Detection of potential reservoirs of the Mezen syneclise of the Eastern European platform

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Abstract. The possibility of discovering new hydrocarbon deposits within the north-eastern segment of the European part of Russia will reduce the cost of transporting hydrocarbons to major industrial centres. And access to Russia's most important transport artery, the Northern Sea Route, in the context of the growing importance of the tanker fleet and reorientation of sales markets proves the need to build up the region's resource base. However, it is necessary to take into account the environmental and climatic risks associated with hydrocarbon production in the Arctic conditions, as well as their transport. This paper presents the data of paleoreconstructions of sedimentation settings of Precambrian sedimentary strata in the light of updating the history of development of the Mezen-Belomr region and studying the reservoir properties of the Riphean-Wendian part of the sedimentary cover section. As a result, formations with enhanced filtration-capacity properties were identified. The Vendian part of the section is characterised by good values of open porosity (up to 20.89%).

1 Introduction

The depletion of conventional reserves in the main oil and gas producing regions determines the need to search for hydrocarbon deposits in hard-to-reach regions, areas of difficult geological structure, in deep water and in new areas of their possible detection: at large depths, in ancient sediments and basal complexes, in shallow and low permeability reservoirs [1].

Significant commercial discoveries and project successes in many sedimentary basins in China [2, 3], on the shelf of the Gulf of Mexico [4] and Brazil (Santos, Campos) [5], as well as theoretical elaborations allowed to refine the possibilities of generation and preservation of hydrocarbons (including liquid hydrocarbons) at large depths [6].These reasons explain the interest in the strata of basal horizons of ancient platforms [7], basement protrusions [8, 9], and transitional (between basement and sedimentary deposits) complexes.

On the territory of Russia, hydrocarbon deposits of ancient Precambrian sediments have been detected in the southern part of the Siberian [10] and essentially eastern part of the East European ancient platforms. However, there are prerequisites for the detection of oil

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and gas accumulations in the northern part of the Siberian Craton (Anabaro-Lensky region [11, 12]) the north-east of the East European Platform (Mezen syneclise [13], Moscow syneclise [14, 15]) and the south-east of the East European Platform (Kamsko-Belsky avlacogen) [16].

One of the least studied structures within the northeastern part of the East European Platform is the Mezen Syneclise [17]. The Mezen Syneclise and the modern White Sea basin (Mezen-White sea tectonic segment) (Fig. 1.) can be considered as a tectonically unified structure [18] taking into account the history of evolution at the early stage of formation.

The formation of the Mezen-White Sea segment is associated with continental riftogenesis in the Riphean [19], preceding the onset of general deflection and formation of the sedimentary cover of the Mezen syneclise and caused by the collapse of the Paleopangaea during the Baltica and Laurentia rifting [20].

The Mezen-White Sea segment is rectangular in shape with a general extension in a north-north-west direction. The total length is 390 km, within the Arctic zone under consideration it is more than 230 km long and the average width is 330 km. The total area is 110,000 km^2, of which 56,000 km^2 are in the Arctic segment and 9,000 km^2 are located in the White Sea.

