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Prischepa O.M., Bogatskiy V.I.
All-Russia Petroleum Research Exploration Institute (VNIGRI), Saint Petersburg, Russia, ins@vnigri.ru
Grigorenko T.I.
TP NITS LLC, Ukhta, Russia, grig@tpnic.ru
Orlova L.A., Chumakova O.V.
All-Russia Petroleum Research Exploration Institute (VNIGRI), Saint Petersburg, Russia, ins@vnigri.ru

NORTHWESTERN TIMAN-PECHORA BASIN - NEW INSIGHTS INTO PETROLEUM POTENTIAL PROSPECTS

The prospective area of hydrocarbon deposits' studied in the northwestern part of the Timan-Pechora Basin and its offshore extension (Izhma-Pechora Syneclise, onshore and offshore parts of Malozemelsk-Kolguev Monocline) are presented. For the moment this area seems to be not very attractive for the subsoil investors and users due to a poorly developed sedimentary cover, concerning the main perspective complexes, small progress in detailed delineation of the objects prepared for drilling and not finally identification of the oil and gas source rocks.

The exploration under government contracts allowed to establish a large development of the Lower-Middle Paleozoic perspective complexes and identify a buried amplitude swell (Novoborsky).

The research aimed at tracking of the Lower Paleozoic buried structures in the offshore and identifying the most promising objects, where parametric wells can be projected and located for estimation of oil and gas systems, is substantiated.

Keywords: *tectonical structure, petroleum potential prospects, buried structures, Lower-Middle Ordovician oil and gas complex, oil and gas accumulation zones, Izhma-Pechora Syneclise, Malozemelsk-Kolguev Monocline.*

Statement of research interest

Approximately 250 oil and gas fields were identified within the onshore part of the Timan-Pechora Basin. Its far north-western and eastern margins are not adequately addressed by the subsoil users due to different geological reasons. Therefore, the petroleum exploration is carried out in a very limited scale. In these areas, due to poor investigation degree, the prospects evaluation of the region, especially of the northern-western areas (onshore and offshore) of the northern half of Izhma-Pechora regional Syneclise and Malozemelsk-Kolguev regional Monocline (Fig. 1), are rather poor.

The uncertainty of estimates petroleum resources is caused by the poor and irregular distribution of parametric and exploration wells and seismic surveys, as well as the lack of "conventional" indicators of petroleum potential prospects, which led to successful discoveries rather in the southern and eastern parts of the Timan-Pechora Basin. First of all, they include a

significant reduction up to the absence (or development in other facies) of two petroleum complexes – Middle-Lower Frasnian and Semiluksky-Tournaisian (Fig. 2).

