Cretaceous-Cenozoic Hydrocarbon Systems of the Eastern Arctic Seas

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Abstract. Analyzing the results of the basin modeling using software complexes, preparing of the maps of the generation and accumulation hydrocarbon systems in the waters of the Eastern Arctic is performed. Studying of sedimentary complexes was performed and graphs of geological events were plotted within the limits of five hydrocarbon systems. Land prospectivity categories were defined in accordance with estimates of the specific densities of the default predicted resources.

1. Introduction

A significant hydrocarbon potential is predicted within the sedimentary basins of the Eastern Arctic. Unfortunately, the above basins remain little studied that stipulates the necessity of estimation of their oil-production capacity. In order to attain the given objective, modeling of the hydrocarbon systems in the Eastern Arctic was performed within the framework of this paper.

2. Research methods

The maps of GAHS were prepared for all the studied sedimentary complexes based on the results of modeling and basin analysis using the Schlumberger PetroMod and QGIS software complexes. A series of necessary structural constructions and lithological-paleogeographic and paleodynamic reconstructions along with other special researches, which allowed defining the boundary conditions for modeling, was accomplished in the process of input data preparation for performance of the modeling procedures.

In particular, analysis of the reconstructed paleogeographic environments showed that modeling of the bottoms of paleobasins of the Cretaceous-Cenozoic age were approximately matching with the depths of the present-day shelf within the limits of the megaregion.

The automatic trend embedded into the software of the applicable complex for the Arctic regions with the latitude of 74° was applied for calculation of the temperatures near the bottom of the paleobasins.

The models were calculated for the conditions of the continuous thermal flow, the accepted values of which amounted to 60 mW/m² for the boundary zones of the sedimentary basins of the East Siberian Sea and the Chukchi Sea, and to the order of 70 mW/m² for the inner area of the Laptev Sea that approximately corresponded to its axial paleorifting zone.
3. Modeling results
Performed in the process of modeling calculations of reflective properties of the vitrinite (Ro; %) within the Cretaceous-Cenozoic sediments and the reflectance distribution upon the sedimentary basins of the Eastern Arctic shelves showed that by the beginning of the Apt age of the Early Cretaceous most part of the Lower Cretaceous sediments of the inner area of the North Chukchi trough had been located within the main gas generation zone. That zone had ceased to exist by the beginning of the Paleogene most probably due to overheating of the OM. At the same time, generation of gas is still possible in the close to the boundaries areas of the trough; and the possibility of generation of petroleum hydrocarbons in such sediments is also preserved within the North Wrangel trough adjacent to the sediments from the south. By the beginning of the Paleogene the Apt-Upper Cretaceous sediments of the sedimentary basins of the region could generate both gas (in the bottom parts of their sections) and oil [1]. At the present stage of development of the Cretaceous sedimentary basins and based on the results of the modeling performed, the most mature (up to the overheated ones) sediments are predicted within the inner area of the Laptev Sea and the North Chukchi trough of the Chukchi Sea (Figure 1, A).

Figure 1. Block diagram of the predicted distribution of reflective properties of the vitrinite (Ro; %) within the oil and gas producing rocks of the Cretaceous-Cenozoic section of the marine Eastern Arctic at the present stage of development of the hydrocarbon systems based on the results of modeling. The oil and gas producing rocks: A – Apt-Upper Cretaceous, B – Paleogene, C – Neogene.

The Paleogene sediments and correspondent to them hydrocarbon systems are also capable of generation of both the liquid and the gaseous hydrocarbons within all the sedimentary basins of the region at the present stage of development. In this case the maximum level of maturity of the OM is predicted within the inner area of the Laptev Sea (Figure 1, B), whereas in the North Chukchi trough and within the inner area of the East Novosibirsk syncline (mega trough) the level of maturity of the OM within the Paleogene sediments is apparently correspondent to the main oil formation phase.
The organic matter from the bottom of the Neogene rocks (Figure 1, C) within the North Chukchi and Laptev Sea sedimentary basins is warmed up, according to the results of modeling, to the level of the “oil window” (R<sub>n</sub>, % ≈ 0.7...1.3). At that, generation of hydrocarbons within the Neogene sediments of the Laptev Sea could have started at the boundary between the Miocene and Pliocene that is during the Messinian “salinity crisis” epoch (≈ 5.3 million years ago), which crisis revealed itself not only in the Mediterranean Sea but also in other parts of the World Ocean including the Arctic waters as well [2]. The rocks of the North Chukchi trough referred to this age were included into the “oil window” a bit later – probably in the Pliocene.

