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New data on oil and gas potential of the Vychegda trough

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Abstract. This article is devoted to the problem of studying the petroleum potential of the underexplored territories of the European part of Russia, in particular, the Vychegda trough. Taken a new approach to assessing the hydrocarbon potential of the Vychegda trough, based on the allocation of petroleum systems, widely used abroad. Based on a comprehensive analysis of the geological structure of the deflection and geological-geochemical results, including those obtained by the authors, two potential petroleum systems – "domanik" and "riphean" – were identified.

The potential domanik petroleum system dominates in the Eastern regions and is a peripheral fragment of the regional petroleum system covering the territory of the Volga-Ural and Timan-Pechora basins. The system is linked to development in the South-Eastern part of the trough and the neighbouring Solikamsk depression of bituminous domanik and domanikoid sediments as a source rock, which is confirmed by the genetic correlation of crude oils of Devonian-Carboniferous deposits of the Northern districts of Solikamsk depression with domanik biomarker. The stratigraphic range of the domanik system is upper Devonian-upper Permian; the formation time is late Devonian-Mesozoic.

The potential Riphean hydrocarbon system can be identified by the fact of oil-bitumen occurrences in the Proterozoic strata and the presence of the productive source rocks in the upper Riphean. The source rocks were at oil window. The Riphean system can cover the entire territory of the Vychegda trough, and the section from the Riphean to upper Permian sediments. The time of the system formation – Riphean-Mesozoic. Due to large thickness of the Riphean sediments, even with a large loss of hydrocarbon potential, the residual potential hydrocarbon resources of the Riphean petroleum system can be very significant.

Based on the research conducted, prioritized exploration studies are substantiated.

Keywords: Vychegda deflection, petroleum system, domanik sediments, source rocks, generation potential, oil and gas potential

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Introduction

Vychegda trough, located between the Timan ridge and the Volga-Ural anteclise and characterized by a significant thickness of a sedimentary cover, in recent years increasingly attracted the attention of geologists as perhaps a promising area for oil and gas exploration. Geological structure and petroleum potential of the Vychegda trough and adjacent areas is discussed in several summarizing published and unpublished works of P.E. Hoffman, A.V. Kuraev, B.P. Elokhina, N.A. Nikonov, T.I. Shilovskaya, A.P. Shilovsky, B.P. Bogdanova, O.V. Merkulov, R.Z. Chenborisova, N.T. Fortunatova, etc. Systematic and targeted regional seismic and geological-geochemical studies of the deflection were not carried out. Drilling is limited to a small number of wells, of which only three have opened Riphean formations. Individual details of the reservoirs parameters, the content of the C_{org} and bitumens in rocks and hydrocarbons presented in unpublished materials of the Timan-Pechora research centre (Uhta), Institute of Geology (Syktyvkar, Russia), KamNIIKIGS JSC) (Perm) and other organizations, as well as in the publications and dissertation work (Bazhenova et al., 2014; Kuzmin, 2006).

Methods

In this paper, a new approach to assessing the prospects of oil and gas potential of the the Vychegda trough, based on the allocation of petroleum systems, widely used abroad (Barnaby, 2006; Mancini, 2006; Albrandt et al., 2005, etc.). Oil (hydrocarbon) systems in oil and gas geology have been distinguished relatively recently. The classification was based on the study of their various elements. In foreign practice, for example,

