

Reconstruction of hydrocarbon generation and accumulation on the Gydan Peninsula and adjacent offshore areas using basin modeling approach

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Abstract. Based on structural and lithological grid models, a three-dimensional numerical dynamic model of the Mesozoic-Cenozoic sedimentary cover of the Gydan source kitchen and adjacent territories was built. The thermal history of sediments was reconstructed. A map of effective deep heat flow was compiled. A good agreement was found between the measured and calculated degrees of catagenetic transformation for Upper Jurassic rocks. The possible types of kerogens from the main Jurassic and Cretaceous source rock sequences were justified. The study also provides assessments of the volumes of hydrocarbon generation from the main source rock sequences, timing of formation of regional seals and possible extent of hydrocarbon accumulation in structural traps.

1. Introduction

Because of significant exploration efforts now being devoted to the hydrocarbon resource potential of the Russian Arctic, there is considerable interest in the magnitude and structure of its resource base, which requires further quantification. One of the modern methods for quantifying petroleum resources is basin modeling, which has been earlier applied to the Gydan source kitchen and adjacent areas [1-10]. However, the most recent geological and geochemical data may provide the basis for the development of more detailed models of petroleum generation processes within the Gydan source kitchen and more precise estimates of its hydrocarbon potential.

The study area is located within the Gydan source kitchen bounded by the Antipayutin-Tadebeyakha megasyncline and the Kara megasyncline [11]. The Kara megasyncline covers the southern part of the Kara Sea and the northern tip of the Yamal Peninsula. The Antipayutin-Tadebeyakha megasyncline is a negative closed super-order structure that covers the eastern part of the Yamal Peninsula, the Ob Bay and a significant part of the Gydan and Taz Peninsulas.

From a standpoint of petroleum zonation, the study area comprises the Gydan petroleum area, the eastern part of the Yamal petroleum area, and the western part of the Yenisei-Khatanga petroleum area. The largest hydrocarbon accumulations are concentrated at the Utrennee (Salmanovskoe), Geofizicheskoe, and Gydanskie fields.



The thickness of the sedimentary cover in the study area reaches 7-8 km and the age appears to range from the Triassic through the Quaternary. The proved net-pay zone includes the Upper Jurassic and Cretaceous.

The numerical model of the study area is based on extensive geological, geochemical and geophysical data, including well logs, as well as determinations of petrophysical properties in reservoir and seal formations.

2. Parameters of model

The surface area of the model block is 375,000 km². The basic structural grid models had a size of 500x700 nodes (with 1 km increment). Note that the simulation is a computationally intensive and time-consuming iterative process. Therefore, for preliminary calculations, the dimensions of the model block were reduced to 250x375 nodes (with a 2 km horizontal step).

The section was subdivided into 34 horizons with isochronous boundaries (35 mutually consistent structural surfaces), which are correlated with the formations or regional clinoforms. For each horizon, a specific lithology was prescribed and determined as a mixture of input lithological types. Petrophysical parameters such as thermal conductivity, heat capacity, etc. were set using the TemisFlow (BeicipFranlab) software database.

An essential step in modeling the evolution of the sedimentary cover is the reconstruction of the amplitude of erosion and paleo-depths. Paleobathymetry and erosion estimations are crucial for reconstructing a thermal history, and, consequently, the timing of hydrocarbon generation within the main source rock sequence (SRS) of the study area. The paleo-depths were determined using the available paleogeographic reconstructions [12, 13].

3. Results

The thermal history of sedimentation was restored based on the data on present-day temperatures, position of the lower permafrost boundary, and vitrinite reflectance [14], which reflects the maximum paleotemperatures.

The calibration of the thermal history took into account a changing density of the effective heat flow at the base of the sedimentary cover. A series of computational experiments using individual model wells and the entire sedimentary cover in the study area allowed a good fit between the calculated and actual values of vitrinite reflectance (figure 1) and present-day temperature profiles [15-17].

