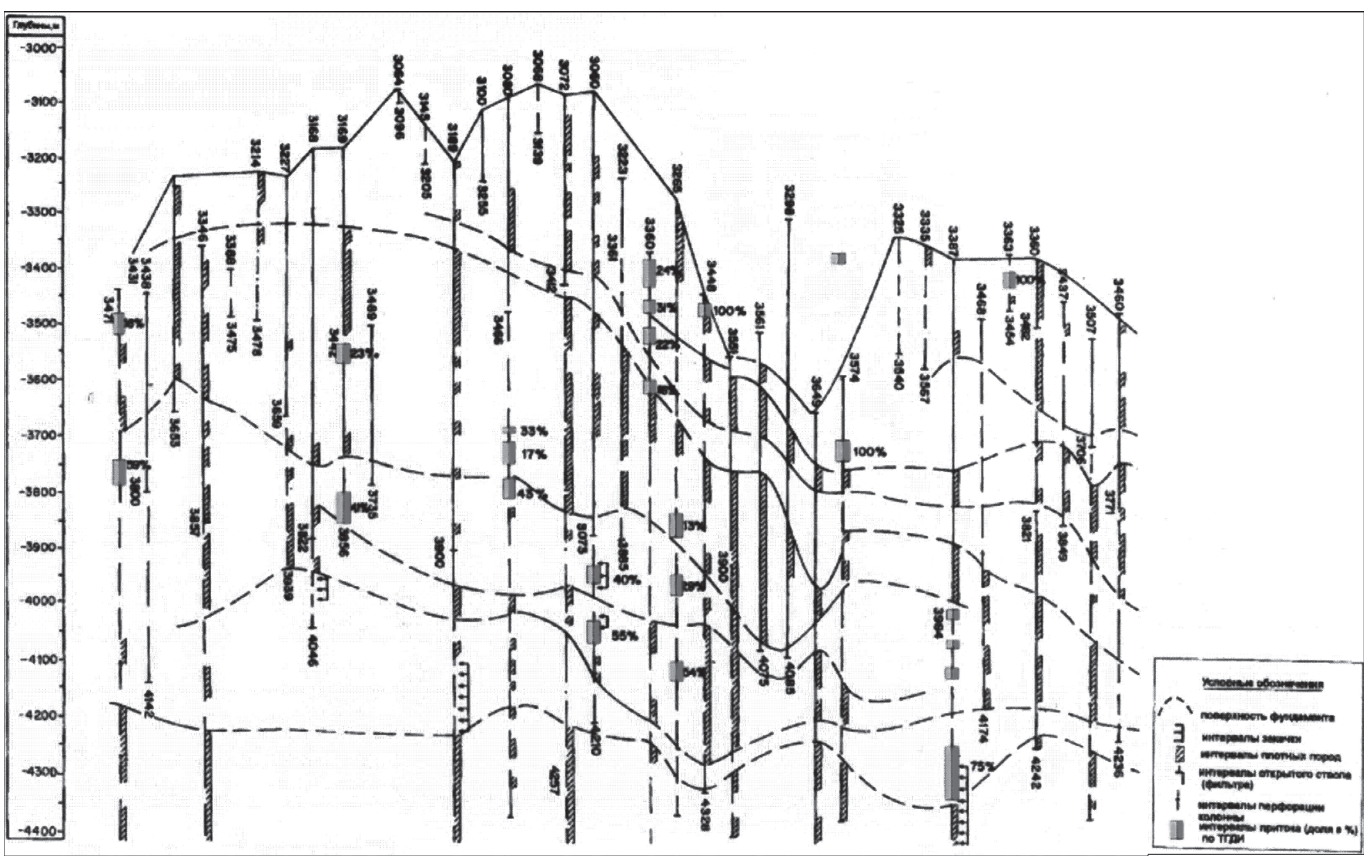

Figure 1. The White Tiger field. Microinhomogeneity of the fractured reservoir (3D seismic survey, logging, field-geological and hydrodynamic data) (Schuster, 2003).