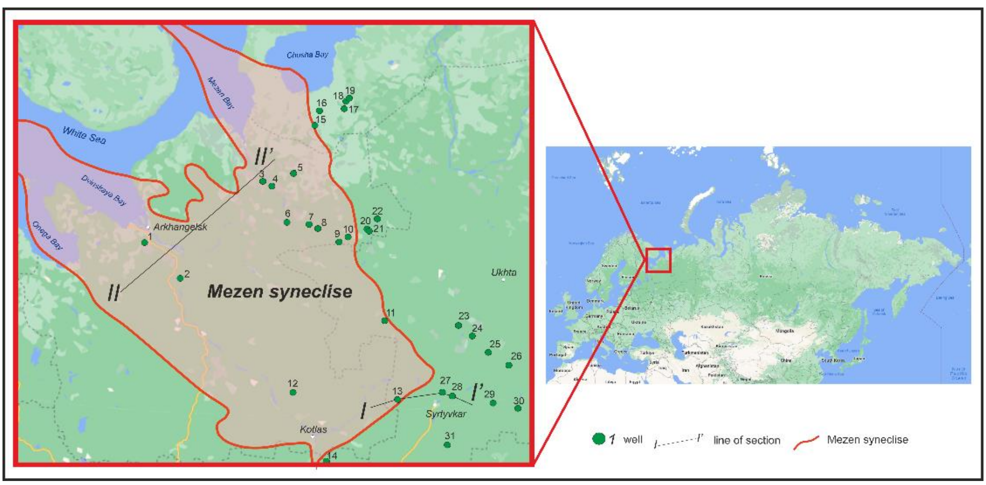

Fig. 1. Location of the Mezen syneclise. Wells: 1-Arkhangelsk, 2-Ust-Pinezh, 3-Ust-Nyaftin 1, 4-Srednenyaftin 21, 5-Safonov 1, 6-Leshukon 1, 7-Selishche 2, 8-Tsenogor 1, 9-Manbas 3, 10 -Koinass 1, 11-Elkib 1, 12-Uftyug 1, 13-Yaren, 14-Kotlas 1, 15-Omen 1, 16-Nezhnepesh 1, 17-Zavorotnaya 3, 18-Zavorotnaya 2, 19-Zavorotnaya 1, 20- Nizhnesul, 21-Koinas OP, 22-Fomin 45, 23-Bolshie rapids, 24-Veslyana-1, 25-Griva, 26-Nivshera, 27-Seregov, 28-Storozhev, 29-Anyb-1, 30-Yelmach-Parma , 31-Sysol).

Multiple geological explorations (including deep drilling) for oil and gas in the Paleozoic and Upper Proterozoic sediments within the Mezen syneclise landmass have not allowed to fully assess the prospects of oil and gas potential of the territory bordering the Timan-Pechora oil and gas province, which is characterised by a wide range of identified oil and gas accumulations and partly similar structural features.

Utterly inferior estimates of the hydrocarbon potential of Precambrian sediments [21] forced to search for new arguments for renewed interest in the region, rethinking of the previously received results and searching for the reasons that prevented a positive estimation of the possibility of generation and preservation of hydrocarbon accumulations in the ancient strata. At the same time, the existence of two hydrocarbon systems (Early-

Middle Riphean and Upper Riphean-Vendian) and three possible oil and gas producing formations (Pezk (Middle Riphean), Safonov (Upper Riphean), and Ust-Pinega (Upper Vendian)) is assumed [22]. Also, the infiltration mode of water exchange in Palaeozoic and Mesozoic low thickness parts of sediments in the absence of own generation potential was revealed [23, 24].

One of the most argued reasons for this is the presence of "catagenetic discord", which led to the destruction of ancient deposits as a result of pre-Wendian and pre-Paleozoic erosion (according to the terminology of Bazhenova T.K.) [25].

The features of sedimentary cover formation within the Mezen syneclise conform to the patterns typical of plate regions, which include the East European Platform [26]. One of the important geological features of the structure of the platform cover of the marginal part of the East European Platform is the presence of a series of rifts (avlkogenes) of the Riphean age. The depth of the basement in avlacogens averages 3-5 km, reaching 7-10 km only in the eastern peripheral parts of the platform. The major thickness of the sedimentary cover is in the pre-Palaeozoic sediments, sediments of the Palaeozoic age do not exceed 1.5 km [27].

The rifted grabens of the syneclise are a system of subparallel zones diverging radially to the northwest [28]. The total length of the rift system (including the part under the White Sea) exceeds 1000 km with a width of 300 to 500 km. From the northeast, the rift system is overlapped by the marginal suture of the Timan-Varanger Baikalid system [29].

2 Materials and methods

The research of the reservoir potential of sediments of the Mezensk-Belomorsk segment is based on the generalisation and analysis of geological and geophysical data using new data on the geological structure of the sedimentary cover of the Mezenskaya syneclise received from the results of VNIGRI researches, processing of parametric well data and data from the Sredne-Nyafta-21 well.

The volume of geophysical research of the Mezen syneclise does not allow the use of modern methods of reconstructing sedimentation conditions using seismic data, which would allow the creation of an objective model of the formation of promising complexes. Areal seismic surveys cover about 7% of the territory [30]. Area seismic surveys are required to completely estimate the reservoir potential of an unexplored region. Modern methods of seismic data interpretation, which allow to estimate the reservoir potential of sediments, include AVO-analysis technology (amplitude-variation-with-offset) and one of its modifications based on the concept of extended elastic impedance -EEI. The application experience of EEI proves that this technology is successful in the research of terrigenous reservoirs [31], which suggests that this technology can be successfully used in the research of ancient strata of the Mezen syneclise. It should be mentioned that modern seismic acquisition techniques are effective for surveys in regions with a short seismic acquisition season, such as the Mezen syneclise, for example using lightweight autonomous nodes [32].

