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Oil and gas potential of the Aldan-Maya depression

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Abstract. The prospects of oil and gas potential of the Aldan-Maya depression, located in the south-eastern part of the Siberian platform, are considered. The lithological-stratigraphic characteristic of the Riphean-Cambrian section has been given, and the compositional features of the organic matter and its bituminous part have been considered. Based on the analysis of geological development history and the seismic exploration results (2014), the platform part territory of the Aldan-Maya depression along the western border expanded to the middle flow of the Amga River. Three main oil and gas potential reservoirs were separated in the cross section of the depression on base geological and geochemical data. The most prospective areas are the middle flow of the Ingili River (the right inflow of the Maya River), where crystal basement is on the surface (Khabarovsk region), and row anticline structures at adjacent platform part near the Aldan-Amga interfluvium of the Republic of Sakha (Yakutia).

According to the seismic exploration data of Yakutskgeofizika OJSC (2014-2016), six local low-amplitude structures of submeridional strike were identified: Belkachy, Bilir, Taryng-Elga, South-Bilir, Mil, Taryng. In our opinion the Belkachy local structure located on the western margin of the Aldan-Maya depression could be the most prospective object. In its western pericline, an oil seepage is detected on the surface. In conclusion we suggest at a long-term perspective to prolong research on oil and gas potential of the upper part of the Malgin suite of the Middle Riphean as a prospective area of shale oil and gas.

Key words: Aldan anteklise, Aldan-Maya depression, Malgin suite, domanicoid deposits, prospective oil and gas bearing complexes, shale oil

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Introduction

The Aldan-May Depression (AMD) is located on the territory of the Republic of Sakha (Yakutia) and the Khabarovsk region. The AMD borders by the Predverhoyansk depression in the north, it overlaps on the eastern slope of the Aldan Anteklise in the west and southwest, it is bounded by the Nelkan-Kyllakh thrust zone of the South Verkhoysk fold belt in the east.

As result of the investigations carried out to date, the territory of the AMD covered by geological surveys, aeromagnetic and gravimetric surveys of scales 1:1,000,000 m 1:200,000. Electrical survey work was carried out to a limited extent. From 1976 to 1979 seismic surveys were conducted by the reflection method (RM) on a single observation system, in the period 1980-1984 – by the common depth point method (CDP) of six-twelve profiling. During 2005-2012 Yakutskgeofizika OJSC engaged in regional seismic

surveys using the common depth point method (CDP-2D) at the Aldan-Maya, East Aldan, Khandyga and Yudomo-Maya (Khabarovsk region) sites with a total volume of 2910.3 linear km. according to the method of CDP sixty profiling. In 2012-2014 a seismic survey within the Amgino-Aldan object covered an insignificant part of the territory under consideration (200 linear kilometers). The total volume of seismic profiles within the AMD amounted to 5509.3 linear km and the achieved density is 0.09 km/km² (in the old AMD boundaries).

The AMD section was studied according to deep drilling data in the wells: Ust-Maya-366, Mokuyskaya-1, Lakhandin-1, Khochom-1 and Dzhebariki-Khaya.

According to the geological and geophysical data and the results of deep drilling in the modern structural plan the AMD sediments on the base of the Malgin suite are monoclinical and plunge sharply in the zone of Nelkan-Kyllakh thrusts (Fig. 1).

The sedimentary cover of the AMD is consisted of the Riphean-Vendian-Cambrian terrigenous-carbonate rocks with 7-8 km depth. The Lower Riphean sediments are by red-colored oblique quartz sandstones, gravelites and conglomerates and overlapped by dolomites. The Middle-Riphean sediments within the AMD