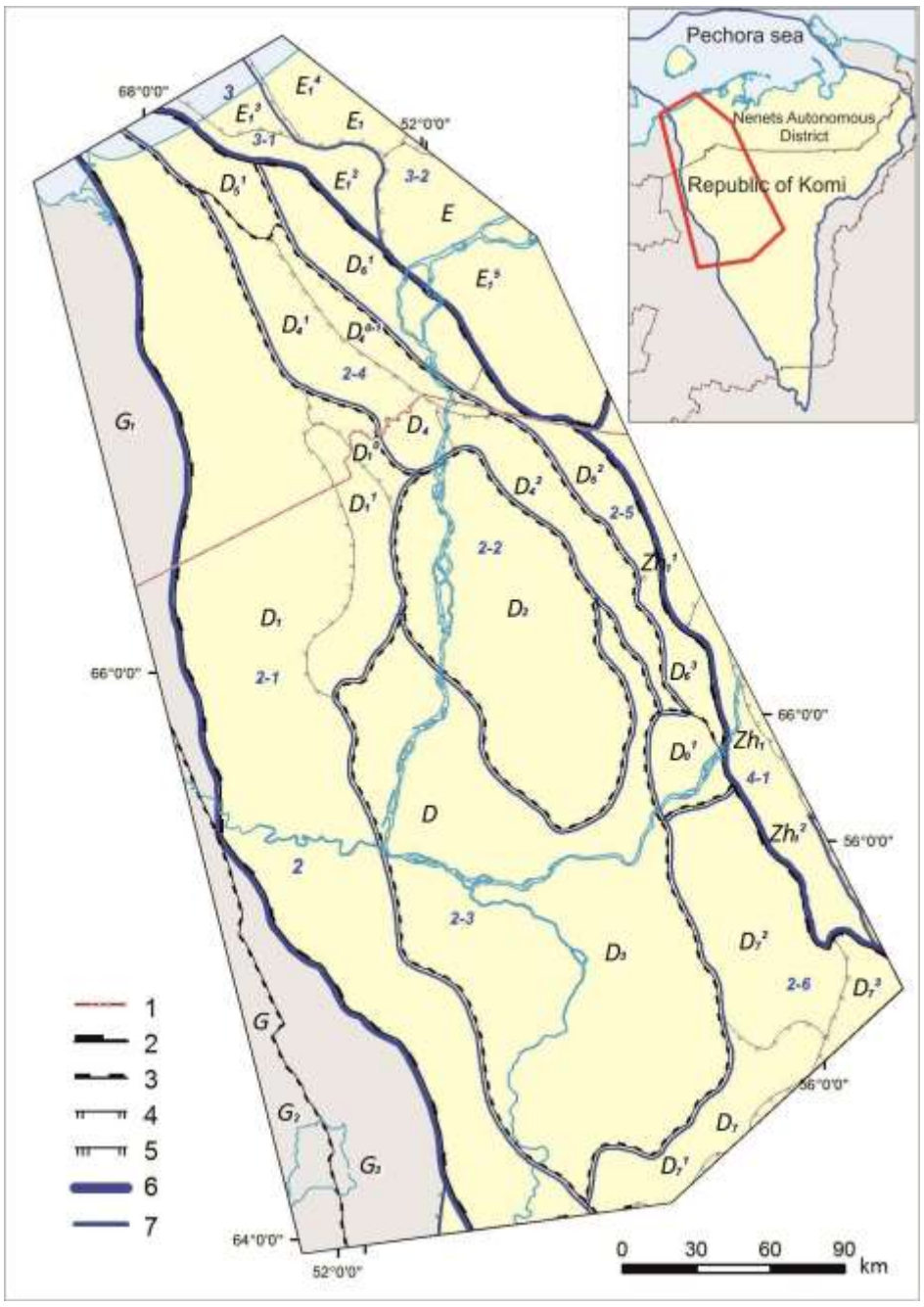

Fig. 1. Structural map and oil and gas zonation of the northern part of Izhma-Pechora Syneclise

1 - administrative borders, 2-5 - tectonic units boundaries: 2 – superorder, 3 - first-order, 4 - second-order, 5 - third-order, 6-7 - boundaries of petroleum-geological units: 6 - petroleum areas, 7 - petroleum regions. Petroleum regions and areas: 2 - Izhma-Pechora region: 2-1 - Pre-Timan petroleum region, 2-2 - Ersin petroleum region, 2-3 - Nizhneizhema petroleum region, 2-4 - Novobor-Sozva petroleum region, 2-5 - Seduyaha-Kipiev petroleum region, 2-6 - Verhnelyzha- Lemyu petroleum region; 3 - Malozemlya-Kolguev petroleum region: 3-1 - West Kolguev petroleum region, 3-2 - Naryan-Mar petroleum region; 4 - Pechora-Kolva petroleum region: 4-1 - Mutnomaterik-Lebedinsk petroleum region. Tectonic elements. Superorder: G - Timan ridge, D - Izhma-Pechora basin, E - Malozemlya-Kolguev monocline F - Pechora-Kolva aulacogen. Structure of the first order: G_1 - North Timan megaswell, G_2 - West and Srednetiman dislocation, G_3 - East Timan complex megaswell, D_1 - Neritsk step, D_2 - Ersin depression, D_3 - Izhem step, D_4 - Novobor-Sozva structural zone, D_5 - Seaside swell, D_6 - Seduyaha-Malolebed megaswell, D_7 - Omra-Lyzha saddle, E_1 - Naryan-Mar monocline, Zh_1 - Pechora-Kozhva megaswell. Second-order structure: D_1^1 - Tobysh swell, D_1^0- East Harius structural bight, D_4^1 - Novobor structural subarea, D_4^2 - Sozva structural subarea, D_4^{0-1} - Predseduyaha structural level, D_6^1 - Seduyaha disjunctive swell, D_6^2 - Yangyt-Dzelyad swell, D_6^3 - Malolebed swell, D_0^1 - Charkayu Kipiev step, D_7^1 - Sotchemyu Ares scarp, D_7^2 - Lyzha step, D_7^3 - Ronael step, E_1^2 - North Seduyaha scarp, E_1^3 - West Kolguev monocline, E_1^4 - Sengey structural ness, E_1^5 - Malozemlya structural terrace, Zh_1^1 - Lebed swell, Zh_1^2 - Mutnomaterik swell.

