Generation and Accumulation Hydrocarbon Systems in the Eastern Arctic Waters

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Abstract. This paper analyses the conditions of formation of generation and accumulation hydrocarbon systems and prospects for searching for oil and gas accumulations in the waters of the Eastern Arctic. The purpose of the research is to build space-time digital models of sedimentary basins and hydrocarbon systems, to quantify the volume of generation, migration and accumulation of hydrocarbons for the main horizons of oil-producing rocks. To achieve this goal, spatial-temporal numerical basin modeling was performed, based on which were determined the distribution areas of probable hydrocarbon systems and was carried out their analysis. As a result of the obtained data, was made the forecast of zones of the most probable accumulation of hydrocarbons, such as fluid in potential traps within the object of research.

1. Introduction

Problems of the geological structure, tectonics and oil and gas potential of the water area are described in the publications of V. A. Vinogradov, V. L. Ivanov, V. Iu. Kerimov, B. I. Kim, M. K. Kosko, D. V. Lazurkin, E. A. Lavrenova, B. N. Senin, S. B. Secretov, O. I. Suprunenko, S. D. Iashin and a number of other researchers of the Eastern Arctic shelf.

With regard to the oil and gas content of the sea areas of the Eastern Arctic, different groups of researchers define these areas differently - as independent promising oil and gas areas, as potential oil and gas basins, or as oil and gas (or potentially oil and gas) provinces.

Significant hydrocarbon potential is predicted in the sedimentary basins of the Eastern Arctic. All known manifestations of petroleum hydrocarbons are located on the land adjacent to the South (Leno-Anabar interfluve, right bank of the Khatanga Bay), as well as in the East of the shelf (Kotelny and Belkovsky Islands). At the same time, these basins remain poorly studied, which leads to the use of the method of geological analogies to assess the prospects for oil and gas potential and, in particular, their resource potential. The closest analog is traditionally considered to be the Colville trough, located within the oil and gas province of Northern Alaska, which is the largest in the Arctic in terms of proven oil reserves and the third in terms of gas reserves (Houseknechtetal et al, 2019). The correctness of the resource assessment depends on how well the geological analogues are selected, which requires appropriate justification.

In the framework of this work, research has been conducted from the perspective of the concept of generation and accumulation of hydrocarbon systems using modern methods of basin analysis and numerical geological modeling. The Eastern Arctic water areas are included in a single model in order to perform an adequate comparative analysis of the evolution of hydrocarbon systems, given that the studied sedimentary basins are part of the same continental margin and their borders do not always
coincide with the conventional borders of water areas. The model developed by Equinor specialists (Somme et al., 2018) is used as the basis for basin analysis. It covers the time period from the Triassic to the Paleogene inclusively and takes into account the plate-tectonic reconstructions performed by Dor’e et al in 2015.

2. Research methods

The main research methods are numerical space-time basin modeling, which allowed us to create models of hydrocarbon systems in the Eastern Arctic and identify the conditions for the formation of hydrocarbon deposits. In order to reconstruct the conditions of occurrence and evolution of hydrocarbon generation centers, restore the conditions of their formation and patterns of distribution of oil and gas accumulations in the waters of the Eastern Arctic of Vietnam, three-dimensional modeling of generation and accumulation of hydrocarbon systems was carried out using the technology of basin modeling and software PetroMod (Schlumberger Ltd, USA).

Basin modeling is a dynamic analysis based on numerical simulation of geological processes (including precipitation accumulation, compaction, thermal regime, generation of hydrocarbons of their emigration, migration and accumulation) occurring in sedimentary basins. Reconstruction of these processes covers the period from the moment of deposition of the oldest layer of sedimentary rocks and continues up to the present time.