- A sufficiently high hydrocarbon generating potential of sedimentary source strata that clothe the basement ledges in Western Siberia, allows us to evaluate the prospects of the basement as favorable for the formation of large oil and gas accumulations.

New geological-geophysical and geochemical data on deep horizons in Western Siberia, as well as modern innovative technologies of the interpretation of these materials allow with sufficient certainty to justify the high oil and gas potential of the Lower (pre-Jurassic) floor, including the basement formations.

Let us consider two of the most controversial and important geological factors in the assessment of oil and gas potential in the basement structures. They include disribution in the basement of reservoir rocks (and their oil saturation) and geochemical assessment of hydrocarbon generating potential of sedimentary source strata that clothe the basement ledges.

The authors studied in detail enough materials for Vietnamese oil fields in the formations of the basement in the period of work in the Russian-Vietnamese joint venture (1991-1995) in Vietnam. A possible mechanism of formation of oil deposits in the basement was justified in the White Tiger field, a model of this field structure (Schuster, 2003). Sharp filtration-capacitive heterogeneity in the structure of granitoid massif and sporadic oil-bearing of the deposit has been established (Figures 1,2). The following features of the crystalline basement structure have been defined.

As a result of non-uniform cooling of the pluton, tectonic processes that occur periodically during the granite massif existence, the impact on the emptiness of deep corrosive solutions and other geological factors, modern filtration-capacitive properties of the basement in the White Tiger field, revealed in drilled wells, are characterized by abrupt changes both in the well section, and area of the structure.

Moreover, the emptiness of rocks as a rule is fractured or fracture-cavernous, and distributed very unevenly to a considerable depth from the surface of the basemenet, up to 2000 m in some areas (Figure 1). The same pattern has been set according to a large factual material in Tatarstan by R.Kh. Muslimov (1996). Another feature of the basement structure established in the White Tiger field – is detection of the first reservoir rocks in the great depth (300-500 m on average) from the basement surface in some areas of oil deposits (in particular in the Northern swell of the White Tiger field, and also on the fields Kyulong, Dayhung, Vietnam).

This phenomenon can be attributed to uneven cooling of the pluton, faster on contact with the 'cold' sedimentary rocks, processes of weathering and the influence of deep hydrochemical solutions that 'heal' the fractures and cavities.

In addition, an important feature has been revealed of the distribution of oil saturated intervals in the basement deposits. In more than 20 wells thermohydrodynamic studies were conducted, in which intervals were identified of oil inflow into wells. In tested 500-800 meter parts of the section, 20-40 meter intervals of oil inflow were discovered in open hole, which were confined to the main part (60-80 %) of oil production rate of the well.

That is, in the basement thickness, zones or areas of maximum oil content were propagated (Figure 1). Seismic survey 3D CDP, held on the White Tiger