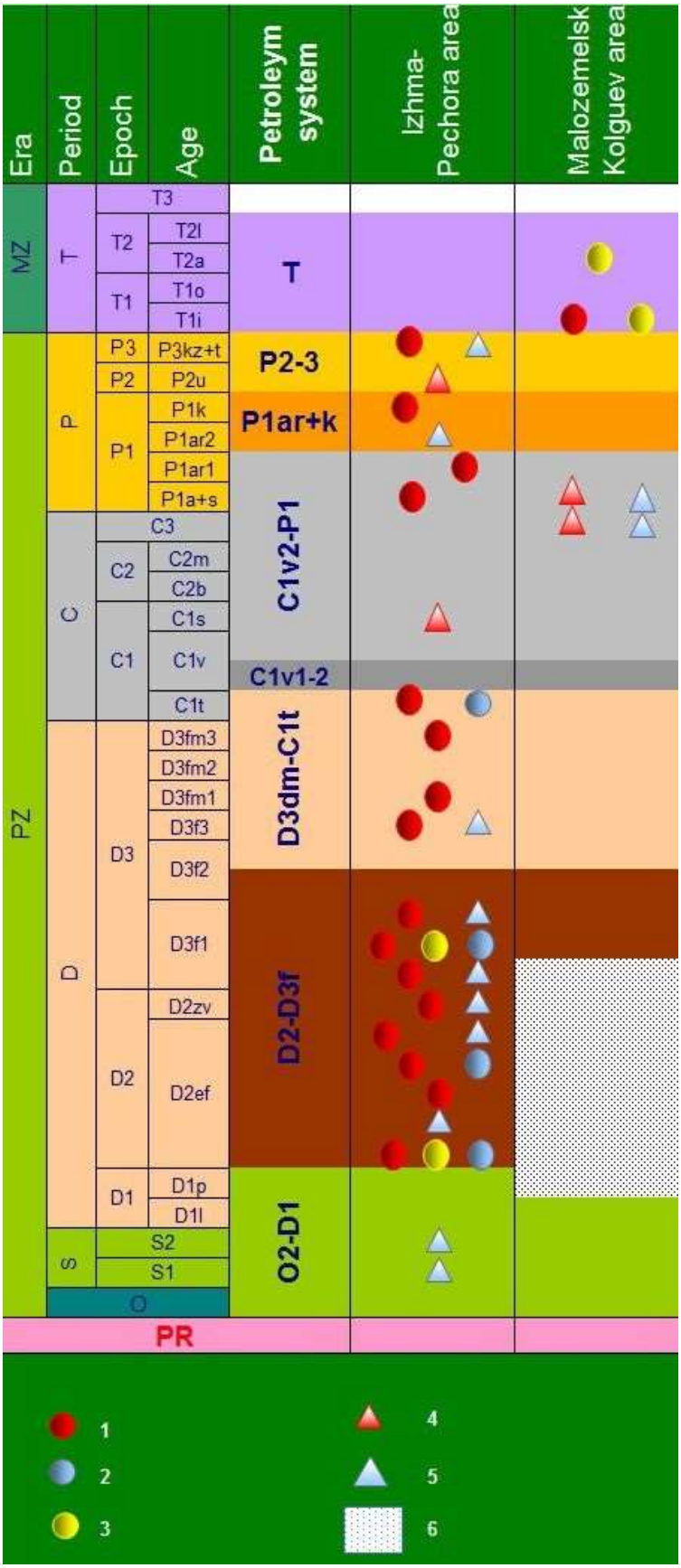

Fig. 2. Petroleum system sketch of the northwestern regions of Timan-Pechora Basin

1-3 – accumulations (1 – oil, 2 – gas, 3 – gas condensate); 4-5 – noncommercial accumulations (4 – oil, 5 - gas); 6 – lithostratigraphic gap (hiatus).

One of the reasons of the meagre appraisal evaluations is the reduction of the section of the Upper Visean - Lower Permian carbonate complex too. Other important point is that many wells have revealed touched the basement without indications of oil and /or gas within the section of sedimentary cover. More, sections of parametric and reference wells showed no source rocks sections.

Two oil and gas fields (Tarksk and Peschanoozersk) were discovered in Triassic sandstones within Malozemelsk-Kolguev Monocline (Kolguev Island), and rather poor oil accumulation was identified in the Upper Carboniferous limestones of the Kharitseysk area, onshore.

Oil fields were too identified within the Izhemsk step area characterized by similar geological structure; the fields belong to the Upper Devonian buildups and the structures of their enveloping too. It should be noted that the fields of the Triassic complex of Malozemelsk-Kolguev Monocline and Upper Devonian of Izhemsk step belong to the border areas of these structural elements; where the formation conditions of petroleum accumulations are close or similar to those that existed in more eastern and southern parts of the province with favorable opportunities of hydrocarbon generation, migration and accumulation. Such areas include the southern half of Izhma-Pechora region Syneclise, which contain more than 70 oil fields.

Petroleum potential prospects of the offshore part of Malozemelsk-Kolguev monocline appear to be more promising due to increasing the thickness of the Paleozoic and Mesozoic sections and their plunging to the north and northeast [Prischepa et al, 2010]. The analysis of oil and gas potential revealed the need for more intensive approach to searching oil and gas source rocks [Senin, Kuranov, Kutlinsky, 2012] and possible migration paths from Pechora-Kozhvinsk mega swell to the adjacent offshore areas [Prischepa, 2012].

During the period 2010-2013 seismic analysis and extensive analytical work were conducted within the north-western poor-investigated areas of the Timan-Pechora Basin to address the challenges of regional stage of investigation - identifying of new areas of oil and gas accumulation.

Large analysis of the revised drilling results, and updated seismic and geophysical data allowed to clarify the view on tectonic structure; while the analysis of geochemical indicators of sedimentary cover rocks together with paleostructural imaging made it possible to assume the models of petroleum systems and to make more reliable assessment of the potential.

