Prospects of Oil and Gas Potential of the Middle Paleozoic Deposits of Eastern Yakutia from Historical Viewpoint of Geological Development

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Abstract. The article considers the prospects of oil and gas potential of the Middle Paleozoic deposits of Eastern Yakutia. Based on the study of the peculiarities of bitumen content intervals of the Silurian-Devonian deposits of Selennyakhsky block, it was concluded about high oil and gas potential of the domanicoid Middle Paleozoic deposits of the Omulevsky terrain. Under favorable structural and tectonic conditions and immersion to shallow depths, Middle Paleozoic deposits can contain oil and gas deposits to clarify the most promising subsoil areas, the author's version of the geological development history of Eastern Yakutia is proposed. The diagrams of the completenses of the main sedimentary complexes are compiled: Middle Devonian-Lower Carboniferous, Upper Paleozoic-Lower Mesozoic, Upper Jurassic-Lower Cretaceous and Upper Cretaceous-Cenozoic. Based on the constructed diagrams of the thicknesses of sedimentary complexes and the shown horizontal displacements, the Tastakhsky depression is identified as the most promising territory. It is assumed that there is a section of the Middle Paleozoic rift basin, slightly affected by the collision. Additionally, the prospects of oil and gas potential of the Upper Jurassic-Lower Cretaceous complex of deposits are substantiated and presented.

1. Introduction

Extensive development of folded structures, absence of large industrial enterprises and focus of prospecting on ore and placer deposits determined extremely heterogeneous and weak geological and geophysical study from the perspective of oil and gas bearing capacity of the territory of Eastern Yakutia. The current state, generalization and analysis of geological and geophysical studies and their main results are presented in [1, 2].

The main indicators of the prospects of regional oil-and-gas bearing capacity of poorly explored territories are: presence of sufficiently thick strata of sedimentary rocks, presence in their composition of oil-and-gas matrices - potential sources of hydrocarbons, presence of reservoir rocks and fluids, as well as zones and areas of their preservation.

All above-mentioned geological elements are necessary but not sufficient condition for forecasting of oil and gas deposits. Determining are the processes (formation of traps, generation-migration-
accumulation, tectonic movements) occurring with geological elements and their sequence. The study of relationship between geological elements and processes as a method of research in scientific literature is called historical-genetic analysis.

The available degree of geological study of the section and peculiarities of tectonic processes does not allow to carry out a full-fledged historical-genetic analysis of oil-gas formation and oil-gas accumulation. At the same time, joint consideration of the history of geological development and peculiarities of spatial localization of direct signs of oil and gas bearing capacity allow to identify the most promising areas for oil and gas.

2. Statement of the problem
In the published scientific literature the greatest number of bituminous events in Eastern Yakutia is fixed in Selennjah block of Omulevsky terrane [3]. Perhaps this circumstance is primarily due to the relative accessibility of the territory for researchers. The Selennyakh block is located in the westernmost part of the Omulevsky terrane (Fig., d). The Omulevsk terrane stretches for 1000 km with a width of 100-150 km along the southwestern and northern margins of the Kolyma-Omolon superterrane [3].

According to conventional tectonic zoning, the Selenyakh block represents the northwestern flank of the Indigiri-Zyrian trough. The deposits have undergone several periods of tectonic activity and are complicated by numerous faults of various ages and kinematics.

The Selenniaxh block is composed of Lower Ordovician-Near Carboniferous, mainly shallow terrigenous-carbonate sediments. Interlayers of gypsum, anhydrite and red-colored rocks are found. Here and there, shallow-water sediments up the stratigraphic section and laterally are replaced by deep-water slope formations [4].

In Selennjah block Klubov B.A. have allocated bituminous horizons in section from upper Ordovician to middle Devonian inclusive [5]. Bitumens are presented from anthraxolites up to oxidised oils, depending on age and depth of occurrence. The Majority of occurrences, localized in separate horizons of the section, is connected with the rocks, in this or that degree enriched with autochthonous sapropelic OM. Composition of bitumens or their hydrocarbon fractions of the lower three horizons of Upper Silurian and Lower Devonian is methane-naphthenic and of the two upper Middle Devonian is aromatic [5]. The joint occurrence of bitumens of different transformations testifies to multistage processes which have caused their occurrence in section.

