The application of basin modeling of oil and gas systems for seismogeological projects for assessment of hydrocarbon potential and risks of exploration work

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Abstract. In this article, the methodology of basin modeling was systematized and the sequence of solutions to the applied problems related to the forecast of deposits of oil and gas was updated, and the applicability of basin modeling to traditional regional projects was evaluated.

Currently most of the territory of the West Siberian Basin has been studied by seismic exploration and drilling, most of the large hydrocarbon deposits have been identified. Therefore, the requirements for the success of the exploration work are increasing many times. Since geological risks in the poorly studied territories remain extremely high, subsoil users are in no hurry to license and to search for these areas. Today, basin modeling (BM) is one of the most effective tools to increase the reliability of the geological model of the subsoil structure and, as a result, reduce geological risks and increase the investment attractiveness of poorly studied subsoil areas.

In the modern world the modeling of oil and gas systems has long become an integral part of exploration, only recently domestic oil and gas companies had started to adopt the experience of foreign countries. Large foreign oil and gas companies don’t begin prospecting and exploratory drilling of wells without creating conceptual models of hydrocarbon systems of the investigated zones. The most striking example of the implementation of BM in exploration projects is the experience of the Brazilian oil and gas company. Geologists of this company were discovering single deposits in various areas of Brazil since the late 1970s. Basin modeling specialists began to appear in the 1980-1990s. They developed the first successful models, and as a result, the number of discoveries increased multiple times. Due to the high confirmation of the obtained forecasts in the period from 2000 to 2009, the use of BM becomes a required condition for choosing the location of new wells.

Considering the experience of foreign researchers, the specialists of "ZapSibNIIGG" first used BM in 2015 as part of a project carried out in the south of the Tyumen region. Regional and zonal 1D and 2D basin models were developed in the territory of the Yamalo-Nenets Autonomous Okrug, the Khanty-Mansi Autonomous Okrug and the south of the Tyumen region for the period from 2015 to 2020. Plans for the foreseeable future include a plan to create a regional framework 2D models for the entire basin, and there is the subsequent creation of a three-dimensional model for the entire West Siberian province.

The purposes of the work is the systematization of knowledge, the formation of methodological recommendations for the modeling of hydrocarbon systems and the assessment of the applicability of basin modeling for poorly studied territories of the West Siberian basin.
The technology of modeling of oil and gas systems is an effective tool in assessment of the prospects of subsoil areas because it allows to create a deeply integrated model of the basin or its fragment, considering the entire array of input data on the geological structure of the area of work, including data from structural and lithological-facial studies, geochemistry of organic matter and fluids, quality of tires and reservoirs.

The main goal of the BM is the prediction oil and gas prospective zones, create a comprehensive reliable geological model of the subsoil structure, reduce geological risks when choosing promising objects for exploration work. Tasks facing the geologist in the modeling process are forecast of the quality of the main elements of the hydrocarbons systems (cap rocks, header, source rocks of oil and gas), analysis of possible scenarios and mechanisms of migration of hydrocarbons and redistribution of deposits, forecast of component composition of accumulations.

There are three types of models for tasks of modeling. 1D simulation involves visualization of calculations on graphs and multigraphs along the well bore and in individual cells over time. 2D modeling lets promptly create and test conceptual models of basin development based on seismogeological lines. The most efficient and complete model is the 3D model. This type of modeling allows for a complete 3D analysis of pressures and temperatures in the sedimentation basin in time and space, predicting possible complications during drilling (by the type of Abnormal-High Formation Pressure) in the early stages, providing a detailed forecast of the maturity, generation, and migration of hydrocarbons; evaluate drainage zones and filling of traps by hydrocarbons.

The first stage of modeling is the determination of the type of basin, because the tectonic history of the development of the region, the paleotemperature regime, the stages of sediments accumulation, as well as the quality of the main elements of the hydrocarbon system (tire, collector, source rocks of oil and gas) is depended on it. There are 3 main types of sedimentary basins which it includes platform basins (intra-platform, edge-platform, passive margins); basins of folded areas; heterogeneous basins of transient type.