Structural analyses

The northern half of Izhma-Pechora Syneclise and Malozemelsk-Kolguev Monocline are border to the Timan Ridge on the southwest along the Eastern Timan fault. On the north - north-east

it is limited by faults of Pechora-Kolvinsk aulacogene - southern flank of Charkayu-Pylemetsk and Shapkina-Yuryakha with its continuation in the Pechora Sea. North-western flank of Charkayu-Pylemetsk fault separates the pre-fault structure of Izhma-Pechora Syneclise from Malozemelsk-Kolguev Monocline [Timan-Pechora province..., 2004].

In the north the bounds are intermittent flexures on the border with North-Pechora monocline, while in the south - Omra-Lyzha saddle of southeastern half of Izhma-Pechora Syneclise with a lot of fields. The structural map of this area was drawn using the top of carbonate rocks whose age in the region varies from Middle Carboniferous to Artinskian of Early Permian (Fig. 3).

In the sedimentary cover of the northern half of Izhma-Pechora Syneclise the following tectonic elements of first order are distinguished: Neritsk step, Ersinsk depression, Izhemsk step, Novoborsk-Sozvinsk structural area, and Seduyahinsk-Malolebedinsk megaswell, and Primorsk swell and Kipievsk step as structural elements of second order. Malozemelsk-Kolguev Monocline contains structures of first order - Korginsk step, Western Kolguev monocline, Eastern Kolguev structural zone, and Malozemelsk monocline [Prischepa et al, 2010].

Sedimentary cover of the Timan-Pechora basin is divided into three regional structural levels. The lower one - the Upper Cambrian? – Lower Devonian level referred to the Caledonian orogeny; the middle structural level - Middle Devonian - Triassic referred to the Hercynian orogeny. The upper structural level referred to the Jurassic-Neogene (Mesozoic-Cenozoic). All these levels and their sublevels are identified in the northern half of the Izhma-Pechora Syneclise and Malozemelsk-Kolguev Monocline. On the onshore area of Malozemelsk-Kolguev Monocline the Caledonian lower level is presented only by the Silurian carbonates grabens. However, in the offshore areas on Kolguev Island the sediments of the terrigenous Upper Cambrian - Lower Ordovician section of over 1300 m thick are identified. The upper part of the Hercynian level (Middle Ordovician - Lower Devonian) is reduced on the island; however, the Ordovician - Devonian carbonate complex with thickness of 2.0 km appears in the western part according to seismic data. The Middle Devonian was not found in the middle Hercynian structural level on the Malozemelsk-Kolguev Monocline, both on land and in the offshore (Kolguev Island). A typical feature of the sedimentary cover structure of the studied subregion is the structural inheritance from multifolding and multifaulting deformation of basement, especially manifested in the lower level and in the lower part of the middle level.