Within the entire Mezen syneclise, only 16 deep basin-scale, parametric and exploratory wells [14] and 15 shallow structural exploratory wells were drilled. No drilling was carried out in the White Sea.

3 Results

The structure of the Upper Proterozoic sediments of the Mezen syneclise is recognized to be almost identical to the same-aged sediments of the Moscow Syneclise [33]. Riphean sediments are almost ubiquitous. The thickness of the deposits reaches 10 km [34]. The

Riphean deposits are overlain by the Vendian strata (mainly the upper part). The section of deposits of the Mezen synecliseis presented in Fig. 2.

The main distinctive feature of the Mezen syneclise is the three-layer structure of the sedimentary cover consisting of synrift, syneclise and slab complexes [17], the active sedimentation of which occurred on the Timan passive margin during the Riphean–Vendian–Early Paleozoic.

In the sedimentary cover of the syneclise, two promising oil and gas complexes are distinguished: Riphean and Vendian [35]. The Riphean complex (corresponding to the synrift stage of development) is represented predominantly by terrigenous rocks with rare limestone interlayers. The thickness of the complex is up to 2.5-3 km [36].

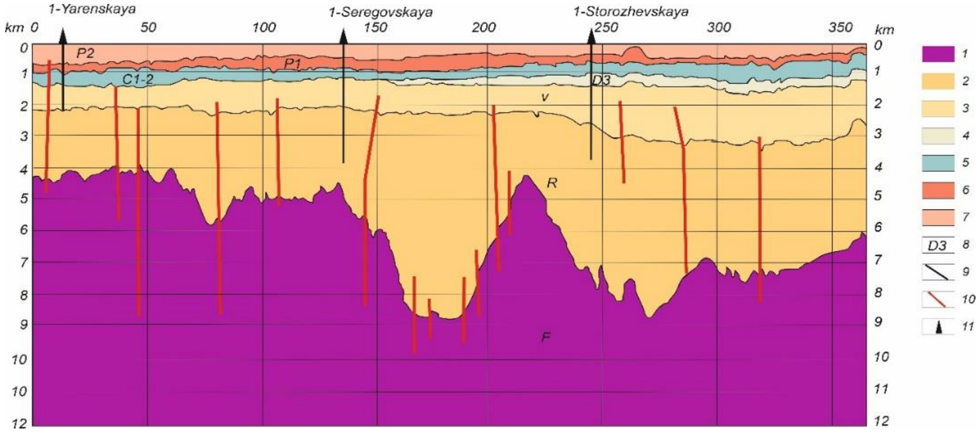

Fig. 2. Section of the Mezen syneclise ([26] with additions by the authors)
1 – crystalline basement rocks; 2 – Riphean sediments; 3 – Vendian deposits; 4 – Devonian deposits; 5 – coal deposits; 6 – Early Permian deposits; 7 – deposits of the late Permian; 8 – indexes; 9 – borders of reflecting horizons; 10 – break violations; 11 – wells.

The Vendian complex (syneclise stage of development of the region) is thinner and is represented by interbedded sandstones, siltstones and mudstones with rare interlayers of tuffaceous and carbonate rocks. A section of the sedimentary cover of the north of the Mezen synecliseis presented in Fig. 3.

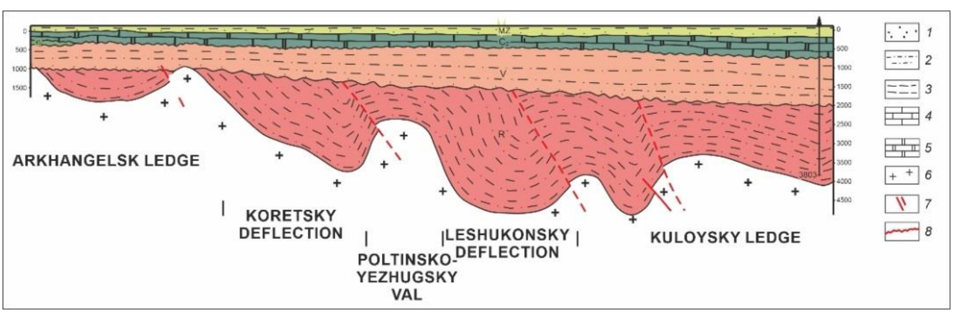

Fig. 3. Section of Mezen syneclise
1 – sandstones; 2 – siltstones; 3 – mudstones; 4 – limestones; 5 – dolomites; 6 – crystalline rocks of the foundation; 7 – tectonic disturbances; 8 – disagreements and blurring.

