Heat flow and presence of oil and gas (the Yamal peninsula, Tomsk region)

V.I. Isaev1,2*, G.A. Lobova1, A.N. Fomin1, V.I. Bulatov2, S.G. Kuzmenkov2, M.F. Galieva1, D.S. Krutenko1

1National Research Tomsk Polytechnic University, Tomsk, Russian Federation
2Yugra State University, Khanty-Mansiysk, Russian Federation

Abstract. The possibilities of Geothermy as a geophysical method are studied to solve forecast and prospecting problems of Petroleum Geology of the Arctic regions and the Paleozoic of Western Siberia. Deep heat flow of Yamal fields, whose oil and gas potential is associated with the Jurassic-Cretaceous formations, and the fields of Tomsk Region, whose geological section contains deposits in the Paleozoic, is studied. The method of paleotemperature modeling was used to calculate the heat flow density from the base of a sedimentary section (by solving the inverse problem of Geothermy). The schematization and mapping of the heat flow were performed, taking into account experimental determinations of the parameter. Besides, the correlation of heat flow features with the localization of deposits was revealed. The conceptual and factual basis of research includes the tectonosedimentary history of sedimentary cover, the Mesozoic-Cenozoic climatic temperature course and the history of cryogenic processes, as well as lithologic and stratigraphic description of the section, results of well testing, thermometry and vitrinite reflectivity data of 20 deep wells of Yamal and 37 wells of Ostanino group of fields of Tomsk region. It was stated that 80% of known Yamal deposits correlate with anomalous features of the heat flow. Bovanenkovskoe and Arkticheskoe fields are located in positive anomaly zones. 75% of fields of Ostanino group relate to anomalous features of the heat flow. It is shown that the fields, which are characterized by existence of commercial deposits in the Paleozoic, are associated with the bright gradient zone of the heat flow. The forecast of commercial inflows in the Paleozoic for Pindzhinskoe, Mirmoe and Rybalnoe fields is given. The correlation between the intensity of naftodogenesis and the lateral inhomogeneity of the deep heat flow is characterized as a probable fundamental pattern for Western Siberia.

Key words: the deep heat flow, oil and gas fields, Yamal, Paleozoic, Tomsk Region, the correlation, Western Siberia

Recommended citation: Isaev V.I., Lobova G.A., Fomin A.N., Bulatov V.I., Kuzmenkov S.G., Galieva M.F., Krutenko D.S (2019). Heat flow and presence of oil and gas (the Yamal peninsula, Tomsk region). Georesursy = Georesources, 21(3), pp. 125-135. DOI: https://doi.org/10.18599/grs.2019.3.125-135

Introduction

Within the development paradigm of hydrocarbon resources base of Russia, the Arctic regions and the Paleozoic of Western Siberia become subsequent objects of geological exploration and demand perfecting of criteria and updating prospecting methods (Kontorovich, 2016; Kontorovich, 2017). Present work is related to the enhancement of possibilities of Geothermy as a geophysical method for solving forecast and prospecting problems of Petroleum Geology (Isaev et al., 2018).

Key role belongs to fundamental geodynamic parameter – the deep heat flow density (Khutorskoy, 1996). This is the main parameter, determining the thermal history of potentially oil source sediments, the realization degree of generation potential of organic matter, the syngenesis of foci of hydrocarbon generation and accumulating reservoirs (Isaev, 2004). To the point, the following is a quotation from monograph (Kurchikov, 1992): “Thus, according to the new obtained data about deep heat flow, a widespread viewpoint concerning the omnipresent confinedness of oil and gas deposits to geotemperature anomalies zones is not confirmed. Nevertheless, it is found out that the majority of hydrocarbon accumulations are located in zones of substantial lateral inhomogeneity of the deep heat flow” (italics by article authors). A relevant contribution to the formation of Geothermy as an oil prospecting method, especially for the Arctic regions, of A.R. Kurchikov (Kurchikov, 2001) and M.D. Khutorskoy (Khutorskoy et al., 2013; Nikitin et al., 2015) must be mentioned.

*Corresponding author: Valery I. Isaev
E-mail:isaevvi@tpu.ru

© 2019 The Authors. Published by Georesursy LLC
This is an open access article under the CC BY 4.0 license (https://creativecommons.org/licenses/by/4.0/)
Objects for present research are territories of hydrocarbon fields localization in the northern part of Yamalo-Nenets Autonomous Okrug, where oil and gas potential is associated, predominantly, with the Lower Cretaceous deposits of the Akhskaya suite, and in Tomsk Region, which geological section contents deposits in the Upper Jurassic as well as in the contact zone of the Paleozoic and the Mesozoic and in the Inner Paleozoic.