Apparently, hydrocarbon deposits formed by realizing the oil and gas maternal potential of Middle Devonian pre-Mannicoid deposits were destroyed during tectonic activation and deep denudation of the section (up to 2.8-3.5 km). At the same time within the Selennyakh block and the entire Omulevsky terrane we cannot exclude the presence of preserved small accumulations of high-viscosity oil, confined to weakly dislocated areas. L.A. Musalitin [6], who described oil puddles and a small saddle filled with a thick oil mass within the Selenniakh Block, as well as a recovered core with slightly oxidized oil from the Taskan area of the Omulevsk terrane [7] (figure 1, d), points to the validity of the assumption put forward.

Thus, the established and described direct signs of oil-and-gas bearing capacity of Selennyakh block allow to consider as the most perspective for oil and gas the deposits of Omulevsky terrane in particular, and all section of the middle Paleozoic of the East Yakutia as a whole.

3. Experimental part
The most important indicator in determining oil and gas potential is the depth of prospective sediments. The temperature field, reservoir properties and the degree of catagenetic transformation of the original organic matter depend on the dip depth. For a simplified estimation of dipping depths of the pre-Middle Paleozoic sediments, let us consider the history of geological development of the region.
Figure 1. Scheme of the thicknesses of the sediment complexes and the prospects for oil and gas potential in Eastern Yakutia.
1 - boundaries of rift zones of the Late Riphean [7] renewed in the Middle Paleozoic; 2 - thickness of rift Middle Paleozoic sediments; 3 - zones of Middle Paleozoic rift grabens according to Tretyakov F.F. [15]: Western rift system, grabens: SV – Zapadno-Verkhoyansky, DR – Derbekinsky, VL – Vilyuysky; eastern rift system: SD-Sette-Dabansky graben; stages: OS-Oljoy, NS-Nerskaya; uplifts: YAP-Yanskoe, TP-Tomponskoye; OH – Okhotsk massif; 4 - the thickness of the Upper Paleozoic-Lower Mesozoic deposits; 5 - the estimated thickness of the Upper Paleozoic-Lower Mesozoic deposits; 6 - thickness of the Upper Jurassic-Lower Cretaceous deposits; 7 - areas of denudation; 8 - the thickness of the Upper Cretaceous-Cenozoic sediments; 9 - the area of the Tastakh trough, 10 - Indigiro-Zyryanskiy trough, 11 - Blocks of the Omulevsky terrane, 12 - promising Cenozoic deposits.
PVT - Predverkhoyanskiy trough; MZT - Momsko-Zyryanskiy trough; IZT - Indigiro-Zyryanskiy trough; TT - Tastakhskiy trough.
Blocks of the Omulevsky terrane: Ul – Ulakhan-Tass, Se-Selennyakh, Ta-Tas-Khayakhtakh, Che-Chemalghinsky, Uch-Uchchinsky, Om-Omulevsky, Ra-Rassokhinsky

The Riphean and Vendian-Lower Paleozoic stages of development are not considered in this paper. During the Late Precambrian and Early Paleozoic, the eastern margin of the Siberian paleocontinent, including the Omulevsk, Prikolymsk, Omolon and Okhotsk terranes, represented a passive continental margin that apparently followed Late Riphean riftogenesis [5, 8-15].
Middle Paleozoic rift stage. The rift stage was expressed by the formation of a system of rift structures in the east of the Siberian paleocontinent. Middle Paleozoic aulacogenes, as well as Riphean ones, are underdeveloped branches of 3-branch rift systems, the main bodies of which are located under Verkhoyansk fold belt. Many researchers [9-11, 13] note the inherited development of rift systems within the eastern part of the Siberian platform. The structural plan of the Middle Paleozoic structural stage, including the Middle and Upper Devonian and Lower Carboniferous formations, is similar to that of the Riphean. Middle Paleozoic deposits, as well as Riphean deposits, are made by linear grabens - aulacogenes. Outside the aulacogenes, Middle Paleozoic sediments are absent in most of the eastern part of the platform.