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the classification of US hydrocarbon systems (Magoon, 1989) was carried out taking into account the different composition of reservoirs (siliceous/carbonate), or by different types of kerogen, types of traps, types of migration, the size of oil and gas reserves in open fields, etc. In the Russian oil and gas literature, the term "oil and gas complex" is widely used, although unlike the term "hydrocarbon systems" it does not include a genetic model of their formation using geochemical data. According to V.V. Payrazyan, one of the important and new directions of studying hydrocarbon systems is the application of methods of reservoir geochemistry. The study of all types of fluids that saturate reservoirs and their mineral component is especially important, since the processes of formation of hydrocarbon systems are associated with the history of formation of the porous reservoir environment (Payrazyan, 2010). Hydrocarbon systems are clearly arranged in a hierarchical series: oil and gas basin – hydrocarbon systems – oil and gas accumulation zones – field – deposit, which is confirmed by the quantitative relationship between the generation potential of oil-and-gas source rock (OGSR) in the source of generation and the size of the deposits identified in them (Payrazyan, 2010). Petroleum (hydrocarbon, generation-accumulation) system is a complex of deposits in a certain area of development of the oil and gas basin associated with the processes of formation of oil and gas content. It includes oil and gas source rocks, hydrocarbon migration routes, reservoir rocks, fluid seals and traps (Magoon et al., 2000; Mancini et al., 2001). To identify the oil system, it is necessary to detect hydrocarbons in the form of deposits or oil and gas-bitumen occurrences. The systems are usually named after one of the key geographical objects or stratigraphic complex, in which the oil and gas source rocks are developed. Typically, the identification of petroleum systems begins with the defining of oil and gas source rocks and their correlation with hydrocarbon deposits or oil, gas and bitumen occurrences (Higley et al., 2006).

Results

Currently, the Vychegda trough, and most of the adjacent tectonic regions (Mezen syneclise, Syktyvkar arch, North-East of the Kazan-Kajim aulacogen, Kama arch and Western regions of the Timan ridge) industrial petroleum potential not established. The only exception is the Northwest area of the Solikamsk depression, where there are several oil fields (Lulinski, Verkhnekubansk, etc.). On the territory of the Vychegda trough marked oil-bitumen occurrences in the Proterozoic, and particularly in the Paleozoic section. A comparison of the materials previously completed geophysical surveys Vychegda trough the results of the last regional seismic profile 26-RS (2007) made adjustments to the study of the deep structure of the South-Eastern outskirts of the Mezen syneclise and Timan-Pechora province, including understudied areas Vychegda trough. For example, the capacity of the sedimentary cover in the central part and on the eastern side of the Vychegoda trough reaches 9-10 km, new large tectonic disturbances of the upthrow fault-thrust type have been confirmed and traced, new structural elements have been identified in the Paleozoic and Vend-Riphean complexes as possible traps (reef formations, non-structural traps, intrusions of various types, etc.) (Vakhnin, 2016). On the results of drilling and geophysical studies in the basin in addition to the powerful Riphean-Vendian deposits are widely spread Paleozoic formations, including the upper Devonian sediments are presented, which revealed domanik, the main source rocks of the Volga-Ural and Timan-Pechora oil and gas provinces (Fig.1).

A comprehensive analysis of the geological structure of the deflection, geophysical and geological-geochemical results, including those obtained by the