Research purpose is to investigate a consistent pattern of the deep heat flow changes, to evaluate the correlation between the heat flow peculiarities and localization of hydrocarbon fields and to define possible prospecting geothermal criteria of oil and gas potential through the example of the territories, which were mentioned earlier.

Investigation and evaluation have been carried out, foremost, based on calculated values of the deep heat flow density from the base of a sedimentary section, besides the experimental determinations of the deep heat flow have been also analysed.

The methodology of deep heat flow calculation

The deep heat flow is determined by solving inverse problem of Geothermy with the aid of software package tools for 1D basin modelling (Isaev et al., 2018a; Isaev et al., 2018b). Solution is performed within the parametric description of the sedimentation history and the history of thermophysical properties of the sedimentary layer only, beginning from the Jurassic, without invoking information about the nature of heat flow and geodynamics below the base of the sedimentary section. For the conditions of Western Siberia, characterized, starting from the Jurassic time, by the quasistationarity of the deep heat flow (Duchkov et al., 1990; Kurchikov et al., 2001), the solution of the inverse Geothermy problem – determining the density of heat flow – is carried out uniquely.

To solve the inverse problem of Geothermy, we use as “observed” both measurements of reservoir temperatures obtained during well tests and temperature logs of steady-state boreholes (Method of definite geotemperature gradient, DGG) and also geotemperatures recalculated (Isaev, Fomin, 2006) from the values of vitrinite reflectance (VR). The geotemperatures from VR are obtained during well tests and temperature logs of steady-state boreholes (Method of definite geotemperature gradient, DGG) and also geotemperatures recalculated (Isaev, Fomin, 2006) from the values of vitrinite reflectance (VR).

The optimality of the “discrepancy” of calculated geotemperatures with “observed” reservoir temperatures is equally important. The optimal “discrepancy” is the mean square difference between the calculated and “observed” values, which is equal to the error of observations (Strakhov et al., 2000). In our case, the solution of the inverse problem of Geothermy with the aid of software package tools for 1D basin modelling is to investigate a consistent pattern of the deep heat flow changes, to evaluate the correlation between the heat flow peculiarities and localization of hydrocarbon fields and to define possible prospecting geothermal criteria of oil and gas potential through the example of the territories, which were mentioned earlier.

The heat flow of Yamal

The Mesozoic-Cenozoic sedimentary cover in the study area began to form in the Lower Jurassic. In this time Kiterbyutskaya argillaceous suite J1, which had an oil-source potential, was accumulating. Till the
end of the Volgian Age the marine transgression has expanded, *Bazhenov formation* (*J*₂₄₋₅ + *K*₁₃), which is the most enriched in organic matter, was accumulating. According to the average VR value – $R_v^0 = 0.96 \%$ – the Bazhenov formation is in the end of the main oil generation zone within the limits of the Arctic area.

Marine regime has prevailed since the Aptian-Cenomanian until the beginning of the Eocene. Thickness analysis of Paleogene-Neogene testified that sedimentation had gone to the middle of the Miocene for 32 million years (Nyurolskaya, Tavdinskaya, Atlymskaya, Novomikhaylovskaya, Turtasskaya, Abrosimovskaya formations) and amounted to 335-535 m, then these sediments have been degraded in the Early Biceul time.

In the Middle Miocene-Early Pliocene, since the end of the Biceul time and till the end of the Novoportov accumulation had gone of the order of 100 m thick sediments, which in the subsequent stage of positive tectonic movements over 1.3 million years were denudated. With the onset of the Late Miocene, Pliocene-Quaternary lacustrine-alluvial sediments accumulated.

The *Middle Jurassic oil and gas complex* (*OGC*) includes reservoirs in Vimskaya suite (*J*₂ᵇ₁) with *YuYa*₂₋₉ formations and Malyshevskaya suite (*J*₂ᵇ₂₋₅₋₆₋₇, *J*₂ᵇ₃₋₅) with *YuYa*₂₋₉ formations in lower subsuite. The *Upper Jurassic OGC* combines Nurminskaya suite (*J*₂ᵇ₁₋₄₋₇₋₈₋₁₀) with *YuYa*₂₋₉ formations, while the *Cretaceous* – Akhskaya, Tanopchinskaya and Yarongskaya the Lower Cretaceous suites. Achimovskaya sequence is identified in the bottom of the Cretaceous with a group of *Ach* formations.