Western Siberia belongs to the intra-platform type and is the largest geosyncline, which passed the rift stage at the early stages of its development. Confirmation of this fact is the presence of a developed system of aulacogenes of Triassic age (Khudoseisky and Koltogorsk-Urengoy aulacogenes). The quality of the hydrocarbons system is often high and is confirming by the discovery of oil and gas deposits on the territory of Western Siberia.

The question of choosing representative wells for multi 1D modeling as well as the choice of composite seismic lines for 2D models for creation a conceptual model of basin development emerges after determining the type of basin and the main regularities prevailing in it.

Wells drilled at the territory of basin modeling can be divided into 2 categories. The first category includes wells located in the immediate vicinity of the lines (1-2 km) selected for 2D modeling. Geologist should have a certain set of geological, geophysical and geochemical information for these wells such as pyrolysis and reflectivity of vitrinite, results of GIS interpretation (determination of porosity and permeability coefficients), temperature and pressure measurements. Based on these wells, reservoir characteristics, thermobaric and other properties of the 2D model are calibrated. The number of selected calibration wells must be sufficient for qualitative forecasting of properties and has to be determined by the geological complexity of the section and the total length of the selected seismogeological line. The second category includes wells that are representative for a given area (they can be located at a far distance from the area of work/seismic lines), having maximum sinking along the section. Usually, these are parametric wells which it includes a complete complex of geological, geophysical and geochemical studies. This information allows to determine regional patterns such as the amount of heat flow, thermal gradient, the amount of rock consolidation with depth, pressure change with depth, etc. The number of wells of this category on average is about 3-5 pcs.

When choosing a regional lines 2D it is necessary to consider that the line should pass through large negative elements (deflections and depressions), which are centers of hydrocarbons generation, as well as through shafts and ascents, which will be areas of hydrocarbons accumulation. To avoid artificial
elongation of lateral migration paths, the trace should go along the smallest distance from the generation regions to the areas of the intended accumulation of hydrocarbons.

The next step is a schematic formation of the history of the basin development with the identification of the main stages of erosion and the assessment of its volumes. According to the selected wells and lines, a diagram of the structural framework is created, with the selection of the main elements of the hydrocarbon system (regional header, cap rocks and source rocks of oil and gas). For this the main lithotypes of the entire section from the sedimentary cover to the folded foundation are distinguished and set according to core and GIS data. To account for the interwell space, mixes of lithologies are created for each facial zone based on paleogeographic constructions. Further, petrophysical parameters (model of lithotype compaction, thermal conductivity, permeability, etc.) and geochemical parameters (vitrinite, pyrolysis data - S1, S2, Tmax) are entered. After setting the structural framework and lithology, boundary conditions are set, such as palaeo-water depth (PWD), sediment-water interface temperature (SWIT), and geothermal heat flow (HF). So, possible scenarios for the development of the basin are formed.

The next step is the calculation multiple iterations of 1D and 2D models to determine boundary conditions and calibrate simulated properties with input data more accurately. This stage is most sensitive to the quantity and quality of input information and to the conceptual history of the evolution of petroleum bearing basin, which is accepted by the modeler. Based on the results of modeling representative wells, geologists can extend the revealed patterns of distribution of properties along the section of the sedimentary cover to poorly studied territories. Geologist can predict the patterns of changes in reservoir characteristics, temperature and pressure in such territories with greater reliability than by traditional geological and geophysical research methods. Based on the results of the 2D simulation, geologists can determine the main trends and scenarios inherent in the given oil and gas system (length of the migration vector, stages of tectonic activation, etc.). The assessment of traps filling is conditional at the stage of building a 2D model because the main task of 2D models is qualitative analysis.

By the results of 1D and 2D modeling in poorly studied areas, if there is a conditioned model, geologists can reliably predict the reservoir characteristics of rocks along selected cross sections, as well as clarify the levels of organic maturity, respectively, geologists can reduce the geological risks of prospective areas.