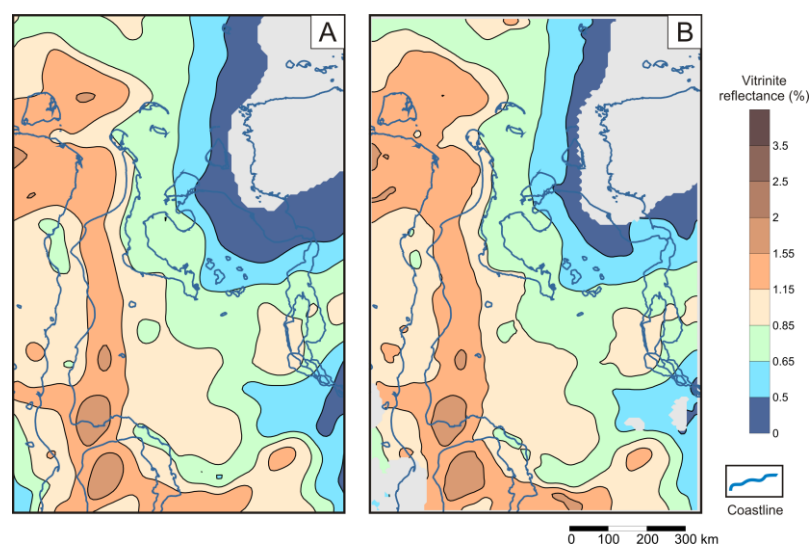


Figure 1. Katagenesis scheme comparison in the roof of Upper Jurassic based on real data (A) [18] and modeling scheme (B).

The data on organic geochemistry of sediments on the Gydan Peninsula and in the western part of the Yenisei-Khatanga trough have been presented in many previous studies [19-21]. The most recent data on organic geochemistry of sediments from the western part of the Yenisei-Khatanga trough and adjacent areas are discussed in detail in [16, 22].

In the model, for each source rock, the input parameters used were kerogen type (which specifies its kinetic characteristics), initial organic carbon content, and initial hydrogen index.

The characteristics of dispersed organic matter (DOM content in sedimentary rocks, hydrocarbon potential, kinetic characteristics of kerogen, etc.) were determined based on the results of geochemical studies conducted at the Institute of Petroleum Geology and Geophysics, Siberian Branch, Russian Academy of Sciences [16, 22]. It is commonly accepted that type I kerogens originate from aquatic lacustrine organic matter, type II kerogens from aquatic marine organic matter, and type III kerogens from terrigenous organic matter. However, the standard characteristics of these types of kerogens needed to be refined based on pyrolysis data [10].

Shale stringers of the Golchikha, Malyshev, Laida, Zimnyaya and Kiterbyut Formations were regarded as potential source rocks. The model predicts that organic matter in the Bazhenov and Malyshev source rocks can be correlated with mixed type II/III kerogens, organic matter in the Laida and Zimnyaya source rocks can be correlated with type III/IV kerogens, and organic matter in the Kiterbyut source rocks can be correlated with type III kerogen.

Using a 3D numerical geological model of the sedimentary cover of the Gydan source kitchen allowed us to reconstruct the extent and dynamics of hydrocarbon (both liquid and gaseous) generation from each source rock sequence (SRS).

The average density of hydrocarbon generation from Zimnyaya source rocks was 11 thousand t/km² for liquid hydrocarbons and 90 million m³/km² for gaseous hydrocarbons. The highest generation densities are calculated for the Vnutrennyaya mesodepression and the Southern Messoyakha mesodepression in the south of the study area. The total hydrocarbon generation was 4.4 billion tons for liquid hydrocarbons and 33.6 trillion m³ for gaseous hydrocarbons.

The average density of hydrocarbon generation from Kiterbyut source rocks was 1260 thousand t/km² for liquid hydrocarbons and 1100 million m³/km² for gaseous hydrocarbons. The highest densities of hydrocarbon generation are calculated for the central and southeastern part of the study area. Source kitchens are confined to a series of first-order negative structures: Tadebeyakha megatrough, Yaptik-Sale, East Antipayutin, Yenisei, and North-Taz megadepressions (figure 2). The total hydrocarbon generation from the Kiterbyut source rocks was 472 billion t for liquid hydrocarbons and 415 trillion m³ for gaseous hydrocarbons.