Stratigraphic breakdowns, well testing results and VR data of deep wells (Database of the Trofimuk Institute of Petroleum Geology and Geophysics of Siberian Branch of Russian Academy of Sciences, 2018) are invoked for purpose of building sedimentation and thermophysical 1D-models. The breakdowns are accepted considering the dynamic of tectonic events during the formation of sedimentary section in the territory of Yamal. Account the permafrost is performed beginning from 0.52 Ma, while ice mass – beginning from 0.182 Ma (Isaev et al., 2017). The glacier has completely degraded by the time of 15 thousand years ago (the end of the Sartan time).

The scheme of heat flow density of Yamal (Fig. 1A) was built using calculated values of heat flow density from the base of the sedimentary section in 8 wells and data of experimental determinations of deep heat flow density in 12 wells (Table 1).

To be noted, that the pattern concerning increasing the deep heat flow density towards the north-west direction (Khutorskoy et al., 2013), which was earlier established, is observed on the obtained calculated scheme as well (Fig. 1).

It is interesting to match calculated values of the heat flow, obtained with the authors’ methodology (Isaev et al., 2018a; Isaev et al., 2018b), with calculated values of heat flow, obtained earlier via use of the physical-mathematical model of A.R. Kurchikov (Kurchikov, 1992). Thus, cataloged values of the heat flow density (Kurchikov, 1992) in wells of Kharasaveyskoe, Kruzenshternskoe and Bovanenkovskoe fields are in the range of 56-62 mW/m², whereas the scheme (Fig. 1) gives the range of 57-62 mW/m². And then cataloged values of the heat flow density (Kurchikov, 1992) in wells of Arkticheskoе and Sredne-Yamal’skoe fields are in the range of 54-56 mW/m², whereas the scheme (Fig. 1) gives the range of 51-57 mW/m².

Presumed, Table 1 and also Table 3 (calculated heat flow, “discrepancies” of modelling) are of self-consistent interest. Along with that, this information is an argument for reliability of modelling results, values of the heat flow in tables may become a basis for following 2D and 3D basin modelling. One of the most problem-plagued and quite difficult stage of the basin modelling is receiving the heat flow appraisals. The complicity and ambiguousness of heat flow determination from the base of sedimentary section, which is based in systems GALA, Temis, PetroMod on the models of the lithosphere rifting (“defined rift phases”) (Hantschel et al., 2009; Kontorovich et al., 2013; Galushkin, 2016), is known, but far from always mentioned.

It is possible to see the following peculiarities in the scheme (Fig. 1B): “positive anomaly” (for example, Bovanenkovskoe area); “negative anomaly” (Yuzhno-Tambeyskoe area); “bay-shaped configuration of isolines” (Rostovtsevskoe area); “non anomalous field” (Sredne-Yamal’skoe area).

Analysis of correlation between the heat flow and localization of 13 well-known fields shows the following. 6 fields are in the zones of positive anomalies of heat flow (46 % of the total number), the biggest among them – Bovanenkovskoe and Arkticheskoе. 1 field is in the zone of negative anomaly of the heat flow (8 %) – Yuzhno-Tambeyskoe. 4 fields are in the zones of bay-shaped configuration of isolines (31 %): Kruzenshternskoe, Nفتinskoe, Rostovtsevskoe and Novoportovskoe.

Consequently, in the order of 80-85 % of known hydrocarbon fields of Yamal are associated with anomalous peculiarities of the deep heat flow.