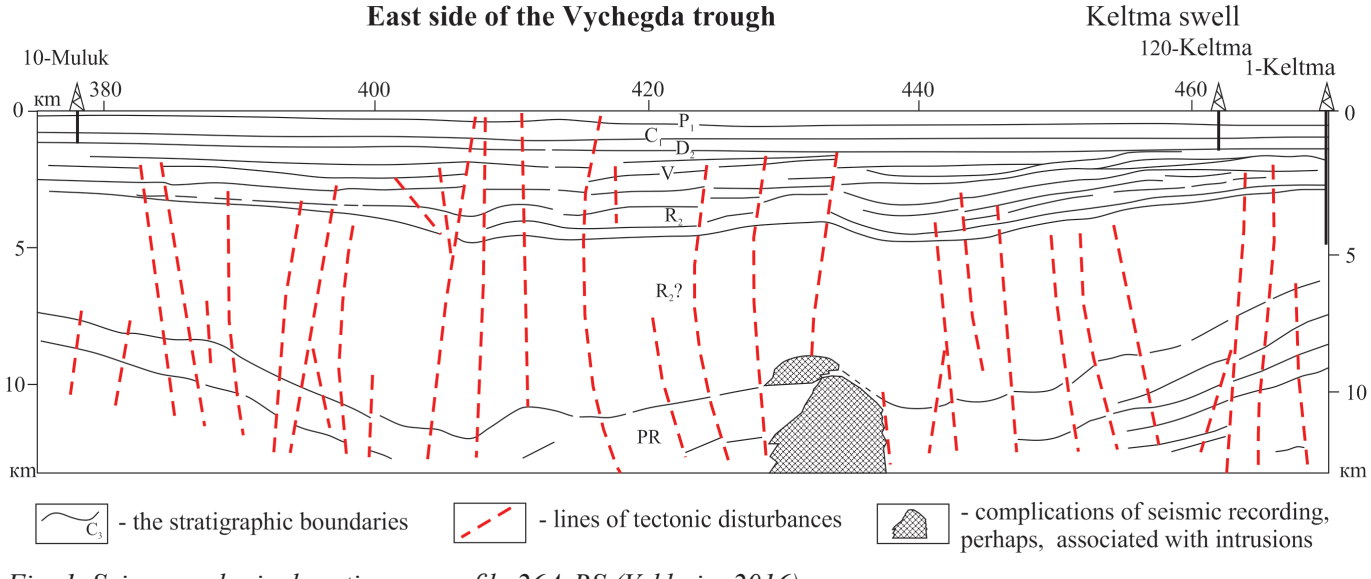

Fig. 1. Seismogeological section on profile 26A-RS (Vakhnin, 2016)

