Hydrocarbon expulsion history in Kuonamka formation of North Tunguska Petroleum region

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Abstract. The computer modelling results for Kuonamka source rock evolution in catagenesis are represented for the area of North Tunguska petroleum region for pre-igneous period. Petroleum generation hotbeds are determined. Petroleum resources indirect assessment is made for Kuonamka source rock for pre-igneous period.

1. Introduction

North Tunguska petroleum region occupies the north-west part of Lena-Tunguska petroleum province, which is known as one of the biggest oil and gas basins of the world. Investigations on the history and the amount of hydrocarbon generation of the area have been carried on since the 1960s of the XX century. However, the geological model of its structure, stated in the past is now sufficiently specified. Similarity of the main petroleum system of Cambrian section (Kuonamka source rock and the clinoform complex of Mayian stage) to that of the West Siberian Jurassic one (the Bazhenov formation and the Neokom clinoforms) significantly increases the interest in the territory under consideration and the prospects of its oil and gas potential [1]. The accumulated factual material makes it possible for the first time for this territory to reconstruct petroleum expulsion dynamics in Kuonamka complex of the North Tunguska petroleum region using methods of basin modeling.

Investigation on such regions as the North Tunguska region is accompanied by some difficulties. The first is that the area is not explored enough. The second is that western part of Siberian platform was completely involved into Permian – Triassic regional trap magmatism. Igneous process is known to affect on petroleum potential of basins. This affection may be positive, consisting in source rock more rapidly getting into the main zone of oil generation (oil window). In contrast, negative influence of traps implies destruction of existing hydrocarbon accumulations [2]. According to existing criteria of oil and gas potential prognosis of petroleum basins one should actualize such a research in two steps: 1) reconstruction of hydrocarbon expulsion dynamics at the time before trap magmatism, 2) trap affection assessment [3]. In the present study, the first group of problems was realized: for the first time, the dynamics of hydrocarbon generation was reconstructed for Kuonamka formation of the North Tunguska petroleum region at the time before Permian age, using the methods of basin modeling. The research is based on factual data and geological models, prepared in IPGG SB RAS.

2. Studing area

The North Tunguska region occupies the northern part of Kureyka syncline, the vast tectonic depression accomplished by Vendian-Lower Paleozoic sedimentary rocks. It is overlaid by Tunguska syncline composed by Higher Paleozoic and Triassic formations [1]. Kuonamka formation is expected to be the
main source rock of Cambrian section of the territory. The formation is spread commonly over the platform. It is characterized by high hydrogen index (varies between 352-557 mg HC/g TOC) and high total organic carbon (averages between 1.5–15% and sometimes reaches 30-35%) [4; 5]. Geochemical properties of Kuonamka formation are widely explored by the outcrop materials of the west and northwest parts of the platform. The results are published in many sources [4–9]. Hydrocarbons expelled by Kuonamka formation are suggested to accumulate in collectors of Cambrian reef barrier, developed in north-west of Siberian platform as well as clinoforms of Mayian age. [1; 10].

3. Methods and materials

Common principles of petroleum system modeling are represented in many studies [11–14]. In current investigation the methods of basin modelling are performed using TemisFlow software. 3D structural-lithological model is formed, and then, the sedimentary cover history is reconstructed by the method of backstripping. Hydrocarbon generation dynamics in Kuonamka formation of North Tunguska petroleum region is reconstructed on the basis of thermal data and kerogen kinetics.

3D structural-litological model is formed on the basis of structural maps of the main reflecting horizons (F, R0, M2, M1, B, K1, H1, ev) and the well data for Kyramkynskaya-1, Kochechumskaya-2, Khoshonskaya-256, Chyryndinskaya-271, Srednetaymurinskaya-272, Ledyanskaya-2, Ledyanskaya-3, prepared in IPGG SBRAS.

Temperature model typically includes surface temperature history, factual data on paleothermometers, present day temperature and sedimentary section heat flow distribution. Poor exploration of North Tunguska region, ancient age of its sedimentary boundary and the lack of reliable data on natural paleothermometers causes 1D modelling of heat field of the basin to be the only way to get information on sedimentary boundary paleothermometer. In order to carry on temperature field reconstruction structural-lithological models of Ledyanskaya-3 and Phokinskaya-225 cuts are applied. Heat flow value is presented as heatflow density through the lower margin of lithosphere and averages about 40 mVt/m² (to consider the influence of Siberian superplume heat flow density is suggested to be slightly increased to 70 mVt/m² at the end of Permian age) [15–17].