**The heat flow of Ostanino group of fields (Tomsk Region)**

The study area is located in Parabel District of Tomsk Region between rivers the Chuzik and the Chizhapka (Fig. 2). As to sediments of the platform cover the research territory is in the articulation zone of two tectonic structures of the first order: Nyurol’skaya megadepression and the south part of Srednevasyuganskiy megaswell (Kontorovich et al., 2006).
| Identification number (Fig. 1A) | Well            | Temperature, °C | Heat flow, mW/m² / depth, m |
|-------------------------------|-----------------|-----------------|-------------------------------|
|                               |                 | Depth, m | Reservoir | By VR | By DGG | Modelling (calculated) | Difference between calculated and experimental | Calculated by authors |
| 1                             | Rostovtsevskoe 64 | 2470   | 75       | -     | -     | 75                | 0          | 50/3485 |
|                               |                 | 2650   | 81       | -     | -     | 81                | 0          |         |
|                               |                 | 2660   | 81       | -     | -     | 81                | 0          |         |
|                               |                 | 2096   | -        | 84    | -     | 85                | +1         |         |
|                               |                 | 2600   | -        | 98    | -     | 101               | +3         |         |
|                               |                 | 2827   | -        | 111   | -     | 108               | -3         |         |
| 2                             | Sredne-Yamal’skoe 14 | 846    | 17       | -     | -     | 23                | +6         | 51/3383 |
|                               |                 | 1700   | -        | 83    | -     | 81                | -2         |         |
|                               |                 | 2200   | -        | 100   | -     | 97                | -3         |         |
|                               |                 | 3000   | -        | 120   | -     | 122               | +2         |         |
| 3                             | Malo-Yamal’skoe 3002 | 2312   | 68       | -     | -     | 68                | 0          | 51/2751 |
|                               |                 | 2355   | 69       | -     | -     | 69                | 0          |         |
|                               |                 | 2391   | 75       | -     | -     | 70                | -5         |         |
|                               |                 | 2552   | 76       | -     | -     | 75                | -1         |         |
|                               |                 | 1917   | -        | 80    | -     | 79                | -1         |         |
|                               |                 | 1922   | -        | 81    | -     | 79                | -2         |         |
|                               |                 | 1937   | -        | 81    | -     | 79                | -2         |         |
|                               |                 | 2300   | -        | 90    | -     | 91                | +1         |         |
|                               |                 | 2315   | -        | 90    | -     | 91                | +1         |         |
| 4                             | Arkticheskoe 11 | 3533   | 125      | -     | -     | 124               | -1         | 58/2792 |
|                               |                 | 3560   | 126      | -     | -     | 125               | -1         |         |
|                               |                 | 2000   | -        | 100   | -     | 102               | +2         |         |
|                               |                 | 2500   | -        | 120   | -     | 121               | +1         |         |
|                               | Bovanenkivskoe 116 | 2610   | 94       | -     | -     | 96                | +2         | 62/3388 |
|                               |                 | 2657   | 97       | -     | -     | 97                | 0          |         |
|                               |                 | 2795   | 103      | -     | -     | 103               | 0          |         |
|                               |                 | 3050   | 113      | -     | -     | 112               | -1         |         |
|                               |                 | 3016   | 90       | -     | -     | 91                | +1         |         |
|                               |                 | 2615   | -        | 120   | -     | 119               | -1         |         |
| 6                             | Ust’-Yuribeyskoe 31 | 469-472 | 67       | -     | -     | -                 | -          | 48/2900 |
|                               |                 | 873-878 | 10       | -     | -     | -                 | -          |         |
|                               |                 | 891-900 | 22       | -     | -     | -                 | -          |         |
| 7                             | Severo-Mantoyskoe 51 | 1368-1376 | 27 | -     | -     | -             | -          | 47/2400 |
|                               |                 | 2322   | -        | 56    | -     | -                 | -          |         |
|                               |                 | 2430   | -        | 61    | -     | -                 | -          |         |
|                               |                 | 2434   | -        | 65    | -     | -                 | -          |         |
| 8                             | Novoportovskoe 54 | 2520-2540 | 83  | -     | -     | -             | -          | 52/2500 |

**Table 1. The heat flow in wells of the Yamal Peninsula**
The Jurassic sedimentary rocks rest with non-depositional hiatus and angular unconformity on erosional suppression of the Paleozoic carbonate rocks of the Devonian-Lower Carboniferous.

Oil and gas fields, mainly, are associated with the Upper Jurassic sandy reservoirs of horizon Y1. Hydrocarbon deposits are concentrated in anticline, fault-bounded traps of the Upper and Middle Jurassic and in the oil-and-gas horizon of weathering crust (M formation) and in the Inner Paleozoic (M1 formation) (Table 2). The deposits of the uppermost part of basement rocks are relating to metasomatically altered bioaccumulated limestones, which represent as reservoir rocks of porous-fissured type.

Commonly spread in the study territory the Upper Jurassic Bazhenov Formation is an oil source rock for the Middle and Upper Jurassic OGC (Fomin, 2011). Potentially oil-source the Lower Jurassic Togurkaya suite is accepted as a traditional hydrocarbon source for the pre-Jurassic OGC (Kostyreva, 2005). However, this formation has quite limited spread – the south-western edge of the study area (Fig. 2A). In this connection it is impossible to except the version, which suggests accounting the Devonian strata as a hydrocarbon generating source for the pre-Jurassic reservoirs (Lobova et al., 2018). The hypothesis of “Bazhenov source of origin” of the pre-Jurassic hydrocarbon deposits is more disputable and it has only indirect arguments (Galieva, Krutenko, 2019).