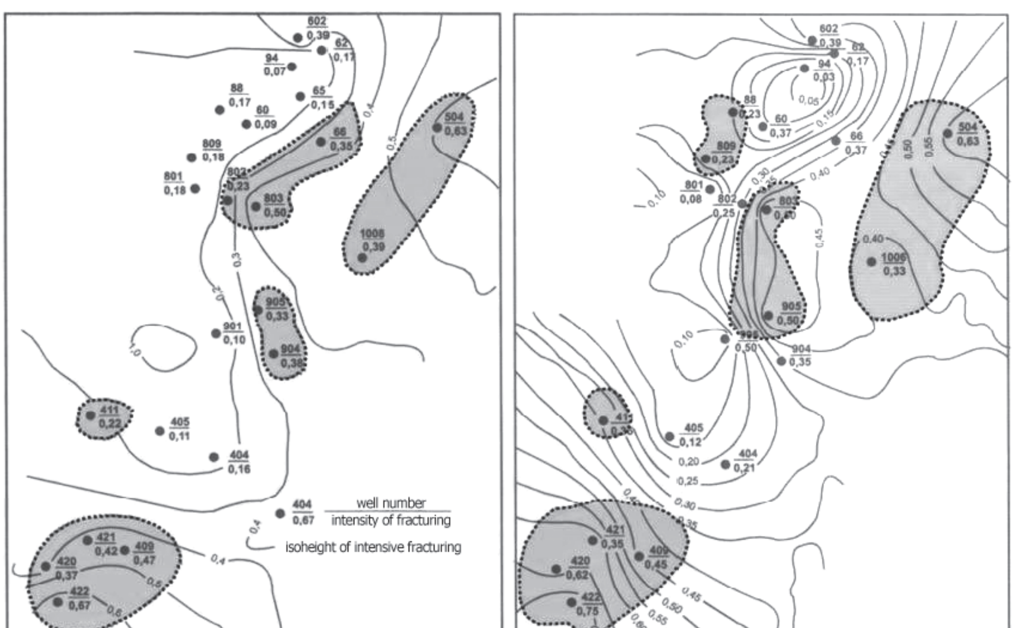

Figure 2. The White Tiger field. Distribution of fracturing in the basement rocks: a) distribution of the fracturing intensity in the penetrated basement (VING data, 1994), b) distrbution of the fracturing intensity in the range of 200 m below the basement roof (VING data, 1994).

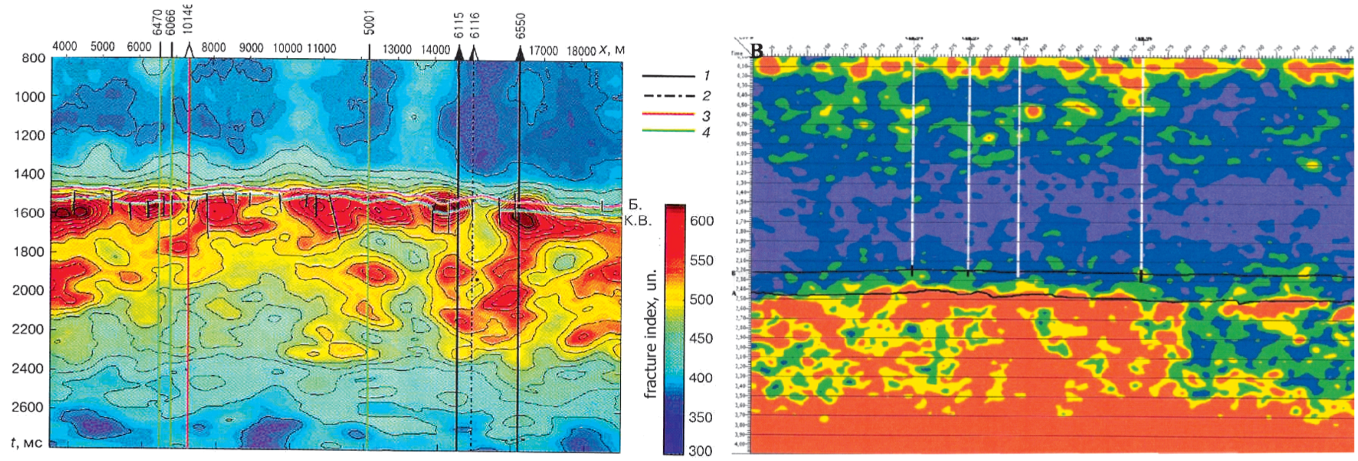

Figure 3. A) Vertical section of the fracturing field along the line with the sustained well test results of the weathering crust: 1 – oil inflow; 2 – oil film; 3 – dry; 4 – the test was not conducted. North-Danilovsky field (Kuryanov et al., 2008). B) Section of the scattered waves energy obtained by the wave CDP method. Ust-Balyk field (Kremlev et al., 2008).

