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Lithology, organic geochemistry, and petroleum potential of the northern areas of the Kureika syneclise

I.V. Varaksina [a,*], I.D. Timoshina [a], A.E. Kontorovich [a,b], I.V. Tumashov [a]

[a] *A.A. Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of the Russian Academy of Sciences, pr. Akademika Koptyuga 3, Novosibirsk, 630090, Russia*

[b] *Novosibirsk State University, ul. Pirogova 2, Novosibirsk, 630090, Russia*

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Abstract

We present results of lithological and geochemical studies of Paleozoic deposits stripped by drilling within the Ledyanskaya area in the north of the Tunguska syneclise. The studied section has a terrigenous sulfate–carbonate composition and is complicated by trap intrusions. We have established that the Ordovician–Devonian sedimentation proceeded within an epicontinental basin, with its depth varying from supralittoral to lower sublittoral zones. In the Carboniferous and Permian, coastal-continental sedimentation was predominant; in the Late Permian it was accompanied by volcanic activity. Analysis of the poroperm properties of rocks has distinguished three potential oil reservoirs: Silurian reef carbonate deposits and Ordovician and Carboniferous sand horizons. The Lower Silurian argillaceous–carbonate rocks and Devonian carbonate–sulfate–clay members, halite beds, dolerite bodies, and tuffaceous rocks are probably confining beds of these reservoirs. Geochemical study of organic matter has shown several possible sources of hydrocarbons: Upper Proterozoic deposits, Lower and Middle Cambrian Kuonamka complex, Middle Devonian Yukta Formation, and Upper Paleozoic coal-bearing deposits.

Keywords: organic geochemistry; Paleozoic deposits; lithology; Tunguska syneclise; Ledyanaya dome

Introduction

The North Tunguska petroliferous province lies in the northwest of the Siberian Platform and is 430,000 km^2 in area. Most of the area is occupied by the Putorana plateau, a basaltic massif with a severe topography and maximum heights of 1500–1700 m. Within the plateau, there are the headwaters of the Kureika, Pyasina, Kheta, and Kotui Rivers and the right tributaries of the Nizhnyaya Tunguska River with abundant deep canyons, thresholds, and waterfalls. The aboriginal population regards the Putorana plateau as the place of living of the God of Fire, the host of hell and a torturer of souls.

The dissected mountainous relief, absence of navigable rivers and roads, very low population density, and harsh climate make the area of the North Tunguska petroliferous province hardly accessible. The relief and nature of the plateau were completely investigated only after the Great Patriotic War of 1941–1945. The inaccessibility of the area, intricate seismogeologic conditions, low informative value of seismic-prospecting materials, big difficulties in the delivery of necessary equipment and in the drilling of deep wells, and high cost of the drilling work are the main reasons for the extremely low state of the geological and geophysical exploration of the region.

Since the 1960s, there have been different viewpoints of the petroleum potential of the North Tunguska province. Geologists of the Siberian Research Institute of Geology, Geophysics, and Mineral Resources and the Institute of Geology and Geophysics (at present, the Institute of Petroleum Geology and Geophysics (IPGG)), Novosibirsk (F.G. Gurari, S.A. Kashchenko, A.E. Kontorovich, V.S. Starosel'tsev, A.A. Trofimuk, E.E. Fotiadi, A.V. Khomenko, and others), considered the area highly oil-promising, although they admitted that their hypothesis was risky. Researchers of the All-Russian Petroleum Research Exploration Institute (VNIGRI), St. Petersburg (E.A. Bazanov, V.A. Zabaluev, V.D. Kozyrev, and others) did not regard this area as highly petroliferous because of the abundance of traps in its geologic section.

Despite all these difficulties, three wells, including the deep (3970 m) Ledyanskaya-358 well (hereafter, L-358), were

* Corresponding author.
E-mail address: VaraksinaIV@ipgg.sbras.ru (I.V. Varaksina)

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drilled in the Ledyanskaya area at the instigation of V.A. Krinin, the leading geologist of the Yeniseineftegazgeologiya Production Geological Association, in the late 1980s–early 1990s. The cores from these wells were geologically described and partly examined by T.A. Divina and V.S. Starosel'tsev (Divina et al., 1992). However, a detailed study of the cores was not carried out because of the started economic crisis. The cores stayed in the drilling area and were inaccessible for many years.

In 2005–2013, geologists of the IPGG, in coordination with Krasnoyarsknedra Territorial Agency on Natural Resources, collected and systematized the core preserved in the north of the Krasnoyarsk Territory and transported it to Novosibirsk. This work was carried out with the participation of students of Novosibirsk State University under the guidance of V.A. Marinov and P.A. Yan. At present, the core, including that from the Ledyanskaya area, is stored at the Center of Geological Collections of the IPGG. Unfortunately, the core from the L-358 well was not found. Saving of the cores from the Ledyanskaya well 2 (L-2) and Ledyanskaya-3 well (L-3) permitted their detailed lithological, petrophysical, and geochemical studies. The results of these studies are given below.