The article adopted the stratigraphic scheme outlined in [37]. In Riphean times, the marginal part of the platform had marine sedimentation environments. The sedimentary material is represented predominantly by clayey gray deposits. This is evidenced by the lithological characteristics, cyclical nature and consistency of the structure of the Riphean section uncovered by wells.

The lower part of the section is composed of Middle Riphean sedimentary strata, which fill graben-like zones. The deposits are represented by ***the Yaren*** and ***Pezhsk*** formations, which are composed predominantly of dark gray mudstones with interlayers in the upper part of fine-grained sandstones. The total thickness of this complex reaches 1.5 km [18].

In the Upper Riphean deposits of the Mezensyneclise, three formations have been identified: ***Dorogor***, ***Omen***, ***Nyaftin***. The Omen and Nyaftin formations are combined into ***the Safonov*** series.

The Dorogor Formation rests unconformably on underlying sediments and is represented predominantly by brownish sandstones. Members of dark gray mudstones are present. The thickness of the formation is 560-573 m. Sandstones of the Dorogor formation accumulated under conditions of long-term sedimentation, since they are distinguished by good roundness, but at the same time they could be buried quite quickly in sediment, which is determined by poor sorting of grains. It is likely that most of the syneclise acted as a periodically inundated plain (Fig. 4A.).

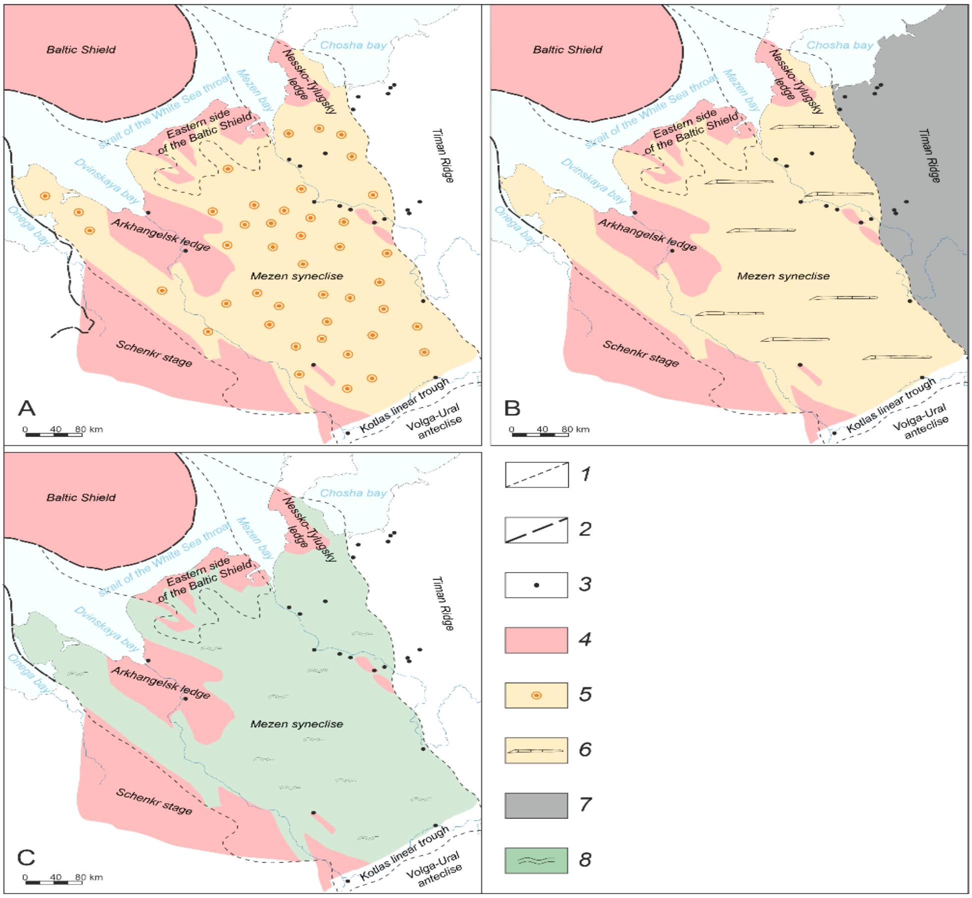

Fig. 4. Schematic lithofacies map of Upper Riphean deposits.