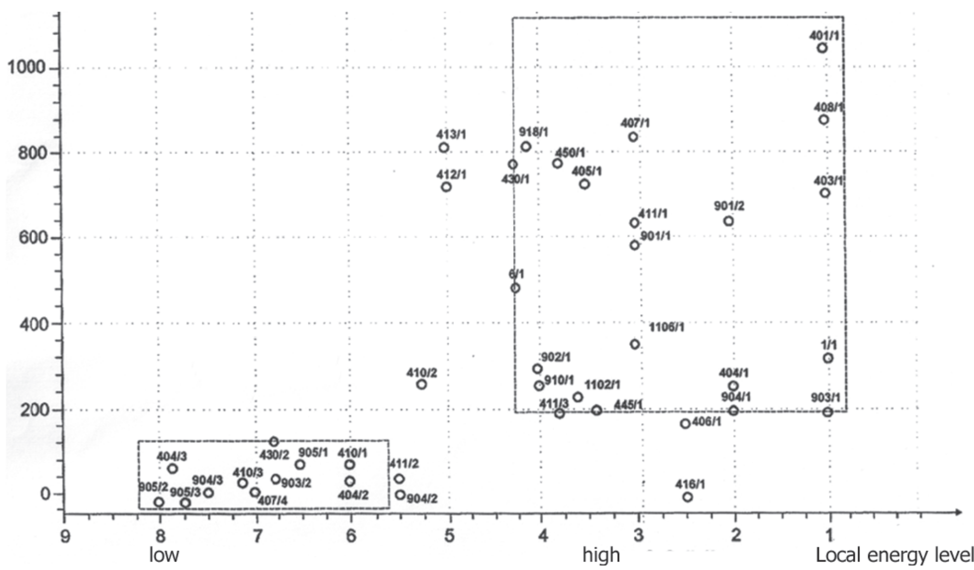

Figure 4. The relationship of the scattered component local energy of the seismic field and reservoir properties (flow rates).

field, allowed in the 1990s to map only the surface (propagation depth) of reservoir rocks. The internal structure of the strata was provisionally mapped by drilling data (logging, core, well testing results).

We have named such a model an uneven-cellular (Schuster, 2003). Assummed structure model can easily be adapted to the conditions of Western Siberia.

In Western Siberia, on numerous oil fields and newly drilled ultradeep wells (SG-6 and SG-7) as well as by core, logging materials, cavernous-fractured, fractured-cavernous-porous space is established, not only in the upper part of the basement (the weathering crust), but in decompressed rocks located at greater depth, below the basement surface (Khakhaev et al., 2008; Kurysheva, 2005). New seismic technology (using the scattered waves) allow today to map the zones and areas of reservoir rocks distribution in the interior of the basement (Figures 3, 4).

The uniqueness of this new seismic technology is determined by the fact that these waves are a response from clusters of irregularity pluralities, which are the fractures and cavities filled with gas or fluid on the falling edge of the elastic wave. The main feature of the scattered waves is their low intensity relative to other types of waves recorded during the seismic survey.

Over the last 10-15 years a number of different technologies for identifying weak scattered waves were developed by local geophysical groups on the background of reflections from extended horizons commonly used in seismic survey (Kuznetsov, 2004; Shlenkin et al., 2000; Kozlov, 2004; Pozdnyakov, 2004; Levyant, Schuster, 2002; Kremlev et al., 2008).

The effective parameter common to all methods is the energy of scattered waves. We (V.B. Levyant and V.L. Schuster) had used in the 2000s this method successfully on materials from Vietnam and India. For Vietnam data in recommended wells a significant flow rates of hydrocarbons were received. Relationship of oil production rate and local energy level is shown in Figure 4.

Focusing on the 'volume' of these zones and their location, we can reasonably predict petroleum potential in objects (ledges) of the basement (Kuryanov et al., 2008; Kremlev et al., 2008; Shlenkin et al., 2000).

In addition, based on the experience of exploring oil in the basement, including in Vietnam (Schuster, Takaev, 1997; Schuster, 2003), where the best reservoir properties in the basement are confined to acidic crystalline rocks (granitoids, adamelites), we can recommend the basement ledges with granitoids in the core as the priority objects (such a 'strip' of acid rocks is distributed in Shaim arch).

No less controversial and one of the important factors for justifying the petroleum potentional of the basement is the hydrocarbon potential of sedimentary source strata that clothe the basement ledges.