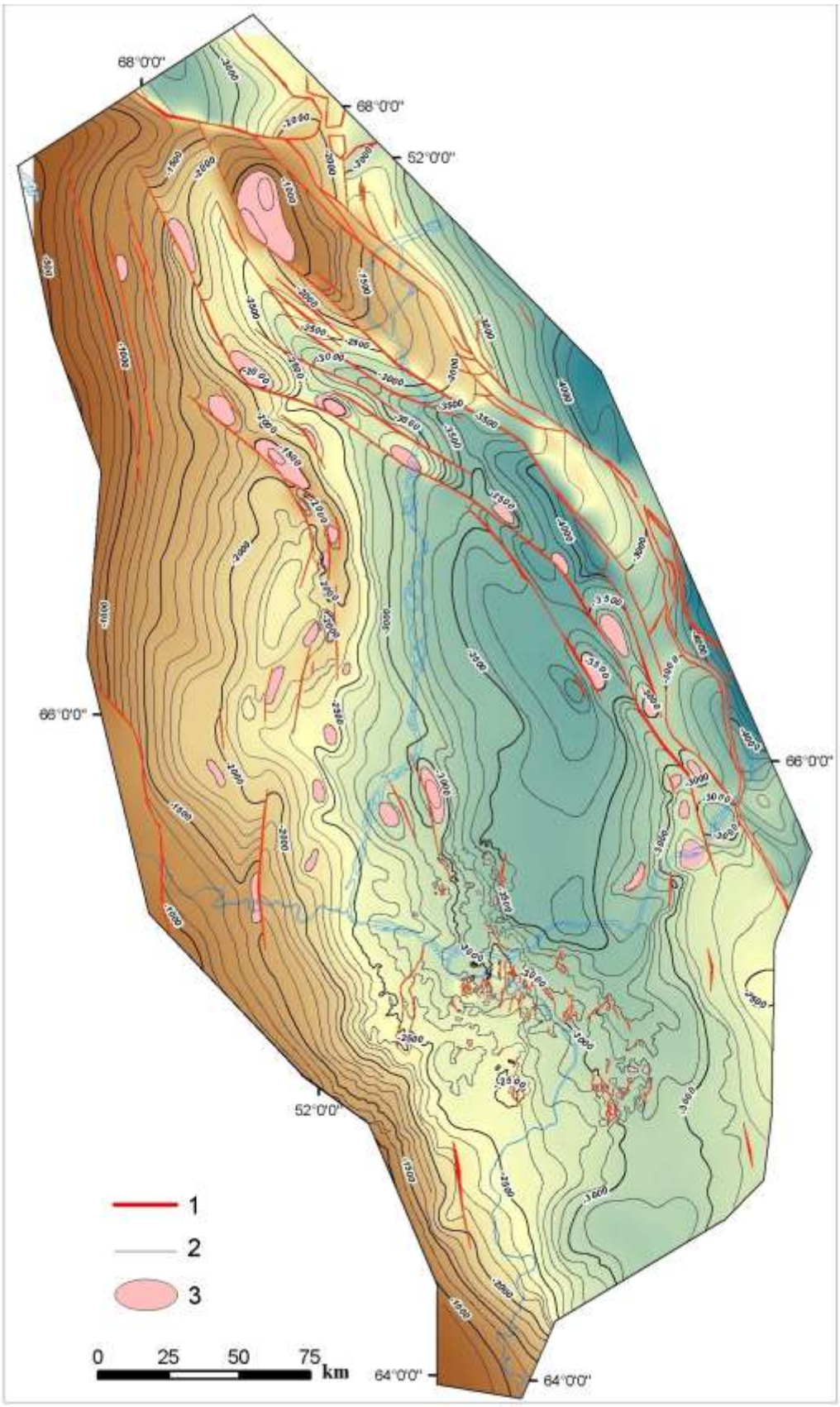

Fig. 3. Structural map - top of the basement (VI seismic marker) of Izhma-Pechora Syneclise
1 - faults estimated on the basis of seismic data, 2 - isobaths (m) on the top of the basement (VI seismic marker*), 3 - local structures.*

In the northern half of Izhma-Pechora Syneclise are identified all structural levels from below; levels inclining towards Pre-Pechora fault system. The thickness of the sedimentary cover in the depocenter, near to the northeastern dislocations of syneclise (Novoborsk-Sozvinsk structural zone and Seduyaha-Malolebedinsk megaswell) is about 3.5-4.0 km.

North-eastern part of the northern half of Izhma-Pechora Syneclise is represented by two major tectonical elements – Novoborsk-Sozvinsk structural zone and Seduyaha-Malolebedinsk megaswell. On the surface of the basement these tectonic elements constitute a single block - disjunctive structures adjacent to Charkayu-Pylemetsk fault. Its length is about 300 km and the width is about 40-70 km.

The Novoborsk-Sozvinsk structural zone consists of two subzones: northwestern Novoborsk and southeastern Sozvinsk. The Pre-Seduyahinsk structural level is located above the Novoborsk dislocations, but significantly below the northern flank of Seduyaha-Malolebedinsk megaswell (Fig. 4). Frontal southwestern extended half-graben, plunging to the southeast, is complicated by adjacent local structures – North-Novoborsk, Verhne-Novoborsk, Sredne-Novoborsk, Novoborsk, Nizhne-Novoborsk, West-Dzelyadevsk, Sozvinsk, Arivansk. Sizes of structures are approximately 17.5-10.0×75-5.0 km, with amplitude of about 100-200 m.

The thickness of terrigenous section between the basement and Pre-Lower-Timan-Sargaevsk unconformity surface increases from 500-800 m on the upthrown frontal shoulder of a half-horst structure up to 1500-1700 m in its lowered section. The increase is apparently caused not only by the growth of thickness of terrigenous Upper Cambrian - Middle Ordovician, but also by increase in the size of Lower-Frasnian strata and, importantly, by possible development of Middle Devonian - Yaransk (Lower-Frasnian) argillaceous sandstone rocks. The latter along with Dzhersk sandstones can be developed in shallow grabens on the front shoulder of Novoborsko-Sozvinsk horst. Along the layers of Devonian-Triassic structural level (Domanic bottom - Visean bottom and top of "the Carboniferous - Lower Permian carbonates") the Novoborsk-Sozvinsk structural zone is morphologically less comparable with the lower structural level.

The Malozemelsk-Kolguev Monocline located almost in the extreme north-west of the Timan-Pechora Basin is characterized by plunging of the Paleozoic and Mesozoic lithostratigraphic units to the northeast, north and north-west towards the South Barents depression of Barents plate. The following tectonic elements of the first order are distinguished by structural characters as part of monoclines: Korginsk step, Western-Kolguev monocline, East-Kolguev structural-tectonic zone, and Malozemelsk monocline.