1 – supra-order structures; 2 – first order structures; 3 – well designations; 4 – crystalline basement rocks; 5 – coastal; 6 – shallow sea basin; 7 – open sea pool; 8 – tidal plain.

Two types of ***the Omen*** Formation section are distinguished within the syneclise: western (platform) and eastern (subgeosynclinal) (Fig. 4B.). The boundary between them is controlled by the marginal suture separating the Epicarelian and Epibaikalian basements of the Russian Plate. The thickness of the Omen Formation increases eastward from 406 m to 736 m.

The western type of section is characterized by interbedded mudstones, sandstones, dolomites, limestones, marls and siltstones, typical of a shallow marine basin. The eastern type of section is dominated by mudstones and siltstones. Sandstones, in contrast to the western type, are sharply subordinate. The rocks are characterized by oblique layering. The sediment of the eastern section type was accumulated in an open sea basin.

The Nyaftinskaya Formation is distributed practically throughout the entire Mezensky Basin. Its thickness does not exceed 200 m. The Formation lies in accordance with the underlying sediments, but with erosion and stratigraphic disagreement it is overlain by the red-colored Uftyug Formation of the Upper Vendian. The formation is represented by interbedded marls, dolomites with interbeds of mudstones, siltstones and rare sandstone interbeds. The sediments of the Nyafta Formation were probably accumulated in the facies conditions of tidal flats of a shallow epicontinental basin (Fig. 4C.), as indicated by interlayers of dolomitic rocks and relict stromotolite structures.

Within the Mezen syneclise, the thickness of Vendian deposits increases eastward due to an increase, mainly, in the thickness of the lower unit of the Vendian complex, which is maximum in the Pritiman part.

The Upper Vendian deposits are divided into four formations: ***Uftyug***, ***Ust-Pinega***, ***Mezen*** and ***Padun***. The last three are combined into ***the Valdai*** series, forming a single transgressive-regressive sedimentation cycle.

The Uftyug Formation is represented predominantly by red-colored sandstones of various grains, turning into gravelites toward the top. Sandstones of the Uftyug Formation often appear as sand in thin sections. It is characteristic that the rather high porosity of the sandstones of the formation has a consistent character. Power up to 350 m.

The accumulation of sediments of the Uftyug strata is associated with the collision of the East European Platform and the Pechersk Plate, as a result of which the rising sections of the territory are actively eroded. As a result of erosion and redeposition of sediments, sandstones are formed, enriched with the most resistant to destruction mineral - quartz. The pelitic component of the eroded sediments is mostly carried out beyond the territory under consideration. The variegated color of sediments suggests that aerial conditions, combined with the absence of microbiota, are characteristic of alluvial-proluvial continental sedimentation environments (Fig. 5 A). The deposits have a molassoid appearance.

The Ust-Pinega Formation is developed everywhere and lies transgressively on the surface of the Uftyug Formation. It is composed of dark mudstones with interlayers of siltstones and sandstones; in its composition and acritarch complex [38] it is comparable to the Redkin Formation of the Moscow syneclise. The thickness of the Ust-Pinega formation ranges from 290-751 m.

There are two types of sections: southwestern and northeastern (Fig. 5B.). The northeastern type of section developed in the Pritiman part, the most characteristic feature of which is the presence in its section of interlayers and lenses of sandy-silty tuffs and tuffites, indicating short-term outbreaks of volcanic activity. The accumulation of sediment in both parts of the section occurred in continental shallow conditions with drying lake-type reservoirs.

The Mezen Formation is developed over most of the territory, with the possible exception of the northwestern region of the White Sea and the Pesh Depression. The formation is represented by interbedded siltstones and sandstones. The thickness of the formation varies from 302 m to 673 m. Sediments of the formation accumulated in a

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shallow marine basin (Fig. 5C.), as indicated by poor sorting of the material and brown tints of the rocks.