The calculations of the heat flow density performed for geological sections of 35 exploratory and 2 parametric wells on the study area (Fig. 2). Data of deep wells testing (reservoir temperatures) and temperature logs DGG were investigated and summed up from primary “well historical data”, reserve calculation reports, operational analysis reports and generalization of geological and geophysical database of Tomsk Region (Database of Tomsk branch of the “Territorial fund of geological information, Siberian federal district”, 2018). VR values determined in the Laboratory of Oil and Gas Geochemistry of the Institute of Petroleum Geology and Geophysics of Siberian Branch of Russian Academy of Sciences (Novosibirsk).
The comparison of modelling temperatures with reservoir temperatures and with temperatures determined by DGG and by VR is provided in the Table 3. As is evident, the calculated model of heat distribution in the sedimentary section coincides with “observed” values in the optimal way at a level of ±2°C.

The reliability of the results of paleotemperature modelling is confirmed consistency of the obtained calculated values of the heat flow density with experimental determinations of A.D. Duchkov (Western Siberia. Geology and mineral resources of Russia, 2000). Experimental data is surrounded with isoline of 60 mW/m², calculated values are in the range of 41-65 mW/m².

The following anomalous peculiarities are observed in the map of the deep heat flow distribution (Fig. 2B): “positive anomaly”, “gradient zone”, “negative anomaly”, “bay-shaped configuration of isolines”.

Hydrocarbon fields in the eastern part of the territory are associated with the striking gradient zone, which surrounds a large positive anomaly. There 6 fields are located: Rybal’noe, Selimkanovskoe, Pindzhinskoe, Mirnoe, Ostaninskoe, Severo-Ostaninskoe, that accounts 50 % of the total number of the fields in the study area. 3 fields (25 %) are in the zone of bay-shaped configuration of isolines – Pel’ginskoe, Gerasimovskoe, Zapadno-Ostaninskoe. Remarkably, hydrocarbon fields are absent in the zone of negative anomaly of the heat flow in the north-western part of the territory.

Therefore, 9 fields (75 %), which are located in the study area, are associated with the anomalous peculiarities of the deep heat flow distribution. 3 fields – Shirotnoe, Yuzhno-Tambaevskoe, Tambaevskoe, do not correlate with the anomalous peculiarities of the heat flow.
Table 2. Oil and gas potential of Ostanino group of fields (according to the Database of Tomsk branch of the “Territorial fund of geological information, Siberian federal district”, 2018). Fluid type: G – gas, O – oil, GC – gas condensate, OGC – oil and gas condensate, GO – gas and oil.

Independently important to note, that Selimkhanovskoe, Ostaninskoe, Severo-Ostaninskoe and also Gerasimovskoe fields, within which deposits are exposed with commercial hydrocarbon inflows, are associated with the substantial lateral inhomogeneity of the heat flow density (gradient zones) (Table 2). Pindzhinskoe, Mirnoe and Rybal’noe fields are also included in the striking gradient zone, within them it is possible to forecast deposits with commercial hydrocarbon inflows.

Yuzhno-Tambaevskoe and Tambaevskoe fields, within which deposits are exposed with commercial hydrocarbon inflows, are separated from anomalous peculiarities of the heat flow. Interesting to point, that particular these fields are located within the boarders of spread of potentially oil-source the Lower Jurassic Togurskaya suite.

Conclusion
The scheme and the map of the deep heat flow were built for the territory of localization of the Arctic hydrocarbon fields of Yamal and Tomsk Region, where the Paleozoic oil deposits were exposed in geological section.
| No. | Well                  | Temperature, °C | Depth, m | Reservoir | By VR | By DGG | Modelling (calculated) | Difference between calculated and experimental | Calculated heat flow, mW/m² / depth, m |
|-----|-----------------------|-----------------|----------|-----------|-------|--------|------------------------|-----------------------------------------------|-------------------------------------|
| 1   | Zapadno-Ostaninskoe   |                 |          |           |       |        |                        |                                               |                                     |
|     | 440                   |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 2   | Zapadno-Ostaninskoe   |                 |          |           |       |        |                        |                                               |                                     |
|     | 447                   |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 3   | Ostaninskoe 424       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 4   | Ostaninskoe 425       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 5   | Ostaninskoe 428       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 6   | Ostaninskoe 438       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 7   | Ostaninskoe 452       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 8   | Severo-Ostaninskoe 1  |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 9   | Severo-Ostaninskoe 8  |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 10  | Severo-Ostaninskoe 9  |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 11  | Severo-Ostaninskoe 7  |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 12  | Severo-Ostaninskoe 11 |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 13  | Armichskaya 1         |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 14  | Gordeevskaya 1P       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 15  | Tambaevskoe 1         |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 16  | Pel'ginskoe 1         |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
| 17  | Pel'ginskoe 2         |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |
|     |                       |                 |          |           |       |        |                        |                                               |                                     |