Rift structures at the base of the Verkhoyansk folded belt were mapped by Tretiakov F.F. based on the interpretation of gravimetric materials [16, 17]. The author interprets them as large linear grabens, bounded by lystric fault zones and originated in the rift stage of the Verkhoyan passive margin development (figure 1, a). Two systems of Middle Paleozoic rift structures are distinguished - Western and Eastern. The western system is represented by the Western Verkhoyanskiy, Derbekinskiy and Vilyuyskiy grabens. The eastern system includes the Oldjoy-Nerka stage framing the structures of the Kolyma-Omolon microcontinent and the Sette-Daban graben (figure 1, a).

The Caledonian sedimentary complex has been almost entirely denuded on the positive forms. Rift grabens were filled with thick strata of predominantly molasse formations with horizons and lenses of halogen sediments [18].

In the Middle Paleozoic, the southern part of the rift graben belonging to the Lena branch of the Preverkhoyan Trough was 300 km or more east of its present location. Studies by Sitnikov V.S. and Spector V.B. have shown a horizontal shift with an amplitude of 300 km along the Vilyui-Aldan system of latitudinal strike dislocations [19]. The eastward correlation of the latitudinal strike-slip suggests that the deposits of the Omulevsk terrane in the Middle Paleozoic were also east of the present-day location and accumulated in a linear rift graben.

The studied Middle Paleozoic sediments in various parts of East Yakutia suggest rather confidently that their thickness in the rift graben was at least 3,000 m (figure 1, a).

Late Paleozoic-Early Mesozoic passive-oceanic stage. During the Late Devonian-Early Carboniferous riftogenesis, the Oymyakon minor ocean was formed. V.E. Khain (2009) with co-authors suggest that these Omyakonsky and South Anyuysky (territory of the East Siberian Sea) oceans were connected by a strait [20]. The western part of the Oymyakonian Ocean was a passive continental margin (PCL) of the Atlantic type [10]. In the eastern part of this ocean, the Omulevsk ridge was formed, including the Omulevsk, Prikolymsk, Omolon and Berezov terranes [4].

In the Late Paleozoic-Early Mesozoic, the Verkhoyansk fold belt was a vast passive continental margin, within which a coastal lowland, shelf, continental slope and continental foothill were distinguished. The seaside lowland, periodically flooded by the sea basin, occupied the territory of the modern Viliui synclise, Preverkhoyanskiy and Lena-Anabar troughs [10]. A maritime lowland is also suggested within the present-day Aldan-Maysk fold and the south-eastern slope of the Yakut uplift [21-23]. Apparently, the sediments of the littoral lowland, confined to the southern Verkhoyan, have been denuded almost entirely thereafter.

The shelf area is more complex. Here, faults genetically linked to the Middle Paleozoic riftogenesis played a determining role in the distribution of sediment thicknesses of various ages. Tretiakov F.F. [16] describes consedimentation faults of the basement associated with Early Triassic and Early Jurassic magmatism. The renewing faults of the rift structures of the fault type periodically involved more and more new sedimentary rocks in the forming progradational prism of the Verkhoyanskiy complex of sediments. Therefore, the shelf section of the passive continental margin is represented by an irregular alternation of sandstones, siltstones and mudstones.

It is practically impossible to determine the position of the continental slope. It can only be assumed that from the Carboniferous through to the Upper Jurassic, the continental slope zone has moved eastward. It is very likely that the thin clastic rocks of the Upper Paleozoic, Triassic and Jurassic, which
are only moderately distributed within the northwestern part of the Selennia block, are the sediments of the continental slope.

A thickness diagram of Upper Paleozoic-Lower Mesozoic deposits within East Yakutia is shown in the figure 1.

In the late middle Jurassic, as the Paleo-Pacific plate advances, the Alazean island arc collides with the Omulevsk ridge to form the Kolyma-Omolen supercontinent. The collision was accompanied by obduction of ophiolites onto the Omulevsk terrane. From the Late Jurassic the collisional stage of development of the region begins. The landmark event of the beginning of the collisional stage is the formation of the Main Batholith Belt. The age of the Main Batholith Belt is within a narrow interval - 143-138 Ma [24, 25] dated by 40Ar/39Ar method (end Jurassic-Early Cretaceous). At the same time, spreading in the South Anyu ocean starts, causing the closure of the Oymyakon ocean. Spreading of the Southern Anyu ocean is a link with formation of the Northern Batholith Belt. Granitoids age is 127-120 million years [4]. As we mentioned above, the collisional stage has caused the latitudinal shift of the Earth's crust with a total amplitude of 300 km within the modern borders of the Aldan and Vilyui lower reaches. It is worth mentioning that the reliably established age of the formation of the Hapchagai megalval of the Viliui syncline falls in the time interval of the collisional stage of the development of East Yakutia, which may testify to the connection of the megalithic formation mechanism with the collisional processes that took place in the east.