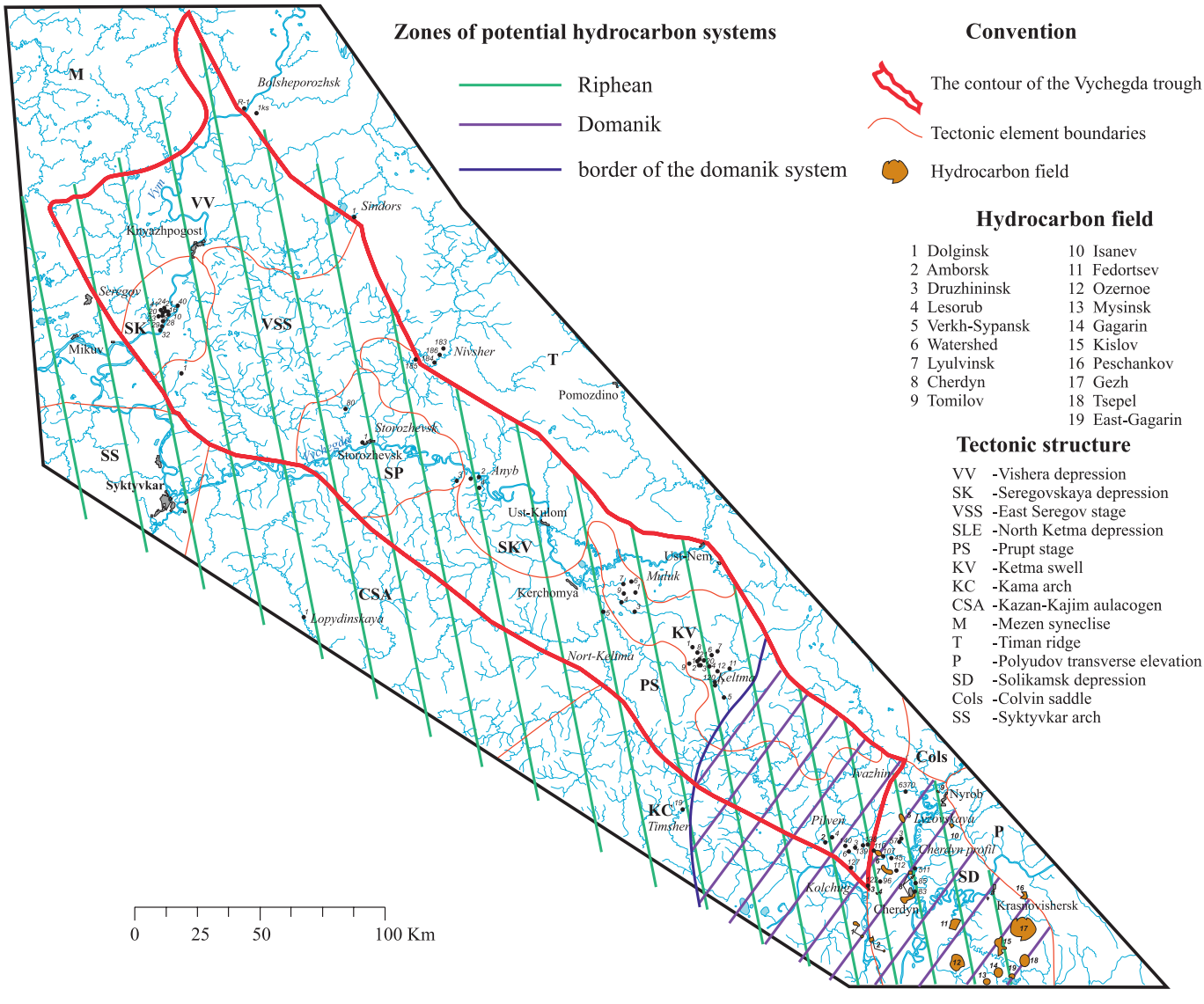

Fig. 2. Distribution of potential hydrocarbon systems in the Vychegda trough

authors, anable us to identify two potential petroleum systems – "domanik" and "riphean" (Fig. 2).

The potential domanik petroleum system of the Vychegda trough dominates in the Eastern regions and is a peripheral fragment of the regional petroleum system covering the territories of the Volga-Ural and Timan-Pechora oil and gas provinces (Lindquist, 1999; Klimenko, 2011; Timothy, Michael, Thomas, 2017). It is associated with the development in the South-Eastern part of the trough and the neighbouring Solikamsk depression of domanik biomarker and domanikoid (domanik-like) sediments as a source rocks. Genetic correlation of crude oils of Devonian-Carboniferous deposits of the northern districts of the Solikamsk depression with the domanik organic matter by biomarkers, such as metalloporphyrins (less than 10 mg/g rock in the oils and bitumens) and isoprenoids (the ratio of the pristan/phytane of less than or equal to 1) confirms this.

The stratigraphic range of the domanik system is upper Devonian-upper Permian; the formation time is late Devonian-Mesozoic.

According to the determination of the T_{max} parameter by the Rock eval method (Kolchugino Area) and the results of the basin modeling, the upper Devonian deposits here reached the sub-stage of the catagenesis MK_{1-2}, i.e. were in the interval of the "oil window" (Bashkova et al., 2018). The potential of the system in the studied area, rather remote from the powerful zones of oil formation in the domanik deposits, is estimated as relatively low in the regional plan, since the content of organic matter (OM) in rocks by C_{org} is only 0.5-0.7 % (Prishchepa et al., 2014). Petrographic studies of coal performed on Lisovsk and Kolchugino boreholes cores and other areas showed that vitrinite reflectance of the lower Carboniferous increases to the East from the Vychegda trough, as a result, the OM catagenesis increases up gradation to MK_2, i.e. emigration potential of the source rocks increases, but mainly outside the territory of the Vychegda trough.