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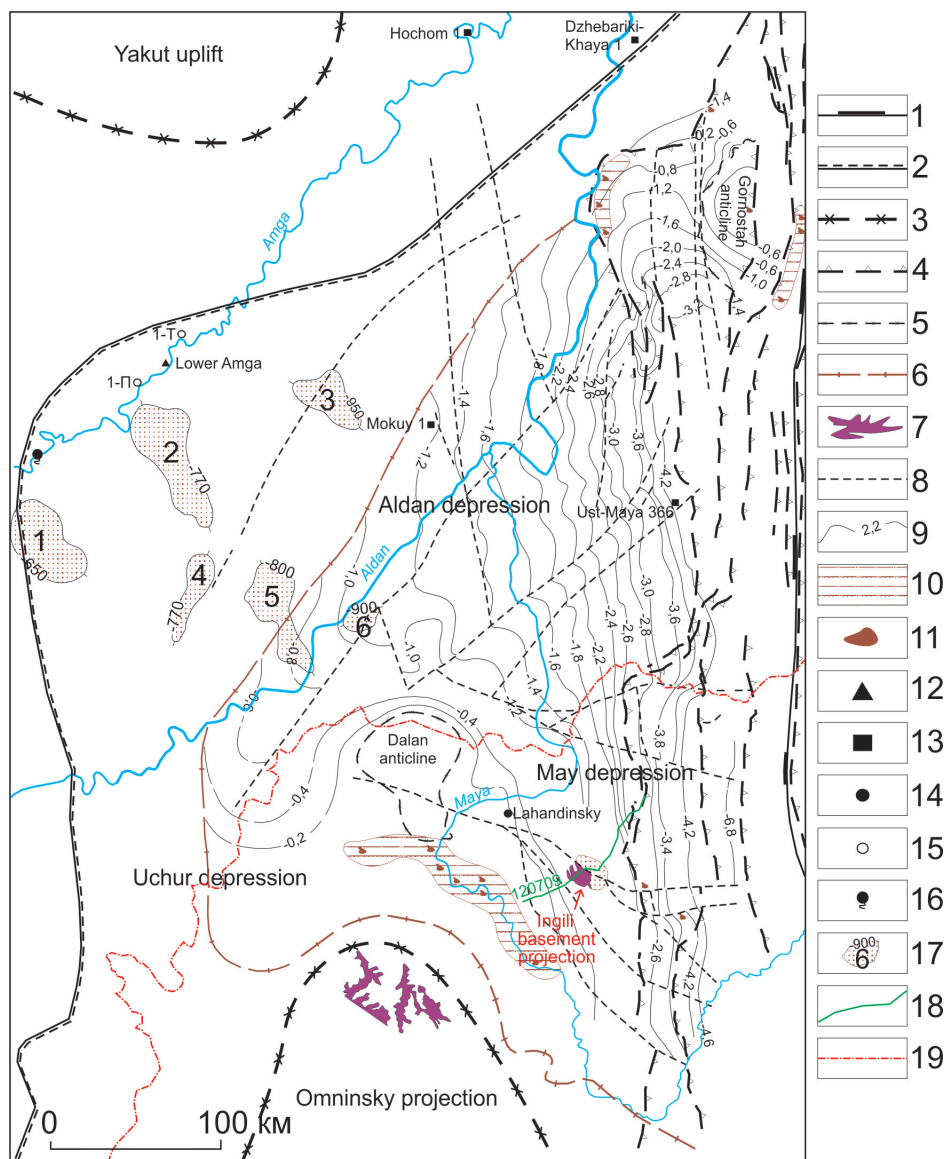


Fig. 1. The structural-tectonic scheme of the Aldan-Maya depression along the base of the Malgin suite (according to the data of OJSC Yakutskgeofizika with revisions and additions). Legend: boundaries: 1 – above-order structures; 2 – Aldan-Maya depression; 3 – structures of the first order; 4 – Nelkano-Kyllakh zone; 5 – local structures; 6 – pinching out of the Malgin suite; 7 – outcrops of basement rock; 8 – tectonic disturbances; 9 – isogips of the base of the Malgin (km); 10 – outcrops zones of oil shales; 11 – rocky outcrops of the oil shale of the Malgin suite; wells: 12 – key hole, 13 – parametric, 14 – core, 15 – hydrogeological; 16 – seepage; 17 – prospective structures on the base of the Vendian deposits: 1 – Belkachin, 2 – Bilir, 3 – Taryng-Elga, 4 – South Bilir, 5 – Mil, 6 – Taryng 18 – seismic profile 120709, 19 – administrative border of the Republic of Sakha (Yakutia).

lie in the Lower Riphean. The Middle and Upper Riphean shallow, marine, and lagoon-marine sediments consist of: dolomites, limestones, marls, sandstones, siltstones, and shales (Nafikov, 2013). Insignificant in thickness terrigenous rocks (sandstones, aleurolites and mudstones) of the Ukugut suite of the Lower Jurassic occur at different stratigraphic levels of the Cambrian and Vendian deposits.