An analysis of the factual material and publications allowed us to join the point of view of scientists who believe that the main source of oil in the basement deposits is the OM of oil source sedimentary strata that clothe and adjacent to the basement. In some fields, where oil deposits were discovered in the basement, a number of indicators mark a close relationship of these oils with oil from sediments overlying sedimentary cover (Schuster et al., 2003). Thus, in the White Tiger field, oil extracted from deposits in the basement and in the Lower Oligocene, are characterized by close values of almost all the studied parameters.

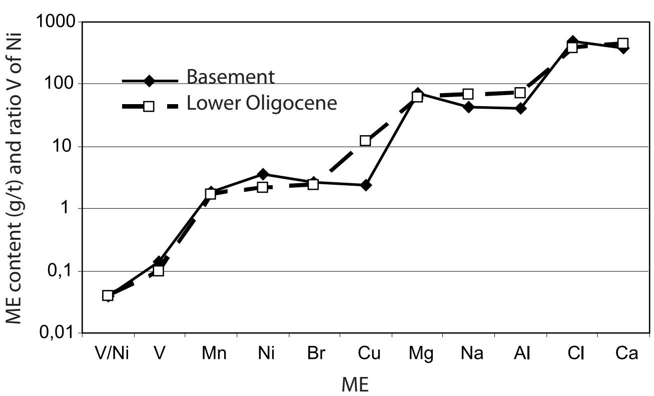

Figure 5. ME content in oil of the White Tiger field

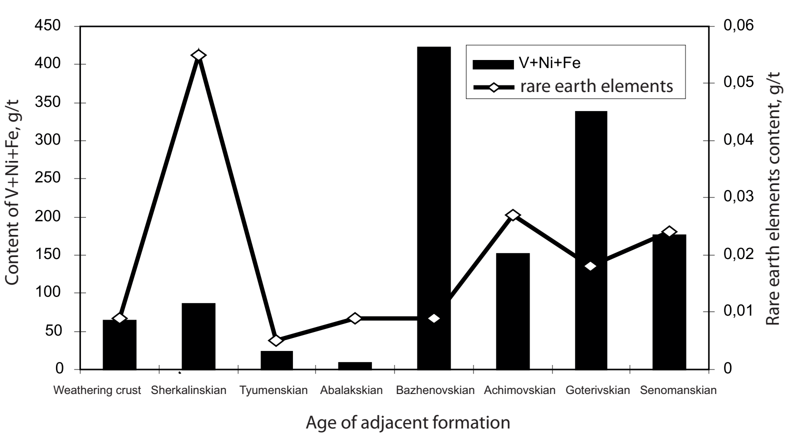

Figure 6. The distribution of elements in oil of Shaim area (data according to rare earth elements (Fedorov et al, 2010)).

This applies to the microelemental composition of oil (definition of microelements is given by Dalat Nuclear Research Institute, Vietnam). We drew attention on the presented Figure 5 on particularly indicative closeness of the oils on the genetic indicator – the ratio V of Ni, which in oil from sediments of the basement and Oligocene is significantly lower than one. Ni predominance over V describes the oil as the catagen converted.

Studying the composition of hydrocarbons (alkanes, terpanes and steranes) in the White Tiger field and organic matter from the deposits of fractured crystalline basement (Serebrennikova et al., 2012) revealed their fundamental difference. According to biomarker indicators these researchers have found that the source of oil was organic matter of mied coastal-algal and surface material of oxidation facies, and in addition, hydrocarbon composition shows a high degree of conversion of these oils.

Assessment of oil and gas potential in pre-Jurassic complex of West Siberia was carried out on a number of key geochemical parameters – the content and type of OM, staging of katagenesis, characteristic of generational kerogen abilities. Based on the analysis of hydrocarbon and microelemental characteristics of naphthides, it is concluded that there are two sources of oil generation, able to saturate the formation of the basement.