In the Central and North-Western areas of the Vychegda trough k deposits have low yields or absent, catagenesis of OM rocks of the Paleozoic sediments does not exceed

protocatagenesis. The Vendian rocks were located in the oil window formation, and the OM of the Dorogorsk Formation of the Middle Riphean (depth 3653-3659 m) was transformed even till the gradation of MK_4, it entered the initial stage of the gas window. Thus, the domanik throughout its geological history was not included in oil window. According to the results of basin modeling 1D (Mubarak, Al-Hajer, Al Saeed, 2009; Hantschel, Kauerauf, 2009) of the Keltma 1 well section, only the Riphean and, partially, Vendian deposits entered the oil window (Fig. 3). At the same time, the Riphean rocks were in this zone for a very long time, which contributed to the significant development of hydrocarbon potential, and also partially entered the gas window.

Studies of rocks of Seregov well 1 by Rock Eval showed that Paleozoic deposits did not leave the zone of protocatagenesis, in the oil window there were Vend rocks, and the dorogor suite of the middle Riphean (depth 3653-3659 m) was transformed even to the gradation of MK_4, that is, entered the initial stage of gas window. A similar pattern is observed for the Storozhevskaya well 1 (the Central part of the studied region).

In the study of gases deeply absorbed on the Riphean limestone rocks, at the depth of 3006-3013 m 0.0388 cm^3/kg of gas enriched with heavy hydrocarbons was extracted: 44.3 % pentanes, 20.6 % butanes. Thus, in the studied part of the section of the well identified productive source rocks that were in oil