In our opinion, in the Later Precambrian and the Early Paleozoic, the AMD was a part of the Upper Proterozoic-Lower Paleozoic passive continental margin of the east of the Siberian Craton. In the Middle Paleozoic (Mid-Upper Devonian), this continental margin has undergone rifting (Safronov, 2017). In the

Late Jurassic-Early Cretaceous, in the process of closing the Oimyakon oceanic basin, the tectonic plates of the South Verkhoyansk folded belt were thrust over the Riphean-Lower Paleozoic monocline.

From the point of the bitumensaturation the AMD cross section has no analogues among other zones of the adjacent platform structures with a folded belt along the entire perimeter of the Siberian platform (the Baikal-Patom folded belt, the Taimyr zone, the West Verkhoyansk fold belt). Here are widely spread various naphthides – from syngenetic bitumens to liquid oil, viscous and solid natural bitumens.

This was due to a large number of factors. In our opinion, the main of them was a high bio-productivity

of the Riphean marine sedimentation basin, in which aquagene organic matter (OM) accumulated in terrigenous-carbonate sediments. As an unfavorable factor could possibly be an absence of reliable regionally sustained beds of fluid saturated rocks (salt-bearing and clayey formations), although in some areas there is an optimal combination of subcovers and reservoirs. The subcovers within the AMD may be clay differences of carbonate sediments, aleurite-argillite strata, etc. It should be noted that within the Nepsko-Botuobinsky Oil and Gas Region, the Botuobinsky horizon, containing the main reserves of oil and gas, is screened by a from 17 to 20 m bench of dolomites with anhydrite and anhydrite-dolomite interlayers.

At the same time, the territory of the AMD is still poorly studied, and in all published maps on oil and gas bearing it has the category of unprospective.

In the AMD cross section, following V.L., Stavtsev (1976) and others, we identify with some revisions three intervals with a favorable combination of source rocks, reservoirs and screening benches: Algin-Zipandinsky, Lahandin and Vendian (Stavtsev et al., 1976; Shishkin et al., 2010; Berzin et al. 2011; Nafikov, 2013).

First of all, it is the upper part of the section of the Malgin suite which consists of black bituminous limestones 15-30 m thickness. By many researchers the enriched with OM bituminous (domanicoid) rocks are considered as oil source (Bazhenova et al., 2011; Bazhenova, Margulis, 2014 Chalaya et al., 2015). In the section of the suite near the Malgin Rock (Maya River), a domanicoid bench thickness is 14 m. From the bottom to the top a massive microgranular light gray bituminous limestones dominate as occasionally with cavities filled with viscous dark brown bitumen. Upper along the section, there are interlaying of gray, microgranular limestones with fine-grained dark gray to black clayey limestones. It should be noted that in the north-east of the AMD, closer to the folded zone, the thickness of the Malgin suite increases up to 400 m, the upper bituminous part reaches 140 m.

The Maya center of oil and gas generation relates with the Malgin suite and is most enriched in OM. This was the most productive in the reef of the Siberian platform, but the safety of the generated hydrocarbons was low. According to some researchers, the total quantity of emigrated liquid hydrocarbons is 204.6 billion tons, gaseous – 73.5 trillion Nm³ (Bazhenova et al., 2011).

The Lakhandin series of the Late Riphean is composed of two suites: the Neryuen and Ignikan. The series consists of a complex of terrigenous and carbonate rocks. On the southern eroded board of the AMD in the upper third part of the Neryuen suite, numerous lenses of brecciated sandstones several kilometers long were installed, which indicate a wide spread of the processes of lateral migration.