3. Simulation results

To analyze the geodynamic development of the simulated hydrocarbon systems, three-dimensional models of the corresponding estimated parameters were calculated (Fig. 1). The results of the simulation showed that by the beginning of the Apt period, most of the lower Cretaceous deposits of the North Chukotka trough were in temperature conditions corresponding to the main gas generation zone and were overripe by the Paleogene. At present, gas generation is possible in the instrument parts of the deflection, and only pre-Aptian sediments of the North-Wrangel deflection are located in the main zone of oil generation. Based on the results of modeling at this stage of study in pre-Aptian deposits, extremely small hydrocarbon potential is predicted, and the prospective objects are located at depths inaccessible for drilling. In this regard, the prospects of this complex are not discussed in this work.

Apt-upper Cretaceous deposits of all the studied basins could generate hydrocarbons by the beginning of the Paleogene: gas - in the lower part, oil - in the middle part of the section. At the present stage of basin development, the most mature deposits are predicted in the Laptev Sea and the North Chukotka trough, where they are superheated in most of the territory (Fig. 2a).

Paleogene rocks are currently capable of generating both liquid and gaseous hydrocarbons in all basins. Maximum maturity is observed in the Laptev Sea basin. The maturity of the organic matter (OM) of the Paleogene of the North Chukotka and Novosibirsk basins corresponds to the main zone of oil formation (Fig. 2b).

The OM of the lower part of the Neogene-Quaternary complex was warmed up to the level of the "oil window" in the North Chukotka and Laptev Sea basins (Fig. 2b). Sediments distributed within the Laptev Sea could generate hydrocarbons about 5.3 million years ago, while the rocks of the North Chukotka trough entered the oil window later.

Indicators of the degree of conversion of OM, specific densities of generation and emigration of hydrocarbons that characterize hypothetical oil and gas producing rocks (OGPRs) are determined, including the type of kerogen. As already noted, under conditions of significant uncertainty in the material composition of the sedimentary cover of the studied basins, a variable approach was used in this study and modeling was performed in two versions: for kerogen types II and III.
Figure 1. 3D models of the estimated parameters of the Eastern Arctic: А - reflectivity of vitrinite, Б - degree of transformation of OM, В - specific densities of HC generation, Г - specific densities of HC emigration.

It can be seen that by now the Cretaceous OGPRs (Fig. 3a, b) have fully realized the potential in most of the territory of all basins, regardless of the type of kerogen. Minor differences are noted in the side parts of the deflections, where OGPRs with type III kerogen are less transformed. For oil and gas-related rocks of the Paleogene and Neogene, the influence of the kerogen type on the degree of transformation of OGPRs is significant, and it is the greater the lower the depth of their occurrence and, accordingly, the maturity of the OM (Fig. 3c, d).

In general, the lower the maturity of the OM is, the less the generation potential of the OGPRs containing type III kerogen is realized. This is especially noticeable when analyzing maps of the degree of OGPRs transformation of Neogene deposits. The forecast for the formation of hydrocarbon accumulations in the Neogene complex of the North Chukotka trough is very sensitive to the OM type. If the rocks contain type III kerogen, then syngenetic deposits cannot be expected here, despite the sufficient modern maturity of the oil and gas-mineral deposits. It should be noted that the distribution of the TR indicator within the modeling domain reflects differences in the tectonic evolution of the studied sedimentary basins and, in particular, their sinking rates. Thus, in the North Chukotka trough,
the slowing down of the sinking rate in the Paleogene-Neogene, compared to the Laptev Sea rift basin, caused lower volumes of accumulated precipitation and, as a result, lower maturity of OM and the ability of OGPRs to generate and emigrate hydrocarbons.

![Figure 2](image_url)

**Figure 2.** The distribution of the reflectance of vitrinite (R0,%) at the present stage of the development of hydrocarbon systems: a - apt-late Cretaceous oil and gas source rock; b - Paleogene oil and gas source rock.