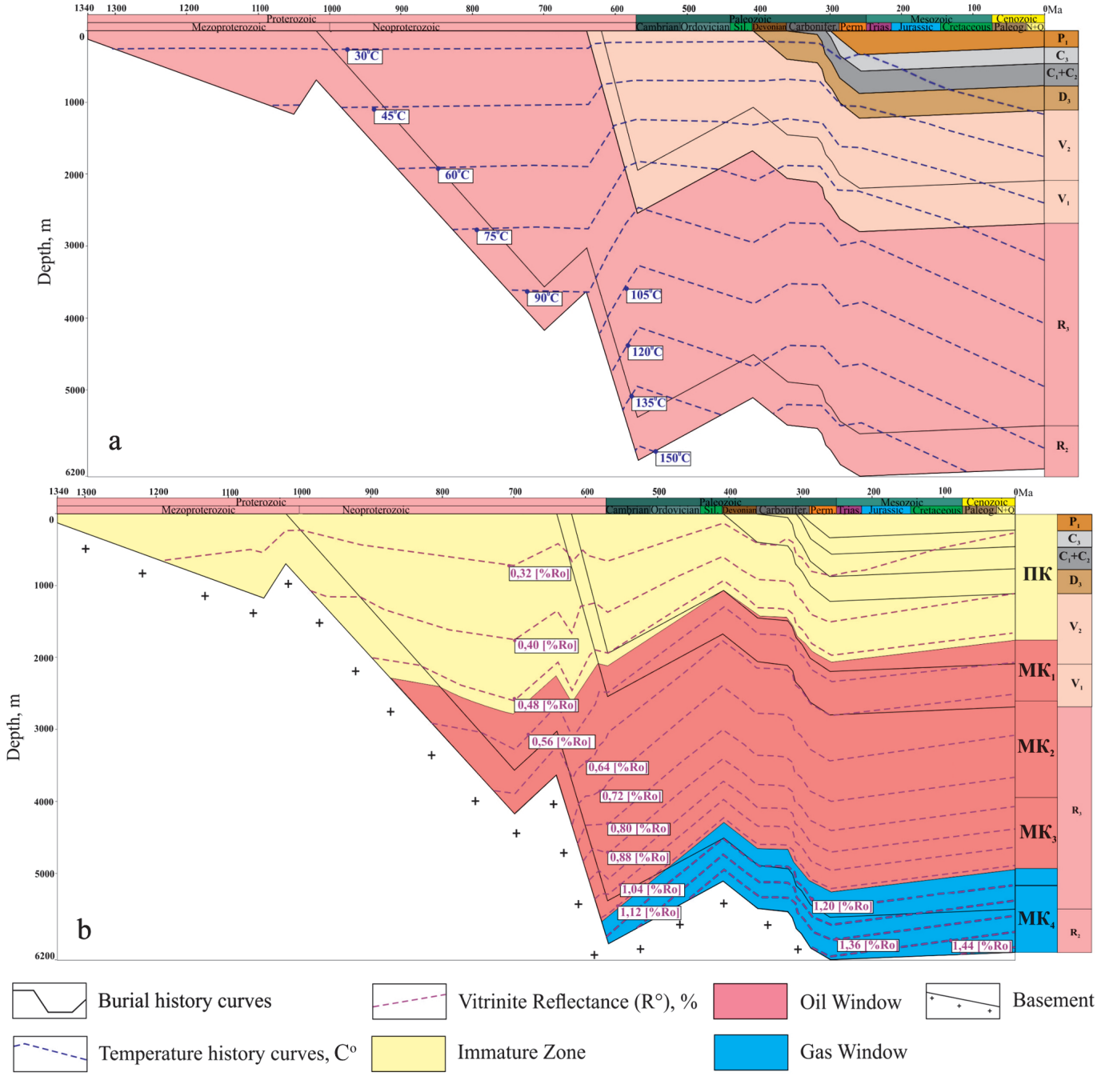

Fig. 3. The Model of the changes of paleotemperatures (a) and zoning of oil and gas windows (b), the well Keltma 1

window and genetically related zones of hydrocarbons micro-accumulation.

For the length of the Riphean system can cover the entire territory of the Vychegda trough, and for the depth – from the Riphean to upper Permian sediments. The time of formation of the system – Riphean-Mesozoic. In conditions of high tectonic activity of the region in the development of the Timan ridge in Caledonian (?) and the Hercynian stages of tectonogenesis repeatedly intensified the West Timan fault and its plumage. In this regard, favorable conditions may have formed for vertical migration of hydrocarbons, traces of which are observed in the form of micro-accumulation of liquid hydrocarbons and oil accumulations in the Paleozoic sediments on Seregowski, Storozhevsky, Nivshersky, Muluccas and Ketmensky areas, where Riphean-Vendian sediments reached the oil window. It is expected that the destruction of the Riphean system will decrease in the South-West as it moves away from the border with Timan. Given the large capacity of the Riphean sediments, it can be assumed that the residual potential of hydrocarbon resources of the Riphean petroleum system may be quite large despite the classification of source rocks as "poor" according to the Tissot and Velte classification (Tissot, Welte,1984; Tissot, Espitalie, 1980).

In the central part of the Vychegda trough in the area of the border with Kazan-Kajim aulacogen, where basement depth is 5 km and more, the Proterozoic magmatic rocks were identified, forming traps. The latter, playing the role of fluid seals, in combination with reservoirs in the Riphean, Vendian and Cambrian sandstones, can form hydrocarbon traps that determine high oil and gas potential (Shilovskaya, Shilovsky, 2011). In addition, areas of the trough of great interest from the point of view of the preservation of hydrocarbon deposits may be, where the catagenetic disagreement between Riphean and Vendian is slightly (Kuzmin, 2006), as well as areas of development of Riphean salts as zonal fluid seals. Particularly important is the presence of salts for the preservation of deposits of gas and gas condensates. Previously, the Seregov-Storozhev potential oil and gas region (Aplonov et al., 2004) stood out quite rightly as a promising one, where the possible oil and gas potential was associated exclusively with the sub-salt Riphean deposits, especially within the structural-tectonic projection of the Seregov structure.

It should be noted that outside the zone of development of the domanik system, there is a fairly frequent occurrence of oil show in the form of viscous oils and bitumen in the upper part of the section, that may be an indicator of the increased degree of destruction of the Riphean petroleum system. So, in shallow wells of the Keltma shaft there are selected layers, saturated with heavy viscous oil in the Permian and Carboniferous sediments. The presence of solid bitumen is recorded in the sandstones of the upper Riphean in the well Storozhevskaya 1 (Kuzmin, 2006). During the existence of the system at the stages of sedimentation breaks, when Proterozoic and Paleozoic sediments were repeatedly removed to the surface of the day, the existing hydrocarbon resource potential in them could be partially lost.