The Vendian sediments obviously did not fully enter in the main zone of oil generation. Perhaps, only the lowest horizons generated liquid hydrocarbons at the time of formation the Lower Jurassic sediments. At the same time, liquid oil with gas bubbles were noted at intervals of 946-966 m and 980-1991 m in the core of the Nizhneamgin well, extracted from the Tolbin (analogue of the Buyagin) suite of the Vendian. It is noted that giant and large oil and gas fields in the Nepsko-Botuobinsky Oil and Gas Region of the Leno-Tunguska Oil and Gas Province are related with the Vendian deposits.

Research methods

The complex analytical methods for OM study included determining of a content of organic carbon in the rock (C_{org}), hot extraction of bitumen from rocks with chloroform (CB), determining of group component composition using column chromatography and structural group composition of CB and their fractions using IR- Fourier spectroscopy «Protege 460» of «Nicolet» in the range of wave numbers 500-4000 cm⁻¹. As well as chromatography-mass spectrometry was used for studies of saturated HCs on a GC/MS system including an Agilent 6890 gas chromatograph interfacing with an Agilent 5973N high performance mass-selective detector. In general, 19 samples from Riphean sediments were analyzed from sections of the Malgin, Zipandin and Lahandin suites along the Maya River in the area from the village Nelkan down to the village Aim, and on 25 samples along sections from the Omnia River mouth along the Aim River (left inflow of Maya River) down to the Yudom River mouth on the Maya River.

Experimental part

According to our own analytical studies and the results obtained by other researchers, the C_{org} content in sapropelic marls and limestones of the Malgin suite ranges from 0.7 to 6-9%; in the layers of oil shale, it is comparable to that in the domanicoid horizons of 13-15% (Bazhenova et al., 2011; Bazhenova, Margulis, 2014; Chalaya et al., 2015). It was determined that the rocks of the Malgin suite were to 3000 m depth. The level of catagenetic transformation OM of Riphean rocks on the southern periphery of the AMD measured up to the thermodynamic conditions of the main zone of oil generation – MK₂. According to our data, the CB yield on the rock is from traces up to 0.136-0.278% and higher values 0.440-0.530%, which is higher than the content of CB in the rocks of the overlying Zipandin suite and the Lahandin sedimentary series. Methane-naphthenic hydrocarbons (63-88%) dominate in the hydrocarbon composition of the CB of the Malgin suite, as well as in all bitumoids from the rocks of the Late-Middle Riphean section. According to the results of GC/MS, the composition of saturated hydrocarbons

is characterized by the dominance of n-alkanes 69-80%, low ratio of isoprenoids to n-alkanes (0.1-0.2), close to unity ratio of odd/even along the whole row of n-alkanes and predominance low molecular homologues in the composition of n-alkanes with a maximum in the region (n-C₁₆₋₁₉). These features of saturated hydrocarbons are characteristic for aquagene OM formed in the reducing environment of sedimentation and diagenesis. It is noteworthy that 12 and 13-methyl alkanes were detected in CB from argillites of the Malgin suite. These components were found in small concentrations (1.8%) and were represented by the first members of the homologous series.

According to the data of IR-Fourier spectroscopy in the chemical structure of CB, the ratio between the content of aliphatic structures, aromatic cycles and the quantity of oxygen-containing groups and bonds varies in a wide range. The large variations in the distribution of CB yield, the content of oils, resins and asphaltenes in the group component composition along the Malgin suite indicate the presence of a wide row of bituminous differences from syngenetic and para-autochthonous, epigenetic and residual bitumens. This can be considered as evidence of the processes of generation and emigration of hydrocarbons generated by source rocks, both within the Malgin suite itself and beyond it (Chalaya et al., 2015).

In the middle part of section of the Zipandin suite there are rare interlayers (0.8-1.2 m) of bituminous differences with a high content of C_{org} (2.7-5.3%). The CB yield of rocks varies from traces to average values of 0.025%. Asphalt-resinous components dominate in the CB group composition. The hydrocarbons content is 39.8%, which is significantly higher than the average value in the Malgin suite (25.8%). In the structural group composition of CB, aliphatic compounds prevail over aromatic cycles. In the hydrocarbon composition of CB, alkanes of normal structure dominate, in which relatively low and high molecular weight homologs are contained in almost equal amounts. N-alkanes predominate over isoprenoids.