During the collisional stage, the Predverkhoyanskiy and Momo-Zyryanskiy troughs were formed (figure 1, c) - extended areas of accumulation of continental coal-bearing sediments [26]. According to Gaiduk V.V. et al. [27], the Moma and Indigiro-Zyrian Troughs and the Ilin-Tass Anticline separating them were isolated in the late Miocene as a result of folding. Most of the later part of the Indigo-Ziryanka foredeep was affected by post-collisional spreading [26].

The present level of Upper Jurassic-Lower Cretaceous deposits within the Predverkhoyanskiy Trough corresponds to the depths of the main oil-forming zone [28]. The thickness diagram of Upper Jurassic-Lower Cretaceous deposits within Eastern Yakutia is shown in the figure, c.

The post-collisional stage of development in the Predverkhoyanskiy Trough begins in the Paleocene. The post-collisional dip led to the formation of the superimposed Nizhealdanskiy depression with the accumulation of Cenozoic deposits with a total thickness of up to 900 m. According to A.F. Safronov, the Nizhealdanskiy depression was formed as a consequence of isostatic reaction of the continental crust to the load of the tectonic plates thrust over the sag [7]. The postcollisional dip in the Indigiro-Zyrian Trough is indicated by an increase in the thicknesses of the Neogene Kyllakh Formation. It has been suggested that the increase in the thicknesses of the Kyllakh Formation is due to similar processes that led to the formation of the Nizhealdanskiy depression [26].

The Cenozoic (modern) rift stage of the region's development is associated with the opening of the Eurasian oceanic basin. It is believed that during the Cenozoic, the pole of rotation of the Eurasian and North American plates changed its position several times, which led to a complex alternation of compression and extension epochs [4]. In the Indigiro-Zyrian Trough, the Cenozoic deposits, according to geophysical data, have a significant thickness (more than 2,000 m). In the northwestern part of the trough, joint processing of drilling and seismic data has reliably established 1600 m of deposits of Cenozoic age (figure 1, d).

To the north, in the Primorskaya Depression along the East Siberian Sea coast, Cenozoic deposits are estimated to be up to 1000 m thick [4]. Based on published geological data and the proposed history of geological development, the thicknesses of Upper Cretaceous-Cenozoic deposits within Eastern Yakutia have been plotted (figure 1, d). In the shelf part of the Laptev Sea, in the area of the Ust-Lena Trough, Meso-Cenozoic deposits are up to 4000-5000 m thick according to overhead seismic works [29].
4. Conclusion
Based on the history of geological development of East Yakutia and plotted thicknesses of sedimentary complexes, the following conclusions can be made on the oil and gas potential of the Middle Paleozoic sediments:

- Organic-rich Middle Paleozoic sediments of East Yakutia, except for those accumulated in the eastern rift graben, have undergone significant dips up to 5\(\pm\)10-12 km beneath the Upper Paleozoic-Lower Mesozoic passive continental margin of the Siberian craton.

- Middle Paleozoic sediments confined to the eastern rift graben were located east of the depocenters of maximum thicknesses of the Upper Paleozoic-Lower Mesozoic passive continental margin. This circumstance suggests that the organic-rich Middle Paleozoic sediments confined to the eastern rift graben did not sink to great depths, i.e., to the apocatagenesis zone.

As a result of the reconstruction, the Tastakh trough and its southeastern extension are proposed as a priority target for exploration work within Eastern Yakutia (figure 1, c). The proximity of the proposed area to the route of the Northern Sea Route is an important favourable infrastructure factor that makes it attractive to investors. It is proposed that a parametric borehole with a depth of up to 4,000 m be drilled. It will provide valuable information, which will clarify the geological structure of the area and the region as a whole.

Certain oil and gas prospects are also associated with the Upper Jurassic-Lower Cretaceous complex of deposits within the Indigiro-Zyryanskiy Trough. More details on the oil and gas potential of this complex of deposits can be found in [26, 28].

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