They are syngenetic organic matter of the sedimentary Paleozoic and epigenetic, generated organic matter of the sedimentary Jurassic and volcanic-sedimentary Triassic deposits. A significant difference in content of microelemental naphthides of Paleozoic and weathering crust of Jurassic sediments indicates on a separate center of oil formation in Paleozoic formations (Dmitriev et al., 2012;. Punanova Schuster, 2012).

This is especially fixed by comparing the content and ratio of biophilic elements of iron groups (V, Ni, Fe, Mo, Cu, of Zn) and rare earth elements (Fedorov et al., 2010) in oils and bitumen on fields of Shaim and adjacent regions (fields Khanty-Mansiysky, Danilovsky, Novinsky, Martymya-Teterevsky, etc.) (Figure 6). When comparing the concentration distribution in oil of various oil and gas complexes of the Shaim region, we have established a variety of accumulation trends of these groups of elements. It seems that such a distribution of micro elements in naphthides is explained by polygenic nature of their revenues in oil – from organic matter of oil-producing strata for biophilic and deep for rare earth elements.

Polygenic nature of micro elements source in oil was previously identified (Punanova, 2004). The presence of zones of high OM transformation in the pre-Jurassic deposits, confined to the linear elongated Triassic rift

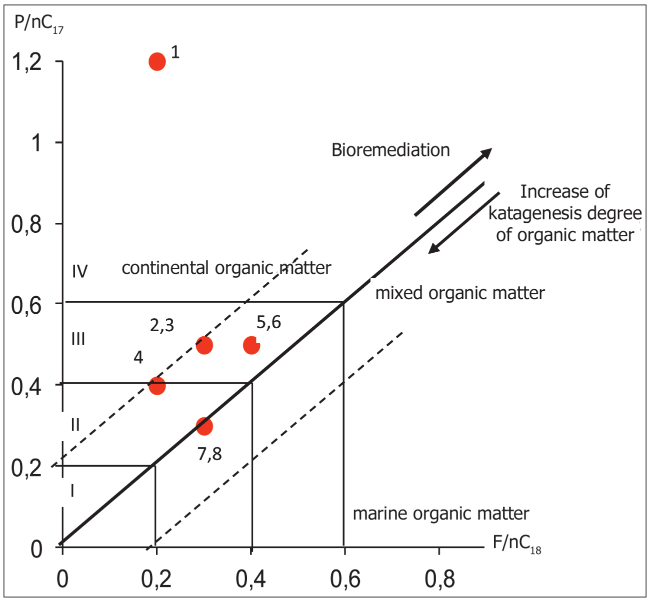

Figure 7. The ratio of isoprenoids and normal alkanes as an indicator of the thermal maturity of rocks and organic matter (chart of Connan-Gassou). Areas: 1. Malyginsky (Ach.); 2. Syadorsky (Ach.); 3. Tarminsky (J_{1-2}); 4-6. Kharasaveysky (J_{1-2}); 7-8. Bovanenkovo (J_{1-2}).

in the basement and large granite blocks and/or fluid-conducting faults (Kontorovich et al., 2008; Fomin, 2008) contributes to these processes.

Evaluation of hydrocarbon potential from the geochemical position is based on the isolation in the section of oil and gas source strata, which in a first approximation are fixed by the generating capabilities of oil and gas source deposits is determined by the results of the analysis Rock-Eval, reflecting the content and composition of organic matter and the nature of