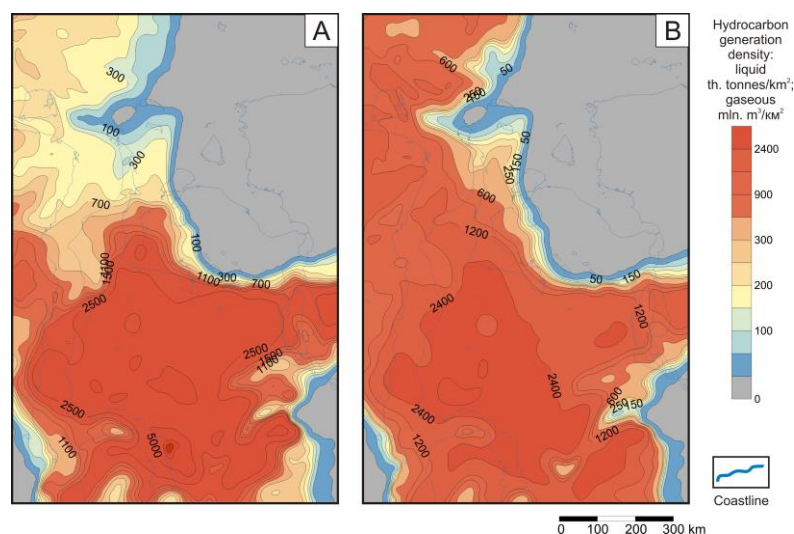


Figure 2. Generation volumes of liquid (A) and gaseous (B) hydrocarbons by Kiterbyut source rocks organic matter.

The average density of hydrocarbon generation from Laida source rocks was 190 million m³/km² for gaseous hydrocarbons and 156,000 t/km² for liquid hydrocarbons. The highest densities of hydrocarbon generation are calculated for the central and eastern parts of the study area. Source kitchens are confined to the Yaptik-Sale, Tadebeyakha megadepressions, and East Antipayutin depression. The total hydrocarbon generation from Laida source rocks was 58 billion t for liquid hydrocarbons and 71 trillion m³ for gaseous hydrocarbons.

The average density of hydrocarbon generation from Malyshev source rocks was 617 thousand t/km² for liquid hydrocarbons and 300 million m³/km² for gaseous hydrocarbons. Source kitchens are confined to the central, eastern, and southern parts of the area, which include the Tadebeyakha megatrough, Anitipayutin-Tadebeyakha and Yenisei mega depressions (figure 3). The total hydrocarbon generation from Malyshev source rocks was 230 billion t for liquid hydrocarbons and 112 trillion m³ for gaseous hydrocarbons.

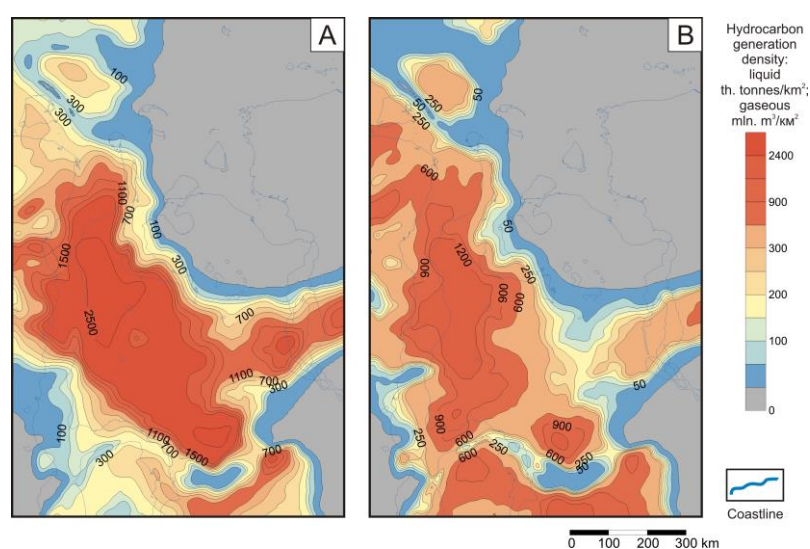


Figure 3. Generation volumes of liquid (A) and gaseous (B) hydrocarbons by Makyshev source rocks organic matter.

The average density of hydrocarbon generation from Bazhenov source rocks was 70 million m³/km² for gaseous hydrocarbons and 680,000 t/km² for liquid hydrocarbons. Source kitchens were relocated from the center to basin's periphery, being confined to the Central Kara megadepression in the north, Yenisei megadepression in the east, North Taz megadepression in the south (figure 4). The total hydrocarbon generation from Bazhenov source rocks was 18.6 billion t for liquid hydrocarbons and 18 trillion m³ for gaseous hydrocarbons.