Geochemical model includes data on kerogen type and kinetics [18, 19]. According to pyrolysis parameters kerogen of Kuonamka source rock corresponds to II type of kerogen. Since the lack of data on geochemical properties of Kuonamka formation directly situated on studying area information was taken on the basis of adjacent territories. The width of Kuonamka formation, enriched by organic matter, was estimated as 15 m, initial total organic matter was taken as 15%, initial hydrogen index as 500 mg HC/g TOC.

4. Results

4.1 1D modeling

According to the results of 1D modelling of Ledyanskaya-3 cut, the Riphean, Vendian and Cambrian deposits reached more than 100°C. The Riphean deposits reached 100°C about 470-440 Ma, Vendian - about 440-420 MA, Cambrian - nearly about 420-450 Ma. Riphean and Vendian deposits reached 150°C. Before the trap magmatism period, the Riphean, Vendian and low-middle Cambrian deposits reached the main zone of oil generation (oil window) with vitrinite reflectance (Ro) about 0.7% [12] and all of them except for middle Cambrian left it (Figure 1).
Figure 1. Burial and thermal history of rocks in Ledyanskaya-3 by preigneous period.

According to the results of 1D modeling of Phokinskaya-225 well, the Riphean, Vendian, Cambrian, Ordovician and Silurian deposits reached 100°C by the end of the Permian period. The Riphean deposits reached 100°C about 480-460 Ma, Vendian nearly about 460-450 Ma, Cambrian about 450-410 MA, Ordovician about 410-260 Ma, Silurian relatively about 260-240 Ma. The Riphean, Vendian, Cambrian and early Ordovician deposits reached 150°C. According to the results of vitrinite reflectance calculation, the Riphean, Vendian, Cambrian, Ordovician and Early Silurian deposits reached the higher margin of Middle Zone of Oil Generation (oil window) with Ro=0.7% before trap period. The Riphean, Vendian, Cambrian deposits reached apocatagenesis (Ro=2.0%), which means it totally exhausted it's hydrogen index.

4.2 3D modeling

Based on factual data on basin structure, Kuonamka source rock kerogen properties and by the results of 1D temperature history modeling regional-zonal schemes of kuonamka formation catagenesis are formed. According to the results of modeling, hydrocarbon generation in Kuonamka formation began in by Ordovician-Silurian age. This is how Tura oil and gas hotbed originated. In the Devonian period hydrocarbon generation reached its maximum and then Kuonamka formation of central part of the hotbed begun to emerge from the main oil and gas generation zones. Hydrocarbon generation of the hotbed periphery continued until the Higher Carbon and then oil and gas potential of the source rock was totally exhausted.

Since the lower Devonian age one more petroleum hotbed originated in the north-western part of North Tunguska region. This was Lama-Khantay hotbed. Kuonamka source rock slightly got into the main zone of oil generation and till the end of the Carbon reached the maximum of generation (Figure 2).

Cumulative mass of oil and gas generated by the Ordovician-Carbonian age is shown on figure. Common mass of hydrocarbons accounts 570 billion tons. With accumulation coefficient taken into account resources of hydrocarbons, generated by Kuonamka formation might amount 5,7-57 billion tons.
Figure 2. HC generation density in Kuonamka formation during the period:
A. 450-425 Ma; B. 425-400 Ma; C. 375-350 Ma; D. 325-299 Ma.
5. Conclusion

Since the higher Ordovician till the beginning of the Permian period two petroleum hotbeds occupied the area of North Tunguska region. These are Tura and Lama-Khantay hotbeds. In Tura hotbed oil and gas potential of Kuonamka source rock was totally exhausted till the Permian period. Thus igneous intrusions could not control source rock potential in this area. In Lama-Khantay hotbed oil and gas generation has reached its maximum, which somehow increases the variety of magmatism influence on hydrocarbon potential of source rock of the territory.

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