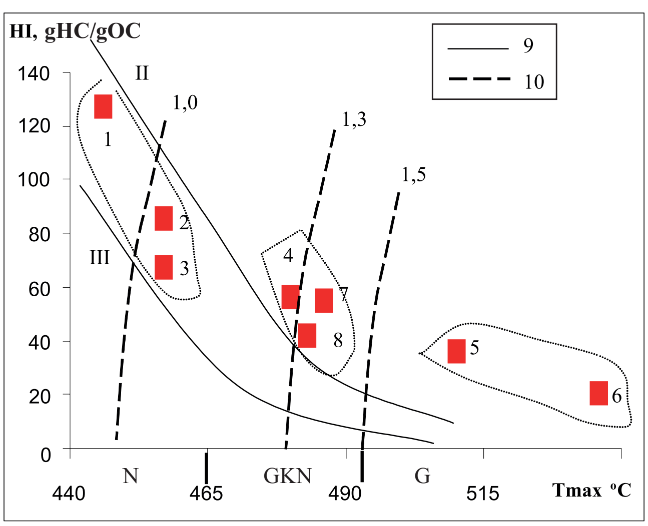

Figure 8. Dependence of hydrogen index from Tmax. Areas: 1. Malyginsky (Ach.); 2. Syadorsky (Ach.); 3. Tarminsky (J_{1-2}); 4-6. Kharasaveysky (J_{1-2}); 7-8. Bovanenkovo (J_{1-2}). Legend: 9 – lines, separating the facies-genetic types of OM (II and III), 10 – contour lines of vitrinite reflectance (R_0) values. Zones of hydrocarbon accumulations: N – oil, GKN – gas condensate-oil, G – gas.

catagenetic transformations. Study of catagenetic staging of organic matter is a necessary tool for geochemical evaluation of hydrocarbon potential, and in the first place, it refers to the deep, heterogeneous, sometimes dislocated Paleozoic deposits of the West Siberian oil and gas basin.

During katagenesis oil formation in significant scale starts from the end of PK_1 gradation, and goes to the middle of mesocatagenesis – MK_2. In the end of protocatagenesis bitumen formation sharply increases, in mesocatagenesis reaches its maximum intensity and later gradually fades as the depletion of oil source potential of organic matter. Interval of katagenesis scale from PK_3 to MK_2 (R_o = 0.4-l.15) is identified as the main phase of oil generation.

It corresponds in the sedimentary basins section to the main zone of oil generation (Vassoevich, 1967; Kontorovich et al., 1967). In this range of katagenesis gradations, processes of petroleum hydrocarbons formation are predominant over their destruction. Interval of katagenesis gradations from MK_{31} to AK_1 stands out as the main phase (zone) of gas generation.

Overall evaluation of the thermal maturity and type of OM was held by the ratio of isoprenoids and normal alkanes – Connan-Gassou chart (Figure 7). It is known that with increasing catagenetic conversion of organic matter therein increases the content of normal alkanes and the number of isoprenoid hydrocarbons falls. The graph conditionally allocates areas of abnormally high, high, moderate and low maturity of organic matter, as well as areas of mixed, sapropel and humic agents. The basic amount of samples falls into the moderate katagenesis zone and is characterized by mixed type of organic matter.

With increase of depth of sample occurrence (East-Bovanenkovo area, Lower Jurassic) the degree of organic matter conversion increases (high maturity zone) and the type of organic matter becomes more sapropel. On P/nC_{17} sample significantly stands out from the Achimov deposits of Malyginsky area. It is characterized by a lower conversion and humus type of OM. This is also evidenced by the higher ratio of pristane to phytane – 3.8. A second sample from the Achimov deposits of Syadorskaya area on the studied parameters in not significantly different from the Jurassic deposits.

To assess the possible oil and/or gas bearing an indicator Tmax is commonly used (maximum temperature of hydrocarbon output from the rock during its warming with the device Rock Eval) indicating the stage of OM evolution and generation of liquid or gaseous hydrocarbons (Kiryukhina et al., 2011). Figure 8 shows a dependence graph of the hydrogen index HI from Tmax taking into account the types of organic matter and R0 values. Comparative analysis of the graphic material allows locating three groups of points.

The first group corresponding to the Achimov deposits and the top of the Tyumen suite is characterized by an interval Tmax of 446 to 457 °C, which corresponds to the area of the ‘oil window’.

Organic matter of Tyumen formation sediments (the second group of points) is characterized by a small scatter of values Tmax (from 480 to 486 °C), which gradually, with increasing the depth of occurrence, reaches very high values – 536 °C. Generation zone of gas-condensate-oil accumularions (East-Bovanenkovo area) is replaced by gas generation area (Kharasaveysky area). As the Tmax increases, HI values drop and the organic matter is classified according to this indicator, as lean, exhausted, lost its generting properties.