The cumulative hydrocarbon generation from all source rock sequences in the study area was estimated to be 950 billion t of liquid hydrocarbons and 650 trillion m³ of gaseous hydrocarbons. It should be noted that at this stage secondary cracking processes were not taken into account by our model. But taking these into account, the actual ratio of generated volumes should be shifted toward gaseous hydrocarbons. In view of the above, the amounts generated from Kiterbyut, Malyshev, and Bazhenov source rock sequences account for >50% ~24%, and 20% of total liquid hydrocarbons, respectively. The generation from Laida and Zimnyaya source rocks accounts for only 6% and <1% of total liquid hydrocarbons, respectively.

The highest generation of gaseous hydrocarbons was from Kiterbyut source rocks, which accounts for 64% of the total amount. The amounts generated from Malyshev, Laida, Zimnyaya, and Bazhenov source rock sequences account for ~17%, 11%, 5%, and 3% of total gaseous hydrocarbons, respectively.

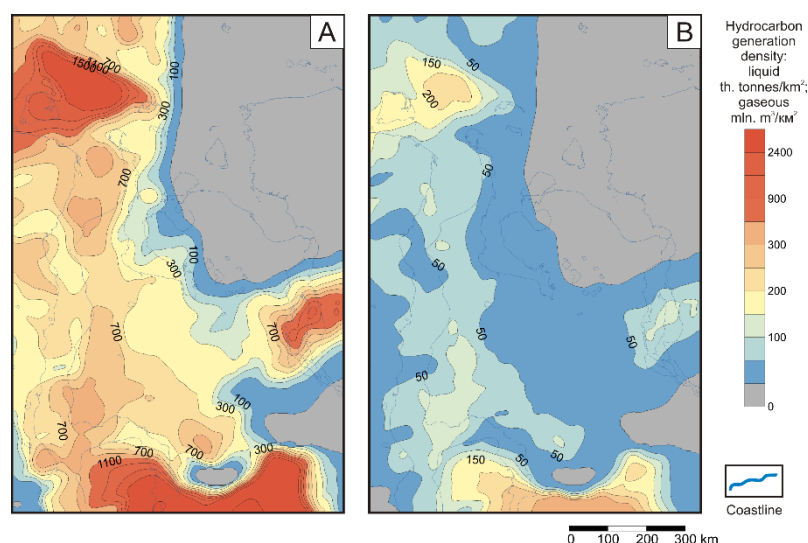


Figure 4. Generation volumes of liquid (A) and gaseous (B) hydrocarbons by Bazhenov source rocks organic matter.

The formation of hydrocarbon fields requires a combination of a number of factors. For example, the preservation of hydrocarbon accumulations, the volume and phase composition of hydrocarbons in traps depends on the timing of generation and lithification of seals. In view of this, we estimated the timing of lithification of the main seals within the Gydan source kitchen area. The boundary value of input porosity at which the rock is capable of retaining hydrocarbons was set to be 30% [7]. The Kimmeridgian-Volgian seal composed of shales of the Bazhenov horizon was lithified at the end of the Early Cretaceous- and beginning of the Late Cretaceous, at ~99 Ma (figure 5). The Lower Hauterivian seal represented by shales of the Ur'yev clinoform was lithified by the beginning of the Late Cretaceous, i.e., at ~100 Ma. The Lower Aptian seal represented by shales of the Aym horizon was lithified at ~80 Ma, in Campanian times. The Albian seal was lithified throughout the netire area at 70 Ma during the Maastrichtian. The Turonian seal represented by shales of the Kuznetsov horizon was lithified only locally in the mid-Paleogene, at 45 Ma.

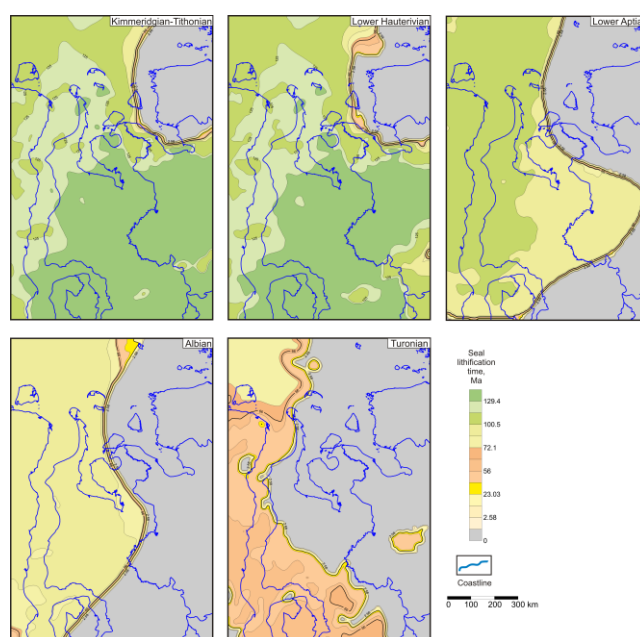


Figure 5. Lithification time scheme for general seals in the study area.