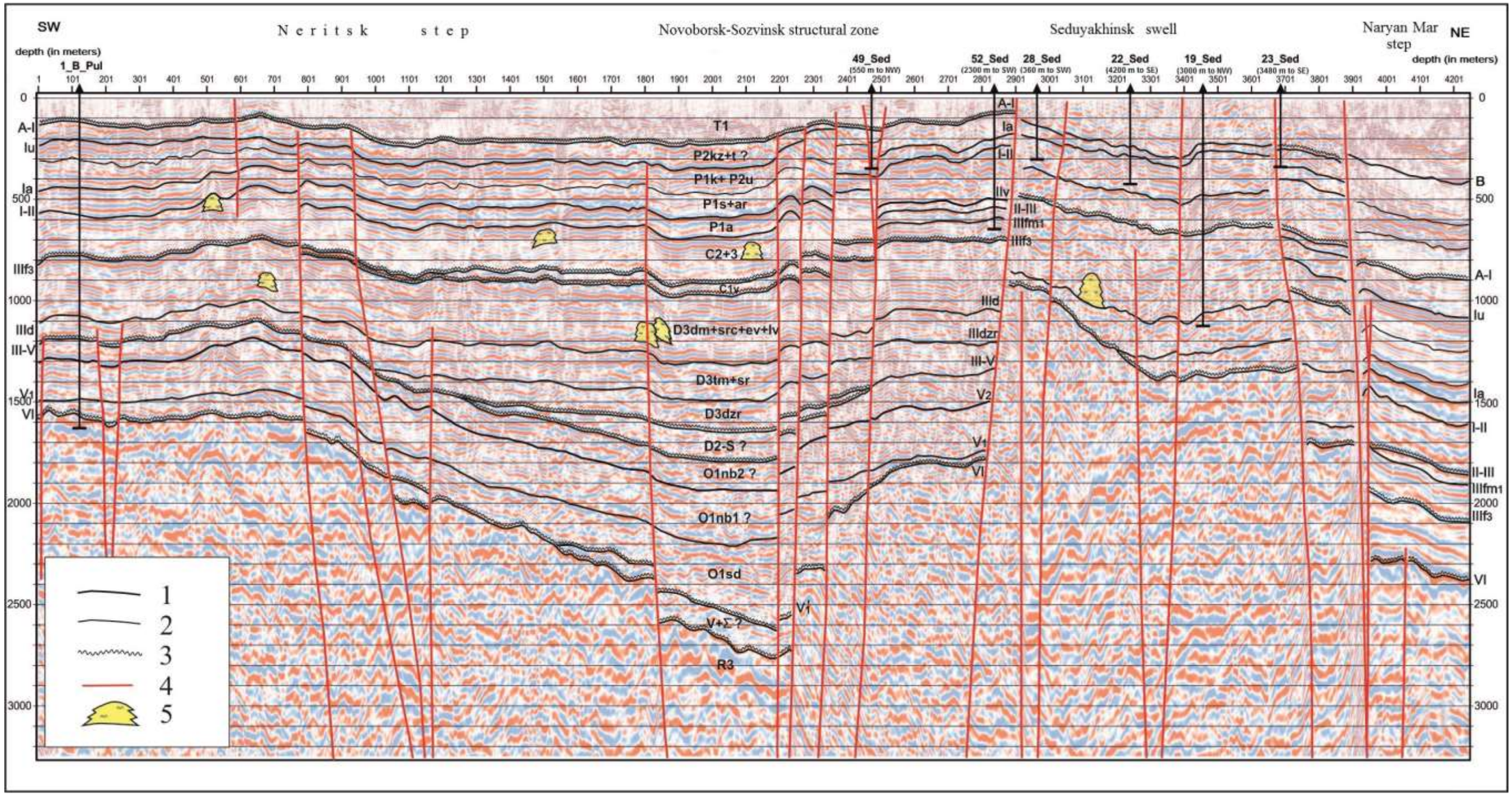

Fig. 4. Seismogeological cross-section along the P-5-10 profile line

1 – seismic marker; 2 – geological boundary; 3 – unconformity; 4 – fault; 5 – organogenic buildup. P_3kz+t - Upper Permian Kazanian + Tatarian, P_1k+P_2u - Lower Permian Kungurian + Middle Permian Ufimian, P_1s+ar - Lower Permian Sakmarian + Artinskian, P_1a - Lower Permian Asselian, C_{2+3} – Middle + Upper Carboniferous, C_1v – Lower Carboniferous Visean, $D_3dm+src+ev+lv$ – Upper Devonian (Domanik+Sirachoy+Yevlanov+Liven Fms.) Middle-Upper Frasnian, D_3tm+sr - Upper Devonian (Timan+Sargayev Fms.) Lower-Middle Frasnian, D_3dzr - Upper Devonian (Dzhersk Fm.) Lower Frasnian, S - D_2 – Silurian - Middle Devonian, O_1nb_2 – Lower Ordovician Middle Nibel Fm., O_1nb_1 – Lower Ordovician Lower Nibel Fm., O_1sd – Lower Ordovician Sedyel Fm., R_3 - Upper Riphean; Seismic markers: B – approximate top Triassic section, A-I – approximate Upper Permian – Triassic boundary, Iu – approximate top Ufimian section, Ia – top Asselian – Sakmarian section, I – II top Carboniferous section, IIv – top Visean section, II – III top Upper Devonian section, $IIIfm_1$ – bottom Lower Famenian section, III f_3 – approximate top Upper Frasnian section, IIId – bottom Domanik section, IIIdzr – top Dzhersk section, III – V – Upper Devonian section unconformity, V_2 – approximate top Nibel section, V_1 – approximate top Sedyel section, VI – top Upper Riphean basement.