The specific densities of hydrocarbon generation and emigration are distributed according to the TR index of the simulated OGPRs. The highest densities of hydrocarbon generation and emigration in the Cretaceous complex are predicted within the North Chukotka trough. For OGPRs containing type II kerogen, these indicators are about 20-30 million tons of oil equivalent (O1), and 10-15 million tons of O1 – for type III. In the Paleogene complex, the maximum specific densities of generation and emigration (at the level of 25-40 million tons of UT and 15-25 million tons of UT are observed for the second and third types of kerogen, respectively) are expected in the Laptev Sea basin. The rest of the studied basins are significantly inferior to the Laptev Sea in terms of specific densities and generation volumes in general, taking into account the area of the basin involved in the generation process.

Insignificant generation and emigration of hydrocarbons is predicted for the Neogene part of the section in the Northern part of the Laptev Sea basin.

Given that OGPRs with the same properties were set for all the studied complexes, the calculated generation and emigration properties are determined to a large extent by the thermal regime and tectonic evolution of the basins.
Figure 3. Distribution of the degree of transformation of organic matter (TR, %) at the current stage of development of the hydrocarbon system: Apt-Late Cretaceous oil and gas source rock. a - second type II, b - type III kerogen; Paleogene oil and gas source rock. c - second type II, d - type III kerogen.

Generation-emigration properties of upper Cretaceous and Paleogene OGPRs are high, their values of generation and emigration balance are approximately at the same level. Similar indicators of Neogene OGPRs are much lower, due to the low maturity of organic matter.
In the model with type III kerogen, the ratio of generation-emigration properties of different-age OGPRs corresponds to the model with type II, but the projected volumes of generated and emigrated hydrocarbons are significantly lower.

The study of the dynamics of the generation and emigration potential of the studied OGPRs shows that rapid sinking and high rates of sedimentation of sedimentary basins in the second half of the Cretaceous and Paleogene led to the fact that the processes of generation and emigration of hydrocarbons began almost immediately after the formation of OGPRs. At the turn of the Cretaceous and Paleogene, these processes in the Apt-upper Cretaceous layer are significantly activated, and by the beginning of the Oligocene they slow down. For the Paleogene OGPRs, there is a consistent increase in the generation and emigration potential. The generation and emigration of hydrocarbons from the Neogene oil and gas-mater strata began at the end of the Miocene. In the model with type III kerogen, a similar dynamic is observed with significantly smaller volumes of generated and emigrated hydrocarbons.

In general, the results of the accumulation forecast in the two models differ in terms of the ratio of liquid and gaseous hydrocarbons in the predicted deposits. In the case of type III kerogen, the amount of the gas component increases. At the same time, despite the fact that all potential traps are filled with hydrocarbons in the model with type III kerogen, the predicted volumes of deposits and the degree of filling of traps are significantly lower than in the model with type II kerogen.

4. Conclusion
The most likely areas of hydrocarbon accumulation in the reservoirs of the upper Cretaceous complex of the North Chukotka and Novosibirsk basins are located mainly in their instrument parts at depths of less than 5 km. In the Laptev Sea basin, in addition to the instrument zones, there is a large area in the Central part of the basin where hydrocarbon deposits are expected at depths of more than 5 km. For the complex as a whole, the proportion of gaseous hydrocarbons in the reservoirs is about 25% for the second type of kerogen and 62% for the third.

In the Paleoene complex, accumulations of hydrocarbons are predicted mainly in the Central parts of the studied basins and to a lesser extent in the instrument basins. The depth of occurrence of promising objects is from 5-6 km in the Central parts to 2-3 km in the instrument parts. The share of the gas component in the predicted clusters is 17% and 64%, respectively, for the second and third types of kerogen.

In the Neogene complex accumulations of hydrocarbons are expected to be mostly within the part on the Laptev Sea basin. These are mainly oil deposits with dissolved gas, the share of which does not exceed 15%. In the case of the third type of kerogen, gas and oil deposits can be expected. The ratio of liquid and gaseous hydrocarbons for the complex as a whole is approximately the same.

In the central and southern part of the Laptev Sea basin, gas deposits are found in all complexes, regardless of the type of kerogen, which is due to increased heat flow and, as a result, a high degree of transformation of oil and gas-producing rocks.

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