To estimate the possible extent of accumulation of hydrocarbons, which is planned to be implemented at the next stage of our study, we evaluated the rock volumes of traps within the main petroleum-bearing complexes of the study area (figure 6). The results were exemplified by the Valanginian-Aptian petroleum-bearing complex. The location of traps throughout the section shows that the actual trap geometries agree satisfactorily with the model ones. In addition to geometries, the calculated volumes of model traps are well consistent with the volumes of actual traps in the corresponding complex (figure 6).

To summarize, the study provides a quantitative assessment of the generation of liquid and gaseous hydrocarbons and possible extents of hydrocarbon accumulation. To evaluate the amounts of hydrocarbons accumulated in the study area, it is necessary to account for their losses during expulsion and migration. Based on earlier assessments [1, 7], it is assumed, in a first approximation, that the accumulation coefficients in these regions may be equal to ~1% of the total generation volumes. Then the initial geological resources of hydrocarbons associated with the Gydan source kitchen would be not less than 16 billion t of conventional hydrocarbons.

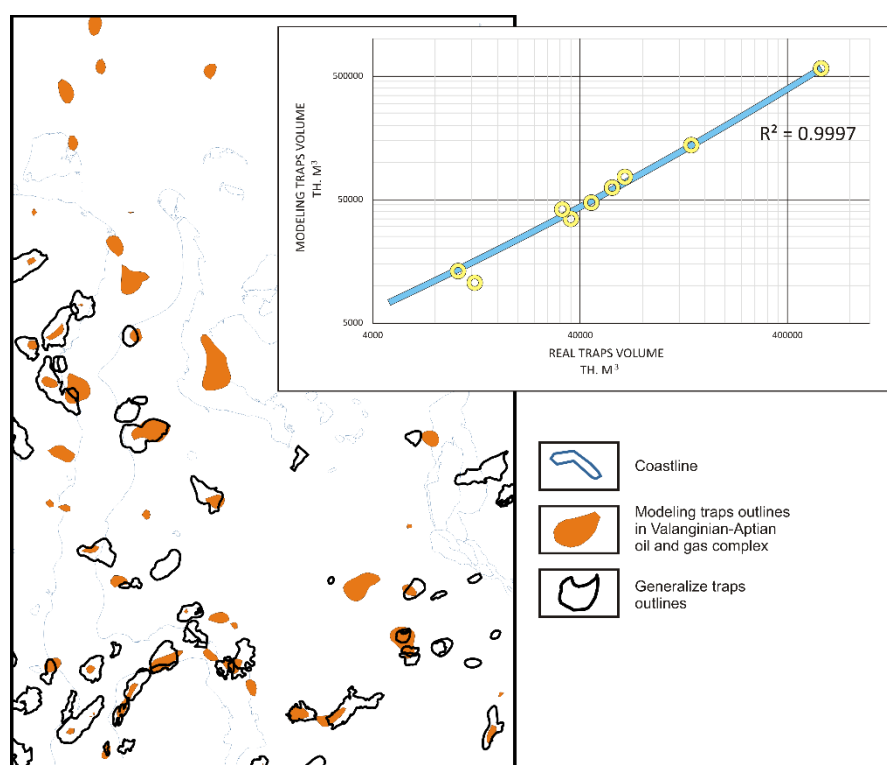


Figure 6. Model hydrocarbon traps in the territory of Gydan source kitchen.

The simulation results were used to estimate the extent of hydrocarbon generation from the main source rock sequences within the sedimentary cover of the Gydan source kitchen area, the timing of seal formation and possible volumes of hydrocarbon accumulation. The next step will involve evaluation of the phase composition of hydrocarbons within the trap and description of individual traps in the main petroleum-bearing complexes.

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