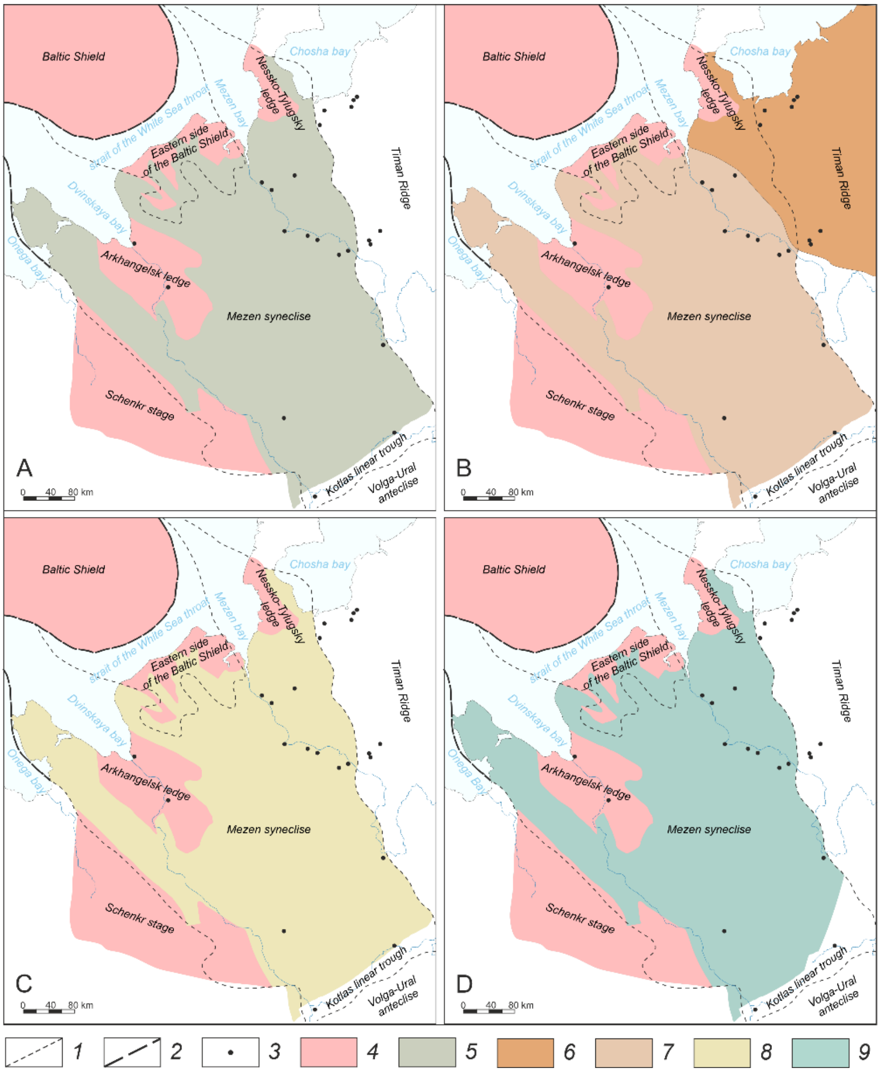

Fig. 5. Schematic litho-facies map of Vendian deposits
1 – supra-order structures; 2 – first order structures; 3 – well designations; 4 – crystalline basement rocks; 5 – alluvial-proluvial deposits; 6 – continental lake-type reservoirs with short-term outbreaks of volcanic activity; 7 – shallow interflowing lake-type reservoirs; 8 – shallow-marine; 9 – plain periodically flooded by the sea.

The section of ***the Padun Formation*** is composed of interbedded siltstones, clays and sandstones. The rocks are variegated. The thickness of the formation varies from 65 to 294 m. Variegated rocks indicate the accumulation of sediment in a plain periodically flooded by the sea (Fig. 5D.).

The Mezen and Padun formations correspond to the regressive part of the sedimentation cycle.

4 Reservoir properties

Riphean deposits are characterized by reduced reservoir potential. Porosity varies from 0.27 to 9.41% (Omenwell), with median values ranging from 0.87-4.9%. Increased indices of filtration and reservoir properties of Riphean sediments are associated with the development of fractured and porous-fractured reservoirs in zones of tectonic activation.