Reservoirs and petroleum source rocks analyses

Regional oil and gas complexes or their fragments are identified in the northern half of Izhma-Pechora Syneclise: the Upper Cambrian – Middle Ordovician sandstone formation of the Upper Cambrian – Lower-Middle Ordovician oil and gas complex $Є_3$-O_{1-2}, Middle Devonian – Lower-Middle Frasnian terrigenous (?) oil and gas complex D_2(?) – D_3f_1, terrigenous-carbonate Middle Frasnian (Domanic)-Tournaisian oil and gas complex D_3dm-C_1t, Middle-Visean-Artinskian carbonate oil and gas complex C_1v_2-P_1ar, Kungurian formation of the Lower Permian terrigenous oil and gas complex P_1, Middle and Upper Permian and Triassic terrigenous oil and gas complex [Prischepa, Bazhenova, Bogatsky, 2010].

Due to the development of regional Lower-Middle Frasnian (Timan-Sargaev) and Kungurian carbonate-clay cap rocks and unique dynamic oil generation, migration and accumulation conditions within the northern and central parts of Izhma-Pechora Syneclise the Upper Cambrian – Lower-Middle Ordovician suite of $Є_3$-O_{1-2} and Middle Devonian – Lower-Middle Frasnian terrigenous (?) D_2(?) – D_3f_1 oil and gas complex as well as D_3dm-C_1t and C_1v_{1-2}-P_1ar oil and gas complex can be located respectively in Below-Domanic and Above-Domanic hydrocarbon systems. Within Below-Domanic system oil and gas source rocks are identified only in Middle Devonian (?) and Lower-Middle Frasnian (Dzhersk-Timan-Sargaev formation); while within the Above-Domanic system oil and gas source rocks are limited in Izhemsk level by domanikits of Domanic sequences and to a lesser extent by the clay-carbonate layers of the Upper Frasnian.

Direct indication of oil saturation sections in the northern and central parts of the Izhma-Pechora Syneclise are observed in the Lower Ordovician sandstones in the six areas (Sosyansk, Bolshepulsk, Nizev, Khabarikhinsk, East Sozvinsk, Charkayu). Increased petroleum saturation is identified in sections of the Above-Domanic hydrocarbon system (Pychsk, Sozvinsk, Charkayu and other areas). Oil accumulation in Domanic reefs and adjacent strata are found only within the Izhemsk step. Various oil flows of several viscosities were obtained from deposits of the Below-Domanic and Above-Domanic hydrocarbon systems within Mutno-Materikov and Lebedinsk swells. All the facts about the regional oil saturation indicate the flow of hydrocarbon towards the oil and gas complexes of northern and central regions of Izhma-Pechora Syneclise.

The source of this migration may be related to the zones of oil-gas-generation in D_2- D_3f_{1-2} and D_3dm-C_1t oil and gas complexes located in the most deep (up to 3.5 km) areas of Novoborsk-Sozvinsk structural zone, where the katagenesis degree is estimated to the MK_4 stages; and in oil and gas source rocks of the Lower Silurian (?), Middle and Upper Devonian section (overall thickness over 4.0 km) of Mutno-Materikov and Lebedinsk swells. The organic matter content in

the Middle Devonian – Lower Frasnian oil and gas source rocks of the swells mentioned above is 1.7-3.3% and in domanikits – up to 12.5%. Katagenesis degree of these rocks reached MK_4-MK_5 stages. The supposed reservoir for far lateral migration of hydrocarbons from these zones of oil-gas-generation can be only the Upper Cambrian-Middle Ordovician sandstones and Middle Devonian-Dzhersk clastic rocks (belonging to the Below-Domanic hydrocarbon system) in the following areas (Novoborsk structural zone, Seduyaha-Malolebedinsk megaswell, Charkayu-Kipievsk step). Open porosity of these hydrocarbon reservoirs reaches 21-23 %. As paleostructural analysis and model of dispersed organic matter maturation shown, the hydrocarbon migration to Below-Domanic system in the north and center of Izhma-Pechora Syneclise from centers of oil-gas-generation in the Middle-Late Devonian paleo-grabens of Pechora-Kolvinsk aulacogene (adjacent along the Charkayu-Pylemetsk fault to the areas of modern Charkayu-Kipievsk step and Malo-Lebedinsk swell) occurred and was active since the beginning of the Carboniferous up to Triassic. Middle and Upper Devonian oil and gas source rocks in centers of oil-gas-generation of paleo-grabens have traverced the main phase of oil generation prior to inversion of Mutno-Materkov and Lebedinsk swells at the end of the Late Permian and Triassic. The main phase of gas production coincided with active inversion of Mutno-Materkov and Lebedinsk paleo-grabens on Charkayu-Pylemetsk fault, which is obviously not conducive to the migration of gas into reservoirs of the Below-Domanic and Above-Domanic hydrocarbon systems of the north of Pechora-Izhma Syneclise, and led to its dispersion. The outcrops of the source of chloride calcium waters are related to the Charkayu-Pylemetsk fault (according to Lubomirova B.N., VNIGRI, 1959; Kushnareva T.I., UNGG, 1960).