The cavernous dolomites of the upper part of the Zipandin suite, overlapped with argillites of the Kumakin suite of the Upper Riphean, could serve as a reservoir for the Malgin and Zipandin oils.

The upper part of the Zipandin suite characterized by high cavernousness. In the Ingili River basin of the Zipandin suite's cavernous horizon for the some samples on 1 square decimeter surface, there were noted up to 10 large (not less than 0.5 cm in diameter) cavities and many smaller cavities and cracks made by solid naphthides.

In the deposits of the suites of the Lahanda series (the Late Riphean) the C_{org} content in the rocks varies in the range from 1.0 to 4.8%. In general, the content of C_{org} is lower in comparison with samples from the underlying Malgin and Zipandin suites. Rocks differ

significantly in the CB yield from 0.007 to 0.265%. The group component composition of CB with a low asphaltenes content of 2.7-2.9% and high hydrocarbons up to 55.3% with methane-naphthenic hydrocarbons prevalence in their composition (up to 81.2%) most likely indicates the epigenetic character of bitumens (β to 17.4%), which belong to the class of maltha. The composition of the CB, in our opinion, is due to a higher degree of catagenetic transformation of OM rocks of the Lakhandin series relatively the Malgin suite. According to some researchers, this composition didn't due with regional level of catagenesis of OM and can be determined by the local thermal effects of trap dikes (Lobzakova et al., 1987). The quartz sandstones of the Kandyk suite, overlapped with aleurolite-argillite differences of this suite, could serve as a reservoir for the Lahanda oils. So, the interlayers of aleurolites and quartz sandstones saturated with semi-fluid naphthides of the Kandyk suite were noted at the field works in the Maya river basin.

The Vendian carbonate sediments contain a small amount of OM 0.23-0.41%, reaching higher values in some samples up to 0.90%. In the group composition of CB, the content of hydrocarbons varies from 46% in synbitumoids to 69% in epigenetic differences ($\beta = 58-108\%$). The amount of resin varies from 25 to 51%, asphaltenes from 1.9 to 15.4%. Methane-naphthenic hydrocarbons predominate in the hydrocarbon composition. Saturated hydrocarbons characterized by the predominance of alkanes of normal structure, constituting 72.85% of the sum of identified hydrocarbons, and relatively low-molecular homologues with a maximum at nC₁₆₋₁₇ are in their composition. The content of isoprenoids is 11%, the ratio of pristane/phytan is 1.24 in the argillites and 0.90 in limestones. The CB of Vendian sediments are characterized by the presence of 12- and 13-methyl alkanes, which account for about 7%. The reservoir for the Vendian oils could be terrigenous sediments of the Sardanian suite, which were overlapped by substantially clayey differences of the variegated suite of the Lower Cambrian.

Results and discussion

The history of geological development of the AMD is poorly studied. At the same time, the flat monoclinical bedding of deposits from the Middle Riphean to the Middle Cambrian inclusively suggests that in the Late Precambrian-Early Paleozoic, this territory was a passive continental margin practically devoided of high-amplitude plicative or near-fracture structures that could allow considering them as potential traps.

The large Ingilian Ledge of the crystalline basement began to isolate itself, apparently, from the Early Riphean (Fig. 2). In this regard it is of a particular interest. Here, on the Ingilian Ledge slopes of the crystalline basement,

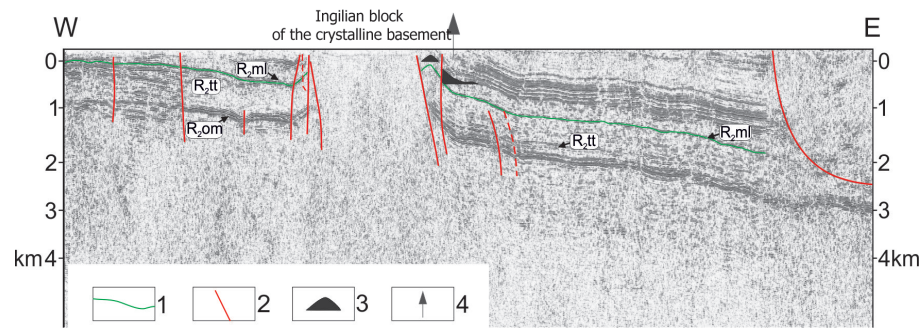


Fig. 2. Sublatitude seismic and geological profile 120709 through the central part of the Ingilian block of the crystalline basement. According to OJSC Yakutskgeofizika. Legend: 1 – the Malgin suite base of the Middle Riphean, 2 – tectonic disturbances, 3 – alleged oil deposits, 4 – the place of core drilling