Table 3. The heat flow in wells of Ostanino group of fields (Tomsk Region)
| No. | Field Name                  | Well Name | Depth, m | Reservoir By VR Modelling (calculated) | Difference between calculated and experimental |
|-----|----------------------------|-----------|----------|----------------------------------------|------------------------------------------------|
| 18  | Pel’ginskoe 3              |           |          |                                        |                                                 |
|     |                            |           |          |                                        |                                                 |
| 19  | Selimkhanovskoe 2          |           |          |                                        |                                                 |
| 20  | Selimkhanovskoe 4          |           |          |                                        |                                                 |
| 21  | Selimkhanovskoe 5          |           |          |                                        |                                                 |
| 22  | Sel’veyinskaya 2           |           |          |                                        |                                                 |
| 23  | Sel’veyinskaya 3           |           |          |                                        |                                                 |
| 24  | Sel’veyinskaya 4           |           |          |                                        |                                                 |
| 25  | Gerasimovskoe 6            |           |          |                                        |                                                 |
| 26  | Gerasimovskoe 7            |           |          |                                        |                                                 |
| 27  | Gerasimovskoe 12           |           |          |                                        |                                                 |
| 28  | Gerasimovskoe 18           |           |          |                                        |                                                 |
| 29  | Gerasimovskoe (Zapadno-Ostaninskoe 444) | |          |                                        |                                                 |
| 30  | Mirnoe 413                 |           |          |                                        |                                                 |
| 31  | Mirnoe 414                 |           |          |                                        |                                                 |
| 32  | Mirnoe 415                 |           |          |                                        |                                                 |
| 33  | Pindzhinskoe 1             |           |          |                                        |                                                 |
| 34  | Pindzhinskoe 4             |           |          |                                        |                                                 |
| 35  | Pindzhinskoe 5             |           |          |                                        |                                                 |

Continue Table 3. The heat flow in wells of Ostanino group of fields (Tomsk Region)
It was stated that 75-80% of hydrocarbon fields, which were located in the study areas, correlated with the anomalous peculiarities of the deep heat flow distribution.

The reliability of calculated values of Yamal heat flow was reasoned with performing of the classical geophysical criterion – criterion of “discrepancy”, consistency with earlier revealed tendency of the heat flow density increase towards the north-western direction, comparability with the catalogue of calculated values of the heat flow, which was presented in earlier published monographic work (Kurchikov, 1992). The reliability of calculated values of the heat flow of Ostanino group of fields of Tomsk Region was substantiated with performing the criterion of “discrepancy”, consistency with the map of the heat flow determinations of Western Siberian Plate.

The confinedness of fields with commercial hydrocarbon inflows from the deposits of pre-Jurassic OGC to the strongly marked gradient zone of the heat flow density values was placed emphasis through the example of Ostanino group of fields. This allows to forecast getting commercial inflows from the pre-Jurassic OGC in Pindzhinskoe, Mirnoe and Rybal’noe fields.

Afore-named characterize lateral inhomogeneity of the heat flow (gradient zones), probably, not as forecast criterion of oil and gas potential, but rather as an existence of the fundamental correlation between the intensity of naffidogenesis and lateral inhomogeneity of the deep heat flow of Western Siberia.

Acknowledgments

The authors thank Professor VI. Starostenko and Professor M.D. Fokin for the constant attention to our research.

References

Duchkov A.D., Galushkin Yu.I., Smirnov L.V., Sokolova L.S. (1990). The evolution of the sedimentary cover temperature field of the West Siberian Plate. Geologiya i geofizika = Russian Geology and Geophysics, 10, pp. 51-60. (In Russ.)

Fomin A.N. (2011). Katagenesis organicheskogo veshchestva i neftegazomosnost’ mezozoiskikh i paleozoiskikh otlozenii Zapadno-Sibirskogo megabassaina [Catagenesis of organic matter and petroleum potential of the Mesoozoic and Paleozoic sediments of the West Siberian megabasin]. Novosibirsk: ISPGB SB RAS, 331 p. (In Russ.)

Galieva M.F., Krutenko D.S. (1999). Geological and geophysical evidences favouring the hypothesis “basenhov source of origins of pre-Jurassic oil deposits of Ostanino group of fields (Tomsk region). Mat. II Vseross. nauch. konf.: Aktual’nye problemy geologii nefti i gaza Sibiri = Russian Journal of Pacific Geology, 23(5), pp. 101-115. (In Russ.)