According to the results of the modelling the highest densities of generation and emigration of the hydrocarbons within the Apt-Upper Cretaceous sediments are predicted in the North Chukchi trough, where they can comprise from 10...15 million tons/km² (at type III of the kerogen) to 20...30 million tons/km² (at type II of the kerogen). Within the Paleogene sediments maximum specific density of generation and emigration of the hydrocarbons (25...40 million tons/km² at type II of the kerogen and 15...25 million tons/km² at type III of the kerogen) can be found within the Laptev Sea sedimentary basin. The most probable regions of accumulation of the hydrocarbons in the reservoirs of the Apt-Upper Cretaceous sediments of the North Chukchi trough and the East Novosibirsk syncline (mega trough) are located mostly within their close-to-boundary zones at the depths of less than 5 km. Within the Laptev Sea sedimentary basin along with the close-to-boundary zones of accumulation of the hydrocarbons there can be noted its central region, where deposits of the hydrocarbons can be formed at the depth of more than 5 km [3], [4]. Within the Paleogene sedimentary complex accumulations of the hydrocarbons are predicted primarily in the central parts of the modeled sedimentary basins and to a less extent – in their close-to-boundary zones. The depths of depositing for the probable deposits vary from 5...6 km in their central parts to 2...3 km – in the periphery. The predicted share of the gas within the fluid composition of the accumulations varies from 17% (at type II of the kerogen) to 64% (at type III of the kerogen).

Within the Neogene section accumulations of the hydrocarbons are expected mostly within the Laptev Sea sedimentary basin, where they can be represented by the oil having the content of diluted gas of up to 15%. Formation of the gas or oil and gas accumulations is possible under the condition of prevalence of the kerogen type III in the composition of the producing rocks. Based on the results of modeling formation of the gas accumulations is expected in the central and southern parts of the Laptev Sea irrespective of the type of the kerogen in this part of the section [5].

It must be noted that according to the obtained results the regions with the most probable accumulation of the hydrocarbons preserve their spatial position regardless of the type of the organic matter contained within the section.

Considering that geological age of the main part of the section, to which generation, migration and accumulation of the hydrocarbons are related, is referred to the geochronological interval tectonically and geodynamically correspondent to the latest phases of the Alpine tectogenesis and the Neotectonic phase, the most recent tectonic motions must play an important role in preservation of accumulations of the hydrocarbons.

Nevertheless, some general and quite simplified vision of distribution of the water areas, where existence of optimal conditions for preservation of the deposits is possible, can be obtained from the data in relation to a rather scarce grid of seismic observations and paleogeographic reconstructions performed as the reviews [6].

It follows from the data of seismic observations that the most recent sedimentations (the Oligocene-Miocene and Pleistocene) level the structures of gently sloping dislocations of the Cretaceous-Paleocene-Miocene and, somewhere, of more ancient sedimentation complexes and form up a blanket like cover characterizing, probably, the regional stabilization of this part of the shelf zone. It is also witnessed by a relatively poorly dissected low gradient regional relief of the present-day bottom beyond the systems of insular elevations, the territory of which relief have remained a plain land during all that time [7].
The depression mode, which is indirectly proving the mode of stable submersions both under the continental conditions and during the epochs of the sea ingresses and transgressions from the part of the Arctic Ocean, was typical for only two regions within the Russian part of the Eastern Arctic shelves – the Central Laptev Sea and the East Novosibirsk [8], [9].

Based on the results of modeling and basin analysis, up to five generation and accumulation hydrocarbon systems (GAHS) can be defined at various levels of the sedimentary section within the Eastern Arctic shelf mega region.

The oil and gas producing rocks of the Apt-Upper Cretaceous hydrocarbon systems (Figure 2, A) are characterized by high level of maturity or overheating in central parts of the potential centers of generation of the hydrocarbons. Pursuant to the results of modeling, the processes of generation, migration and accumulation within their boundaries started as early as in the Late Cretaceous and were substantially reduced by the present time.