Probable signs of the Riphean system in the South-East is an oil discovery in the Devonian terrigenous deposits of the Cherdyn oil field, and a large oil show in the timan deposits of the Fedorov field by the wells Yasva-22, 27, 28 and Lisow-96. Minor oil shows along the core in the form of impregnation of sandstones with oil are noted in the well Lisow-101 (Lesorub oil field). Most of oil obtained from the devonian, famenian, turonian, visean and bashkirian deposits, are light-weight, low-viscosity and sulphur, resin, paraffin, light fractions with a high content. It is possible that they are generated by Riphean deposits, as indicated by their low density, but with vertical migration they were "diluted" by heavy sulfur oils of the later, domanik system.

It should be noted that the implementation of the own generation capacity of domanikits of the underlying Devonian clastic sediments in this area is unlikely. In the Vendian deposits of the Vychegda trough the content of OM is negligible (up to 0.10 %, in isolated cases increased to 0.14 %). According to pyrolysis data, the generation potential (S_2) of OM is also small – less than 0.05 mg HC/g of rock, and the concentration of free hydrocarbons (S_1) is less than 0.03 mg HC/g of rock, indicating the absence of source rocks.

Within the spatial development of the Riphean system in the middle Carboniferous on Elmach-Parmin, Nivsher and Muluk areas, and also in the Vendian sediments of the well Kolchugino-140 gas shows observed. The composition of gas was nitrogen with a very low content of hydrocarbon, but with a helium content of 0.6-1.89 % vol., which may be an indicator of the deep origin of the fluid. According to T.G. Karasik (1959), the formation of nitrogen gas associated with the destruction of oil deposits, and within the Keltma shaft has been offloading of hydrocarbons in deep faults. At the same time, it is known that nitrogen often dominates in the oil deposits of the Udmurt Republic.

The formation of two hydrocarbon systems within the Vychegda trough is largely predetermined by the active tectonic factor of the formation of the Timan ridge in the Mesozoic. An indicator of the stress impact of Timan on the section of Proterozoic and Paleozoic deposits is a high stratigraphic range of oil-bitumen occurrences (up to the upper Permian deposits) along the North-Eastern boundary of the trough, that may be associated with vertical migration channels along the West Timan fault and operating disjunctives. In this

regard, it can be assumed that in the South-Eastern parts of the Vychegda trough is probably a superposition of two potential hydrocarbon systems with more clearly defined "domanik" component.

Summary

Thus, according to the results of the research, the following is established.

1.The two potential petroleum systems – "riphean" and "domanik" – are identified on the territory of the Vychegda trough. The first developed throughout the trough, the second – in the South-Eastern regions adjacent to the Solikamsk depression.

2. The domanik system oil source rocks entered the oil window, while the emigration potential increased in the Eastern direction. The upper Devonian, lower Carboniferous and Bashkir deposits are promising to the discovery of oil deposits.

3. In relatively deep horizons, the increased generation potential may be associated with strong Riphean deposits located in the oil window and partially gas window.

4. Priority areas of exploration should be planned based on the territorial development of the domanik system, mainly in the South-Eastern part of the Vychegda trough, taking into account the analogs of oil deposits and deposits discovered in the North-Western regions of the Solikamsk depression. Search objects may be prepared depression structures with the opening of wells of terrigenous deposits of the Devonian and deeper horizons.

5. For objective evaluation of oil potential of the Riphean petroleum system, it is recommended to drill a parametric well with a depth of not less than 5000 m in the South-Western border of the Vychegda trough with the Kazan-Kajim aulacogen, where projected development of source rocks, reservoirs and seals.

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