In Vendian deposits there is a slight improvement in reservoir properties. In the Uftyug Formation (lower Vendian), the average open porosity ranges from 6.85 to 10.05%, permeability ranges from 0.17 to 2.73 mD, with a maximum of 16.13 mD in the well. Uftyug-1. Despite this, the Uftyug formation is considered one of the most favorable in terms of reservoir properties.

The overlying Ust-Pinega formation has much worse reservoir properties. Mudstones in the section of the Ust-Pinega formation make up from 70% to 90% of the entire thickness of the section, which makes it possible to unambiguously classify this sequence as screening. The cover of the (Ust-Pinega) formation is the most homogeneous in structure, composed of an almost monotonous clayey strata.

The group of medium and medium-high pore rocks includes the rocks of the Mezen and Padun formations, i.e. the upper half of the Vendian of all areas studied by drilling.

The rocks of the Mezen and Padun formations have enhanced reservoir properties in all areas studied by drilling. In terms of reservoir parameters, the Padun Formation is slightly superior to the deposits of the underlying Mezen Formation. Potential reservoirs are of the pore type. The maximum value of open porosity does not exceed 20.89%.

In the Omen-1 and Ust-Nyafta-1 wells, mudstones with siltstones separating the sandstones of the Mezen and Padun formations are supposed to be fluid seals, and in the well. Leshukon-1, siltstones interbedded with mudstones themselves can represent either reservoir rocks or semi-cap rocks due to increased porosity values.

The decompression of rocks and high porosity are confined to the Riphean-Vendian boundary (Uftyug Formation), to the top of the Vendian (Padun Formation), and to large breaks in sedimentation, which can be explained by processes associated with supergenesis.

There is a dependence of the open porosity of sandstones on the depth of their occurrence and, accordingly, on the degree of transformation of the rock. The decompression of rocks and high porosity (loose rocks) are confined to the Riphean-Vendian boundary (Uftyug Formation), to the top of the Vendian (Padun Formation), and to large breaks in sedimentation, which can be directly related to the processes of supergenesis.

It can be summarized as follows:

- the physical properties of Riphean rocks indicate low reservoir potential, there is practically no porous reservoir;

- in the Vendian there is an improvement in reservoir properties relative to Riphean deposits. In the lower part of the Vendian (Uftyug Formation), one can expect the development of porous-fissure type reservoirs. In the upper part of the Vendian (Mezen and Padun formations) there are reservoir rocks of class V-IV-III. The rocks of the Padun suite (II-III reservoir class) have the highest capacitive and filtration potential.

The shielding strata for the reservoir rocks of the Mezen and Padun formations can be Paleozoic sulfate-carbonate deposits;

- the Ust-Pinega formation is unambiguously classified as a regional screening sequence;

- good reservoirs are found in Paleozoic deposits, but they are shielded by low-quality zonal seals, so long-term preservation of the supposed hydrocarbon deposits in this strata is unlikely.

5 Discussion

The work assessed the reservoir potential of pre-Paleozoic deposits of the Mezen-White Sea segment. The problems of assessing the oil and gas potential of the Mezen syneclise and the adjacent part of the White Sea are associated with a number of factors:

– extremely low level of knowledge of the basin using geophysical methods and drilling;

– small thickness of the Paleozoic part of the sedimentary cover;

– large-scale stratigraphic unconformity separating the base of the oil and gas system and potential Paleozoic reservoirs with high reservoir potential;

– active hydrodynamic regime, promoting the destruction of potential accumulations of hydrocarbons in potential Paleozoic reservoirs;

– low values of filtration and reservoir properties and the difficulty of predicting fractured zones of sediments of the Riphean complex;

– difficulties in predicting porous-fractured reservoirs of the most promising Riphean deposits;

– lack of wells in the shelf part.

Thus, the Precambrian deposits of the Mezen syneclise have rather low reservoir properties. In general, the following patterns can be identified:

- the physical properties of Riphean rocks indicate low reservoir potential, there is practically no porous reservoir;
- in the Vendian there is an improvement in reservoir properties relative to Riphean deposits. In the lower part of the Vendian (Uftyug Formation), one can expect the development of porous-fissure type reservoirs. In the upper part of the Vendian (Mezen and Padun formations) reservoir rocks are found. The rocks of the Padun Formation have the highest capacitive and filtration potential;
- it is possible to identify traps of a non-anticlinal type associated with local zones of development of improved reservoirs.

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