the prospects of oil- and gas-bearing are related with the pinch zones of the Vendian Riphean sediments. So, in a core from the well drilled on the north-eastern ledge slope (with the purpose of assessing the metal content), an oil show was recorded at 40 m depth from the Vendian sediments (to oral report by S.Yu. Sevostyanova, chief geologist of Yakutskgeofizika, 2015), which can be considered as a direct sign of a presence of oil deposits in deeper horizons.

At the present level of study on the structure and history of the geological development of the territory, it is difficult to propose exactly a mechanism of isolation of this tectonic element. Most likely, this was a result either of a slower immersion of this ledge of the crystalline basement on the background of the general immersion of the passive continental margin structure or of the sedimentary uplift of this block. But in this or that case, the surface of this ledge was not the scene of any large-scale sedimentation. During the entire subsequent time period, layers of Riphean sediments were pinned out on the eastern slope of this ledge, forming a peculiar adjacent structure, which could play the role of a trap for hydrocarbons which migrated from the east. By the end of the Late Riphean time, the Ingili Ledge of the crystalline basement was a large high-amplitude block (more than 1000 m) with an area of more than 2 thousand square km (Fig.2). In our opinion, in the Late Precambrian-the Early Paleozoic the most part of the AMD territory was «transit zone» of hydrocarbons generated within this passive continental margin. Therefore, significant volumes of hydrocarbons capable to migration from the generation zones were «spread» as in layers-reservoirs as cavernous-porous-fractured carbonate rocks. Based on the analysis of the geological development of the AMD, which was a part of the broad eastern passive continental margin in the Late Precambrian-the Early Paleozoic, the nature of the structure and composition of the Riphean-Vendian section, the broad spread of naphthides shows of a different nature and scale, it is possible to state unique about the wide development of the processes lateral and vertical migration of hydrocarbons in the considered territory. The hydrocarbons generated in the Riphean

deposits could migrate to the west along the regional uplift of the strata, which existed for a long time.

Obtained in recent years (2014-2016) results of seismic exploration showed the extension of the platform AMD wing to the middle flow of the Amga River, which expands its territory (Fig. 1). This circumstance explains the presence of oil-saturated strata in the middle flow of the Amga River due to a lateral migration from the AMD and makes the territory of the middle flow of the Amga River the main accumulation zone of hydrocarbons generated in the Maya center of generation.

The detection of oil saturation the Vendian dolomites in the Nizhneamgin well and drop-liquid oil in the Tanhai suite of the Middle Cambrian can be considered as a substantive confirmation of the lateral migration of hydrocarbons from the generation zones. These oil shows were revealed in a row of hydrogeological wells drilled along the right bank of Amga River in 70-80s of the last century (Fig. 1) at 282 m and 83 m depth (Kashirtsev et al., 2004). In 2012, to the south from these wells a natural oil seepages had been discovered by the resercheres of the Institute of Oil and Gas Problem of the Siberia Branch of the Russian Academy of Sciences in the floodplain of the Amga River,delete (Safronov et al., 2014).

Numerous naphthides shows in the Maya River basin, 50 km above the mouth of the Yudom River for at least 100 km long can consider as traces of lateral and vertical migration of hydrocarbons. In the Lakhandinskaya well, drilled on the Bolshaya Lakhanda River – the right-hand tributary of the Maya River, 6 km from the mouth, the core with inclusions of drop-liqued and light yellow colour oil was raised from the interval of 510.83-513.17 m from the deposits of the Malgins suite of the Middle Riphean,. Unfortunately, the results of oil analysis are not. Here at the upper flow of the Lahanda River a 2-meter stratum of medium-grained black quartz sandstones containing 10.2-13.1% of asphaltite-type bitumen was revealed among the limestones of the Lahandin series. In burning process bitumen boiled, turning into a highly mobile fluid (Dymovich et al., 2012).