Main stages of formation of the traps in the sediments concerned are related to the Late Alpine/Laramian (66...45 million years ago) and the Early Neotectonic (34...20 million years ago) phases of the tectogenesis and fit approximately within the general geochronological limits of the period of generation, migration and accumulation of the hydrocarbons within the related systems. However, the development patterns of the latter show that main phases of the oil and gas generation and migration within the boundaries of the systems are completed prior to extinction of the structure formation processes, which are still ongoing up to the present time within the limits of several GAHS (the Laptev Sea and the Novosibirsk GAHS) [10]. Due to the foregoing the risks of destruction of the previously formed accumulations of the hydrocarbons and non-filling of the formed traps still exist for the GAHS of such age.

**Figure 2.** The predicted Cretaceous-Cenozoic generation and accumulation hydrocarbon systems (GAHS) of the Eastern Arctic Seas based on the results of modeling. A – Apt-Upper Cretaceous, B – Paleocene-Eocene, C – Oligocene-Miocene. 1 – GAHS distribution domain, 2 – OM maturity in the center of generation (Ro %), 3 – GAHS index, 4 – coastal line. Encircled numbers (GAHS): 1 – Laptev Sea, 2 – East Siberian, 3 – North Chukchi, 4 – Novosibirsk, 5 – Dremkhed.
According to the results of modeling the Paleocene-Eocene hydrocarbon systems (Figure 2, B) realized more than a half of their generation potential during the Late Oligocene – Early Miocene (28 million years ago). At that, apparently due to the particularities of the thermal mode and the rates of submersion of the sedimentary basins, that “crucial moment” had been passed at the earliest in the Laptev Sea GAHS, and the most recently – within the North Chukchi hydrocarbon systems.

Considering that the traps in the North Chukchi and East Novosibirsk hydrocarbon systems, as it was shown by the models, had already been formed by the above-mentioned geochronological interval the ratio between the “crucial moment” and the time of formation of the traps was considered as quite favorable for such hydrocarbon systems, and the traps formed within their boundaries could be filled.

Risks of destruction and restructuring of the deposits are available within the Laptev Sea GAHS, where increased tectonic and geodynamic activity is preserved for quite a long time as it is mentioned above [11].

Solely the Laptev Sea GAHS (Figure 2, C) can be noted within the Oligocene-Miocene interval of the sedimentary section within the limits of the modeling domain based on the available data and their analysis. The hydrocarbon accumulations formed within the boundaries of this hydrocarbon system can be represented primarily by the liquid phase and located in the south-eastern part of the GAHS distribution domain.

Estimation of risks and probability of explored accumulations of the hydrocarbons within the Cretaceous-Cenozoic sediments of the Eastern Arctic shelves (Table 1) within the framework of the analyzed and modeled sedimentary basins and their hydrocarbon systems is based on the applied by the oil companies methodology, which is suggested by American geologists for estimation of oil and gas perspective zones and objects.

**Table 1.** Summary table of estimations of the probability of exploration of the hydrocarbon accumulations within the Cretaceous-Cenozoic GAHS of Russian Eastern Arctic based on the results of regional analysis and modeling of the sedimentary basins.

| The generation and accumulation hydrocarbon systems (GAHS) | Age of GAHS and probability of exploration of the hydrocarbon accumulations | P_{1},P_{2} | P_{3},N_{1} |
|-----------------------------------------------------------|--------------------------------------------------------------------------|-----------|-----------|
| The Laptev Sea GAHS                                       | K_{1,p}-K_{2}                                                            | 0.126     | 0.147     |
| The Novosibirsk GAHS                                      |                                                                         | -         | -         |
| The East Siberian GAHS                                    |                                                                         | 0.147     | -         |
| The Dremkhed GAHS                                         |                                                                         | -         | -         |
| The North Chukchi GAHS                                    |                                                                         | 0.147     | -         |

4. Conclusion

All the hydrocarbon systems related to Cretaceous sediments and characterized by the lowest probabilities for discovering of the deposits are the most high-risk ones from the point of view of the possibility of discovery of the hydrocarbon accumulations. The Paleocene-Eocene and Oligocene-Miocene hydrocarbon systems are different by an order in terms of higher probabilities of their discovery. In this case, the East Siberian and North Chukchi systems are the most interesting from the point of view the possibility of exploring accumulations within the boundaries of the Paleocene-Eocene generation and accumulation hydrocarbon systems (GAHS), and within the boundaries of the Oligocene-Miocene GAHS the interest is represented by the Laptev Sea system only.

5. References

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