Isaev V.I., Fomin A.N. (2006). Loci of Generation of Bazhenov- and Togur-Type Oils in the Southern Nyurul’ ka Megadepression. Russian Geology and Geophysics, 47(6), pp. 734-745.

Isaev V.I., Gulenok R.Yu., Veselov O.V., Bychkov A.V., Soloveychik Yu.G. (2002). Computer technology of integrated assessment of oil and gas potential of sedimentary basins. Geologiya nefti i gaza = Oil and Gas Geology, 6, pp. 48-54. (In Russ.)

Isaev V.I., Iskorkina A.A., Kosygin V.Yu., Lobova G.A., Osipova E.N., Fomin A.N. (2017). Integrated assessment of paleoclimatic factors of reconstructing thermal history of petromaternal Bazhenov suite in arctic regions of Western Siberia. Ekspliavta Tomskogo politekhnicheskoj universiteta. Izvishenje georesursos = Bulletin of the Tomsk Politechnic University. Geo Assets Engineering, 328(1), pp. 13-28. (In Russ.)

Isaev V.I., Iskorkina A.A., Lobova G.A., Fomin A.N. (2016). Paleoclimate’s factors of reconstructing thermal history of petroleum bazhenov and togor suites southwestern West Siberia. Geofizicheskii zhurnal, 38(4), pp. 3-25. (In Russ.) https://doi.org/10.24026/geo.2016-3100.v38i4.2016.107798

Isaev V.I., Iskorkina A.A., Lobova G.A., Luneva T.E., Osipova E.N., Ayupov R.Sh., Igenbaeva N.O., Fomin A.N. (2018). Mesoizoz-Cenozoic climate and the geothermal regime of the oil source Kiterbyutskaya suite of the Arctic region of Western Siberia. Georesursos = Georesources, 20(4), Part 2, pp. 386-395. https://doi.org/10.18599/gres.2018.4.393

Isaev V.I., Lobova G.A., Mazurov A.K., Starostenko V.I., Fomin A.N. (2018a). Zoning of mega-depressions by shale oil genegation density of Togur and Bazhenov source suites in the southeast of Western Siberia. Geologiya nefti i gaza = Oil and Gas Geology, 1, pp. 15-39. (In Russ.)

Isaev V.I., Iskorkina A.A., Lobova G.A., Starostenko V.I., Tikhotskii S.A., Fomin A.N. (2018b). Mesoizoz-Cenozoic Climate and Neotectonic Events as Factors in Reconstructing the Thermal History of the Source-Rock Bazhenov Formation, Arctic Region, West Siberia, by the Example of the Yamal Peninsula. Ekspliavta, Physics of the Solid Earth, 54(2), pp. 310-329. https://doi.org/10.13140/RG.110.699351138020064

Iskorkina A., Isaev V., Terre D. (2015). Assessment of Mesoizoz-Kainozoic climate impact on oil-source rock potential (West Siberia). IOP Conf. Series: Earth and Environmental Science, 27, https://doi.org/10.1088/1755-1315/21/01/0203

Khutorskoy M.D. (1996). Vvedenie v geotermiyu: kurs lektsiy [Introduction to Geothermy: lecture course]. Moscow: RUDN Publ., 328 p. (In Russ.)

Khutorskoy M.D., Akhmedzyanov V.R., Ermakov A.V. et al. (2013). Geotermiya arkticheskikh morey [Geothermy of Arctic seas]. Moscow: GEOS, 232 p. (In Russ.)

Kontorovich A.E. (2016). Problems of re-industrialization of the oil and gas complex of Russia. Nefteyano khozayastvo = Oil Industry, 3, pp. 14-15. (In Russ.)

Kontorovich A.E. (2017). I.M. Ghikkin’s paradigm of the development of the USSR oil industry in the 20th century. Russian Geology and Geophysics, 58(3-4), pp. 283-293. https://doi.org/10.1016/j.rgg.2016.12.005

Kontorovich A.E., Burshtein L.M., Malyshnev N.A., Safronov P.I., S.A. Gus’kov S.A., Ershov S.V., Kazaunenkov V.A, Kim N.S, Kontorovich V.A, Kostyreva E.A., Melenevsky V.N., Livshits V.R., Polyakov A.A., Skvortsov M.D. (2013). Historical-geological modeling of hydrocarbon generation in the meseozoc-cenoicentered sedimentary basin of the Karra sea (basin modeling). Russian Geology and Geophysics, 54(8), pp. 1179-1226. https://doi.org/10.1016/j.rgg.2013.07.011

Kontorovich V.A., Berdnikova S.A., Kalinina L.M., Lapkovskiy V.V., Polyakov A.A., Soloviev M.V. (2006). The model of geological structure and petroleum potential of sediments at the Paleozoic-Mesozoic boundary in the Chuzik-Chizhapka zone of oil-gas accumulation. Geologiya, geofizika i razrabotka nefteyanych i gazovykh mnerozhdeniy = Geology, geophysics and development of oil and gas fields, 5-6, pp. 91-102. (In Russ.)