According to the results of seismic exploration works

of Yakutskgeofizika OJSC (2014-2016), structural traps were identified in adjacent platform part of the AMD (Fig. 1). At the present level of study, six local low-amplitude anticline structures of submeridional spreading have been determined: Belkachin, Bilir, Taryng-Elgin, South-Bilir, Mil, Taryn. In our opinion the Belkachin local structure on the western margin of the AMD is the most prospective object. On the northern pericline of this structure, an oil seepage is set to the surface (Safronov et al., 2014). According to our retrospective constructions Belkachin structure occupied the highest hypsometric position during both the Vendian and the Cambrian.

In the Khabarovsk part of the AMD the zone of pinching out of the Upper Riphean deposits is the most prospective, which is confined to the eastern slope of the Ingilian Ledge of the crystalline basement (Fig. 2).

In 2014 drilling works were finished at the Ust-Maya parametric well No. 366 situated within the AMD near the Kyllakh uplift. The well drilled sedimentary deposits of the Upper Riphean, the Vendian, the Lower-Middle Cambrian, the Lower-Middle Jurassic and the Quarter. The drilled geological section of the Riphean part has appeared significantly different from the design one. The presence of rocks of the Ust-Kirbinsk suite (251 m) and an increase in the thickness of the Kandyk suite from 670 m (in the project) to 1100 m (in actual) showed a significant increase of the roof depth of the Ignikan and the Neryuen suites near 750 m and 740 m. The upper part of the section also showed an increase by 269 m (the Jurassic +450 m, the Cambrian -330 m, the Vendian +149 m). Thus due to incorrectly estimated speed characteristics of the section of the AMT stationary wing and poor study of the area, well No. 366 did not reach the design horizon – the Malgin suite.

According to the drilling results of the Ust-Mayskaya parametric well No. 366, the oil and gas field was not discovered. At the same time, the results of processing the obtained materials confirmed the high prospects for the oil and gas bearing of the AMD (Sobolev et al., 2017). They are the confirmation of the presence of the Kuonam oil-prone complex of the Lower-Middle Cambrian (the Inikan suite), a spreading of numerous naphthides shows at the level of the Sardan suite of the Vend and the Kandyk suite of the Upper Riphean, also the identification of probable oil source rocks in the section of the upper part of the Lakhanda series.

In addition to the above oil- and gas-bearing prospects of the upper part of the Malgin Formation section may be a certain interest due to the rapid development of technologies of shale oil and gas production. It was determined that in the Riphean the Maya center of oil and gas generation was the most productive in the Siberian platform (Bazhenova et al., 2011; Bazhenova, Margulis, 2014). According to many reserchers by a whole row of

geological and geochemical indicators, the upper part of the Malgin suite is belong to a typical domanicoid formation. The same group includes the Bazhenov Formation of the Western Siberia, the expected reserves of shale oil are estimated at 22 billion tons; the Kuonam Formation of the eastern part of the Siberian platform, the kukersites of the Estonia and the Leningrad region and, in fact, the domanicoid formation in the East of the Russian platform in the Pre-Ural Depression.

Conclusion

From the geochemical positions a high oil-prone potential of domanicoid rocks of the Riphean as a wide spreading of various naphthides shows – from syngenetic bitumen to drop-liquid oil, viscous and solid natural bitumens indicate the prospects of discovery of liquid hydrocarbons accumulations within the AMD.

The presence of liquid oil and abundant shows of migration processes in deposits of the Upper Riphean and Vendian levels in the eroded southern parts of the depression allows highly to assess of the prospects for the oil- and gas-bearing of closed western periphery of the AMD. The latest obtained seismic data allow(s) us to expand the western periphery of the AMP platform part to the middle flow of the Amga River, where there are numerous signs of the liquid hydrocarbons presence.

In further the mapped local low-amplitude anticlinal structures of the submeridion strike on the western adjacent platform part the AMD are the priority interest for oil and gas exploration where oil seepage in the Cambrian sediments has been found. The accumulations of higher density oils are expected in structural lithological traps.

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