In Izhma-Pechora Syneclise, despite the much smaller depth than in paleo-grabens of Pechora-Kolvinsk aulacogene, the Middle Devonian (?) - Sargaevsk oil and gas source rocks and Domanic reached the katagenous maturity (MK_3-MK_4) and could produce their generation potential until the end of the Mesozoic. This is explained by a significantly higher heat flow gradient from the basement into the sedimentary cover due to the presence of "granitic section". However, they did not reach the main gas generation section. Therefore, the studied territory of Izhma-Pechora Syneclise according to two sources of oil and gas generation is forecasted to be predominantly oil prone.

The lateral migration contributed to the formation of oil and gas accumulation areas in Below-Domanic hydrocarbon system. In the overlying oil and gas complexes - from the Upper Devonian to Permian - formation of oil and gas accumulation zones was possible through vertical migration along the low-amplitude fractures and favorable lithology.

Unlike the northern part of Izhma-Pechora Syneclise, there are no Upper Cambrian – Middle Ordovician basal sandstones in the mainland sector of Malozemelsk Monocline. However, they are identified on Kolguev Island in the offshore. Their thickness is greater than 1.3 km. The presence of terrigenous and carbonate rocks of the Lower-Middle Ordovician and Middle Ordovician – Lower Devonian age in Korginsk step, West Kolguev trough and Malozemelsk Monocline (which was not identified in the extreme northern half of Izhma-Pechora Syneclise) draws attention.

According to the opportunities of katagenous maturation of dispersed organic matter and paleotectonic conditions of migration flows of generated hydrocarbons the zones of oil and gas generation that feed oil and gas accumulation zones of Malozemelsk-Kolguev Monocline could occur in their buried negative structures. Such structure is the West Kolguev trough filled with the Middle Ordovician - Lower Devonian, Middle Devonian - Lower and Middle Frasnian and Domanic-Tournaisian oil and gas complex. The total thickness of these deposits is about 4.0 km. Other zone of oil and gas generation was outside Malozemelsk-Kolguev Monocline, in Denisov trough of Pechora-Kolvinsk aulacogene, where basic oil and gas source rocks are concentrated in the Upper Ordovician oil and gas complexes. The third zone of oil and gas generation is located in East Kolguev structural tectonic zone. The Lower and Middle Permian terrigenous deposits rich in sapropelic-humic organic matter can serve as source rocks here, in addition to the well-known Upper Devonian domanikits.

Oil-and-gas zonation - remarks

The updated petroleum geological zonation of the northern and central parts of Izhma-Pechora Syneclise and Malozemelsk-Kolguev Monocline was carried out on the tectonical basis considering the lithofacial, capacitive and geochemical features of oil and gas complex, analysis of zonal conditions of formation and distribution of hydrocarbon deposits with distinguishing of oil and gas regions (see Fig. 1).

As part of the northern segment of Izhma-Pechora oil and gas region the selection of the following districts is substantiated: Pre-Timan, Ersinsk, Nizhneizhemsk, Seduyahinsko-Kipievsk, and Verhnelyzha-Lemyu. Oil and gas regions usually belong to one or two tectonic elements of the first order, but may also include the structures of a lower order too. An important argument for substantiation of the region is the similarity of oil and gas accumulation zones in terms of formation conditions and phase composition of hydrocarbons accumulation [Prischepa, 2008].

Evaluation of hydrocarbon resources

Evaluation of hydrocarbon resources of the northwestern part of the Timan-Pechora Syneclise, which includes the northern and central areas of Izhma-Pechora region and Malozemelsk-Kolguev oil and gas region, had been carried out using an approach developed in VNIGRI based on use of comparative geological analogies for assessment of oil and gas accumulation zones and integrated use of the results of geochemical modeling [Neruchev et al, 2006; Bazhenova et al, 2008; Prischepa, 2011; Prischepa et al, 2010].

Total hydrocarbons resources (in-situ) in promising areas of oil and gas accumulation on the studied area of Izhma-Pechora Syneclise is estimated at 1.4 billion tons oil equivalent. The priority of liquid hydrocarbons is assumed - 1.1 billion tons. The Novoborsk area is characterized by the highest estimate values in terms of the sum of the resources confined to the areas of oil and gas accumulation zones overlapping (367 million tons oil equivalent).

The next stage of the study of the northwestern areas of the Timan-Pechora hydrocarbons province will be the completion of the network of regional seismic profiles and creation of crosscuts to optimize locations of parametric wells and their subsequent drilling activity. The results of drilling will provide the opportunity to draw conclusions on the development of reservoirs and possible oil and gas source rocks, clarify parameters of forecasted oil and gas systems, assess the extent of the generation and accumulation, and thus prepare a new direction for large-scale exploration, associated with newly identified major buried structure (Novoborsk swell) and previously un-estimated complex (Cambrian ? - Lower Ordovician terrigenous).

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