The conclusions drawn on the basis of hydrocarbon composition of dispersed organic matter involving pyrolysis data are confirmed by the analysis of the dependence of Tmax from the depth in various areas.

Comparison of geochemical assessments of Lower-Middle Jurassic and Triassic deposits of the Yamal Peninsula areas with the findings that were obtained previously according to estimates oil and gas potential of deep deposits of Nadym-Taz oil and gas region, has revealed the following. Deposits of the top of the Tyumen suite, studied in detail on the materials of ultradeep Tyumen well (SG-6) are located, as well as on the Yamal Peninsula, in the final stages of oil formation, and its lower classes and the underlying sediments of the Lower Jurassic fall into the zone of gas condensates and gas generation.

Differences lie in the fact that the depth of the main zone of oil generation in these different tectonic zones is on a completely different elevations. If on Urengoy uplift the lower boundary of the main zone of oil generation is recorded at a depth of 4250 m, at Urengoi and Tyumen, Samburg and Geological areas – up to 4750 m, then at the Yamal this boundary is raised much higher: up to 3000 m for the Tyumen Formation on the Kharasaveysky area and up to 3800-4000 m in Tyumen deposits on the Tarminsky area and Achimov deposits on the Malyginsky and Syadorsky areas (Chahmahchev et al., 2003; Punanova, Schuster, 2012).

Triassic sediments occurring in deep depressions and not everywhere in the studied area are penetrated on the East-Bovanenkovo and Bovanenkovo areas. By analogy with the well-studied Triassic deposits of the Urengoy ultra-deep well on the territory of Yamal they can be attributed to the gas generating. The depth of the Triassic deposits is 3-4 km. In the Yamal Peninsula the Lower-Middle Jurassic deposits of the Tyumen suite are attributed to the petroleum generating strata. They contain organic matter of a mixed sapropel-humus type (II-III type of kerogen).

On the territory of the Yamal Peninsula and the adjacent shelf most of the Lower and Middle Jurassic deposits are in the gas generation zone, that along with mostly humus type of OM provides extensive development of gas generation processes (Skorobogatov et al., 2003; Skorobogatov, 2014).

Thus, given the large productivity of the Lower and Middle Jurassic deposits and a favorable geochemical environment of pre-Jurassic deposits of the northern regions in the West Siberian oil and gas basin (relatively high content of organic carbon and chloroform bitumoid), high realized generation potential (moderate and sufficient katagenetic warm up of the bowels), in conjunction with other geological prerequisites (reservoirs and confining beds), studied sediments can be regarded as highly promising objects to discover new oil and gas fields.

In Western Siberia, the most favorable conditions for oil and gas accumulation have erosion tectonic ledges of the basement with granitoids in the core, divided into blocks (riftogenic geodynamic regime) and clothing sedimentary rocks that play the role of confining beds and oil source strata.

Confining beds for deposits of oil (gas) in the basement formations of Western Siberia can be Jurassic clay-argillic, carbonate confining beds and low-permeable basement rocks at the top of the crystalline arrays.

For the most of studied areas, where commercial and non-commercial oil flows were produced from the upper part of the section (weathering crust) – 50-100 meters, we have processed the actual material on 72 areas and, using geological and mathematical programs, have given the outlook for oil-bearing of deep basement horizons (Schuster, Punanova, 2013; 2014; Schuster et al., 2014; Bogoutdinov et al., 2015). When processing data in different programs – geological and mathematical program ‘Vybor’ and using fuzzy logic algorithms, we have obtained similar results. The most promising were exploration areas in the Krasnoleninsk swell and Shaim arch.

Conclusions

Using the new features of the basement heterogeneity mapping and isolation of reservoir rocks distribution zones and areas, as well as the evaluation of hydrocarbon generating potential of sedimentary source strata, that clothe ledges of the basement, we can reasonably allocate perspective objects in the basement, specifically choose the location and depth of project wells.

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