The composition and structure of the Paleozoic section

In this work we consider the Paleozoic deposits stripped in the Ledyanaya dome in the central zone of the Putorana salient (Fig. 1) (Kontorovich et al., 2009). The section of the L-358 well was described based on the data of Divina et al. (1992, 1996). Litohologic and stratigraphic subdivision of the deposits of the L-2 and L-3 wells was made by I.V. Varaksina, N.G. Izokh, O.T. Obut, I.V. Tumashov, and other geologists of the IPGG. Stratification of the Ordovician rock unit was performed in accordance with the scheme adopted by the Interdepartmental Stratigraphic Committee (ISC) in 2014. Subdivision of the Middle and Upper Paleozoic rock units was made using the basic materials of projects of the new stratigraphic schemes admitted by the ISC in 2012–2015. The Lower Paleozoic rock unit was totally penetrated by the L-358 parametric well. The L-2 and L-3 core wells were drilled down to the Middle Ordovician beds; therefore, their sections were compared starting from this stratigraphic level (Fig. 2).

The Lower Cambrian section of the L-358 well is formed by the dolomites of the *Kheta* and *Ledyanaya* Formations. The rocks are recrystallized, with alga relics. The Ledyanaya Formation contains intercalates of clastic dolomites (Divina et al., 1996). The Middle Cambrian *Tamukan* Formation consists of alternating organogenic-clastic and argillaceous limestones, dolomitized to different degrees. Dolomitization of the rocks increases upsection. The Upper Cambrian formations are mostly of dolomite composition. The lower *Arykan* Formation is made up predominantly of stromatolitic, microphytolithic, and oölithic dolomites. The upper *Khibarba* Formation is composed of finely alternating dolomites, dolomitic mudstones, and anhydrites.

The Ordovician deposits are assigned to the Maimecha structure-facies zone according to the adopted scheme of stratigraphic regionalization. It comprises the following formations (from bottom to top): Lower Ordovician Bysyyuryakh and Ust'-Kuranakh and Middle Ordovician Kuntykakha and Moiero (Divina et al., 1992; Kanygin et al., 2007; Resolutions..., 2014). The lower Lower Ordovician strata in the L-358 well are formed by dolomites and clays (*Bysyyuryakh* Formation), and the upper strata are composed of algal and argillaceous dolomites (*Ust'-Kuranakh* Formation). The Middle Ordovician strata were penetrated by all wells. Their basement is the *Kuntykakha* Formation. Its lower subformation is composed of alternating variegated mudstones, siltstones, and feldspar–lithoclastite–quartz sandstones, and its upper subformation is made up of red-colored intensely anhydritized limestone–dolomite mudstones. In the L-358 well, the formation is thick because of a large (~140 m thick) intrusion of olivine gabbro-dolerites, which constitutes 64% of the Ordovician strata thickness. The *Moiero* Formation is also of distinct two-member structure. The lower member is composed of thin-layered dolomite–limestone mudstones with frequent paths of detritovores. The upper member is argillaceous dolomite–limestone deposits with a gradual increase in the amount of carbonates.

The Silurian deposits are assigned to the Ledyanaya facies region and rest, with a stratigraphic break, upon the Ordovician rock unit (Resolutions..., 1982; Tesakov et al., 2002). Five formations were recognized within it; the L-3 well is their stratotype (Tesakov et al., 2000, 2002). The Lower Silurian strata comprise three formations. The clay–limestone *Oran* Formation is divided into three subformations according to variations in the content of argillaceous material and fauna remains (Tesakov et al., 2002). Its rocks are of nodular structure, which usually results from differentiated compaction of irregularly distributed argillaceous and carbonate matter (Flügel, 2010). The limestones contain faunal detritus. In the lower subformation it consists of fine ostracods, brachiopods, cephalopods, and crinoids. In the middle subformation, the fauna remains are larger and are dominated by tabulates. The upper subformation has massive intercalates enriched in coarse clastics of stromatoporates and corals. The overlying *Khukelchen* Formation has a more argillaceous composition and is also divided into three subformations. The lower subformation is made up mostly of argillaceous limestones with thin intercalates of fine organoclastic varieties. In the middle subformation, argillaceous limestones alternate with calcareous mudstones (locally, of nodular structure). Carbonate nodules contain bioclasts of shells, echinoderms, and, seldom, corals. The upper subformation consists of organoclastic limestones. The fauna remains are predominant tabulate and subordinate crinoid and brachiopod clastics. In the L-3 well drilled in the roof of the *Khukelchen* Formation, there is a ~11 m thick bioherm of dolomitized coral–stromatoporate limestones, with their dolomite content increasing upsection. The *Munil* Formation consists of massive coral–stromatoporate dolomites forming a ~30 m thick reef-like structure in the L-3 well. In the southern (L-2 well) and northern (L-358 well)