**Forecast of reservoir characteristics.** The prediction of reservoir properties throughout the section is executed based on actual data about rocks compaction, lithostatic and hydrostatic pressures, the history of submergence and upheaval of the territory. As a result, reservoir characteristics can be predicted for intervals where there is either no incomplete set of geological and geophysical information to determine the quality characteristics of both cap rocks and reservoirs. The undeniable advantage of basin modeling in contrast to traditional modeling, when a geologist works with a static hydrocarbon system, is the possibility of predicting the evolution of the hydrocarbon system and its properties over time. This tool has shown itself well in the territory of poorly studied zones of the Western Siberia basin where the quality of seismic lines and well production is insufficient for the reservoir characteristics forecast by low-frequency FDPI analysis.

**Forecast of geological risks.** Any geological project is highly dependent on geological hazards, so their assessment is a priority in the exploration process. The complex of geological and geophysical studies must characterize the following key factors: the availability of source rocks of oil and gas, the availability of hydrocarbons migration routes, the availability of header, accommodating oil and gas; confidence in the geometry of the trap; the availability of cap rocks, holding the hydrocarbons. Along the regional 2D lines, zones with simulated properties characterizing both the quality of source rocks of oil and gas and headers, cap rocks and migration routes can be identified and ranged.

For example, companies often accept the chance of success in the presence of oil and gas source rocks as 0.9-1 if there are proven source rocks of oil and gas in a particular area. But this approach is conventional, takes into account regional patterns and does not consider the quality characteristics of the rock, its ability to generate hydrocarbons. As well as such a criterion as the preservation of deposits
is rarely taken into account in a static model. From the experience of the authors, the last two criteria are the most important because there is a high proportion of uncertainty for it. Thus, geologists have to understand conditions of the sedimentation and to predict its qualitative properties with a certain proportion of conventions at subsequent sedimentation stages, including tectonic activity after rock formation, catagenesis transformation of source rocks of oil and gas. BM helps to take into account all stages of formation and post-sedimentation transformation of deposits, so the reliability of forecasted property maps is increased significantly. Thus, geological risks and uncertainties of each of the elements of five-factor analysis are reduced.

**Forecast of lead zones.** When integrating the results of both traditional geological studies and basin modeling, namely, when combining the contours of traps identified by the results of seismic exploration and contours of structures whose saturation is possible by the results of BM (for example, the use of maps of OWC, which by the classical approach are often determined according to the closing isoheight), geologists can allocate zones of interest whose reliability is an order of magnitude higher than without taking into account modeling (Figure 1). Thus, we solve the main problem of 1D and 2D modeling, specifically the forecast of interest zones, which subsoil users have to pay attention to first of all.

![Figure 1. Identification of perspective objects: A – on the seismogeological lines; B – on the lines by results of the basin modeling; C – on the map of oil and gas potential. Red objects are perspective traps by results of the basin modeling](image)

It should be noted that a few difficulties occur in the modeling of oil and gas systems. So, for example, there is always a risk of incorrect and/or insufficient selection of wells and/or seismic lines for modeling, therefore the result will not fully correspond to the geological history of the basin and will not solve the problems of reducing geological risks and predicting areas of interest. Also, 1D and 2D modeling are often included in the specifications, mistakenly believing that this tool will allow assessing the degree of filling of traps, clarifying oil-gas-condensate contacts, and increasing the resource potential of the project. However, these modeling methods (creation of 1D and 2D models) allow to estimate only the qualitative characteristics of the system (the degree of transformation of the organic matter, the reservoir characteristics model, the time and destination of migration, etc.) and do not determine of quantitative filling of prospective traps.

Thus, both applied and scientific tasks are solved in getting new information on the structure of the subsoil, the extraction of new or passed intervals of hydrocarbon generation, drainage zones and fluid migration paths in the process of modeling. 1D, 2D and soon 3D models allow geologists to identify and range oil and gas prospective zones in poorly studied territories, increase the reliability of existing models, as a result, geologists can offer a specific territory with the least risks for licensing and further
exploration to the subsoil user. However, basin modeling is not an end point, and after the exploration work, new data should be included in the model to refine the frame of the territories.

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