Kostyreva E.A. (2005). Geokhimija i genezis paleozoiskikh neftey yugo-vostoka Zapadnov Sibiri [Geochemistry and genesis of Paleozoic oil of south-eastern Western Siberia]. Novosibirsk: SB RAS Publ., «Geo» Branch, 183 p. (In Russ.)

Kurchikov A.R. (1992). Gigaseiicheskij kriterii neftegazonasnosti [Hydrogeothermial criteria of oil-and-gas potential]. Moscow: Nedra, 231 p. (In Russ.)

Kurchikov A.R. (2001). Geothermal regime of hydrocarbon accumulations in Western Siberia. Geologiya i geofizika = Russian Geology and Geophysics, 42(11-12), pp. 1846-1853. (In Russ.)

Lobova G.A., Isaev V.I., Kuzmenkov S.G., Luneva T.E., Osipova E.N. (2018). Oil and gas reservoirs of weathering crusts and Paleozoic basement
in the southeast of Western Siberia (forecasting of hard-to-recover reserves). *Geofizicheskii zhurnal*, 40(4), pp. 73-106. (In Russ.) https://doi.org/10.24028/gzh.0203-3100.v40i4.2018.140611

Nikitin D.S., Ivanov D.A., Zhuravlev V.A., Khutorskoy M.D. (2015). Three-dimensional geological and geothermal model of sedimentary cover in the north-eastern part of the Barents Sea shelf in connection with the development of hydrocarbon resources. *Georesursy = Georesources*, 17(1), pp. 13-19. (In Russ.) https://doi.org/10.18599/grs.60.1.3

Popov S.A., Isaev V.I. (2011). Modeling of naphthyogenesis in Southern Yamal. *Geofizicheskii zhurnal*, 33(2), pp. 80-104. (In Russ.)

Strakhov V.N., Golizdra G.Ya., Starostenko V.I. (2000). Theory and practice of interpreting potential fields: Evolution in the 20th century. *Izvestiya, Physics of the Solid Earth*, 36(9), pp. 742-762.

Western Siberia. Geology and mineral resources of Russia (2000). V. 2. Chief Ed. V.P. Orlov. Ed. of the 2nd v.: A.E. Kontorovich, V.S. Surkov. St. Petersburg: VSEGEI Publ., 477 p. (In Russ.)

About the Authors

Valery I. Isaev – DSc (Geology and Mineralogy), Professor, Department of Geology, School of Earth Sciences & Engineering, National Research Tomsk Polytechnic University; Leading Researcher, Institute of Oil and Gas, Ugra State University
30, Lenin ave., Tomsk, 634050, Russian Federation
Phone: +7 (3822) 701-777 ad. 2942
E-mail: isaevvi@tpu.ru

Galina A. Lobova – DSc (Geology and Mineralogy), Associate Professor, Department of Geology, School of Earth Sciences & Engineering, National Research Tomsk Polytechnic University
30, Lenin ave., Tomsk, 634050, Russian Federation

Alexander N. Fomin – DSc (Geology and Mineralogy), Chief Researcher, Trofimuk Institute of Petroleum Geology and Geophysics of Siberian Branch of Russian Academy of Sciences
3, Ak. Koptyug ave., Novosibirsk, 630090, Russian Federation

Valery I. Bulatov – DSc (Geography), Professor, Institute of Oil and Gas, Yugra State University
16, Chekhov st., Khanty-Mansiysk, 628012, Russian Federation

Stanislav G. Kuzmenkov – DSc (Geology and Mineralogy), Professor, Institute of Oil and Gas, Ugra State University
16, Chekhov st., Khanty-Mansiysk, 628012, Russian Federation

Margarita F. Galieva – Student, Department of Geology, School of Earth Sciences & Engineering, National Research Tomsk Polytechnic University
30, Lenin ave., Tomsk, 634050, Russian Federation

Daniil S. Krutenko – Student, Department of Geology, School of Earth Sciences & Engineering, National Research Tomsk Polytechnic University
30, Lenin ave., Tomsk, 634050, Russian Federation

Manuscript received 10 May 2019; Accepted 6 August 2019; Published 1 September 2019