Results of reinterpretation of marine geochemical survey on the Sakhalin shelf

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Abstract. Geochemical survey of hydrocarbons (HC) all over the world is a reliable tool of the complex of geological exploration, which allows to localize hydrocarbon saturation in structures exposed by seismic exploration, as well as to identify non-structural deposits. In 2011, a marine geochemical survey of the sorbed gases of bottom sediments was carried out on the shelf section of the northwest of Sakhalin Island. Based on the results of geochemical studies, 12 maps of the distribution of hydrocarbon and non-hydrocarbon gases in the work area and 7 maps of the distribution of metals in bottom sediments were constructed. Promising areas were distinguished by anomalies with the maximum content of parameters. The research area is characterized by a complex structure, located within the Baikal synclinal zone of the North Sakhalin oil and gas basin, which is part of the rift system of the Cenozoic sedimentary basins the Sea of Okhotsk. In 2019, the authors began to re-process and reinterpret the data in order to clarify the results. The work was based on modern theoretical foundations and methodological approaches of oil and gas prospecting geochemistry. The interpretation of the results was carried out on the basis of the model of interpretation of geochemical anomalies developed by the authors. Maps of anomalies were constructed according to 11 geochemical criteria and two geological and geochemical sections. The complex interpretation of geological and geochemical data was carried out taking into account the results of seismic exploration and drilling in a single project. According to the results of the complex interpretation, 6 promising sites were identified, which are ranked according to the degree of prospects.

1. Introduction

The efficiency of forecasting, prospecting and exploration of hydrocarbon accumulations (HC) can be significantly increased as a result of the use of geochemical prospecting technologies for oil and gas fields. These methods and technologies are becoming important in poorly studied and hard-to-reach regions where the resolution of traditional geological and geophysical studies for oil and gas is not high enough. Their complex use can lead to a significant optimization of the entire process for oil and gas, including in conditions of non-structural (non-anticline and complex) traps [1, 2].

To date, the theoretical foundations of geochemical methods have been sufficiently developed, including the theory of geochemical fields; models of the formation anomalous geochemical fields over hydrocarbon accumulations in various geological conditions. Optimal complexes of search indicators are used, separate forecast for individual stages and stages of exploration for oil and gas; integration of geochemical prospecting methods for oil and gas fields with other methods, including geophysical, at various stages of exploration for oil and gas. New methods (with vibration, the use of
geochemical surveys with seismic exploration, remote types of research, etc.) and modifications of search operations are scientifically substantiated [3, 4].

On Sakhalin Island, geochemical work was carried out in the northeast of the island in the period 1945–1979. Prospecting geochemical works in the period 1945–1951 identified promising areas where the following deposits were later discovered: Gilyako-Abunan (1950), Erri (1953), Odoptu-susha (1955), Tungor (1958), Nelma (1964), Northern Okha (1967). In the period 1976–1981, geochemical oil and gas prospecting works were carried out on Sakhalin by methods of surface gas and fluorescence evaluation. Among the recent regional works, one can single out the article [5].

2. Data and main results

In 2011, a marine geochemical survey of the sorbed gases of bottom sediments was carried out on the Astrakhan section of the shelf of the northwest of Sakhalin Island (figure 1A).

![Figure 1. Location map (A) and contrast distribution over the HC C_2-C_4 (B).](image)

Geochemical studies included sampling of bottom sediments in the volume of 410 samples, 20 samples of sediments on land, sampling of near bottom water in the volume of 25 samples. Laboratory chemical-analytical studies included: degassing of samples on the ship, chromatographic analysis for free gases (Ne, H_2, CO_2, N_2+O_2, C_1-C_6), (figure 1B); chromatographic analysis for light hydrocarbons (vaporous C_7-C_9, including aromatic); chromatographic analysis for heavy hydrocarbons (C_10-C_24); trace element analysis for 28 elements; isotopic analysis of gases δ13C; total organic carbon (TOC); biomarker study. A total of 430 gas-geochemical samples and 860 lithochemical samples were analyzed. Based on the results of geochemical studies, 12 maps of the distribution of hydrocarbon and non-hydrocarbon gases in the work area and 7 maps of the distribution of metals in bottom sediments were drawn. The samples are represented by sands with inclusion of clay and silt. The prospect areas were identified by anomalies with the maximum value of geochemical parameters. At the same time, the permeability of faults was not taken into account, since when compared with seismic survey
materials, the location of the selected prospect areas was questionable. In this and similar cases, geochemical methods are good and relatively cheap alternative to other research methods (geophysical, drilling, etc.).

In 2019, we started to re-process and reinterpret geochemical data in order to clarify the results.

As the primary processing of an array of analytical data, R-type cluster analysis was applied (figure 2), based on a multidimensional statistical procedure for calculating Euclidean distances (similarity/dissimilarity of properties). The interpretation was carried out on the basis of a model developed by the author in the fields of Western Siberia and modified in accordance with the conditions of a marine geochemical survey on the Sakhalin shelf [6].

Figure 2. Distribution of alkane hydrocarbons and helium in bottom sediments.

The main factors affecting the generation of the anomaly are: the formation pressure, the depth of deposit, the thickness structure above the deposit (mainly the quality of the caprock), fault tectonics and the structural position of the deposit. On the basis of the model described above, a model of interpretation of the Astrakhan site has been developed, taking into account the geological structure and conducted laboratory study and criteria have been pre-selected for various areas of the forecast.

1) The main criteria for assessing the permeability of discontinuous faults are helium, hydrogen, HC gases - C1-C4, heavy HC C7+, bitumen HC, heavy metals (V, Ni, Co).
2) The main criteria for the presence of hydrocarbon deposits are: low-contrast annular or areal anomalies C2-C4, C5-C6, helium, hydrogen, carbon dioxide, the sum of the limiting hydrocarbons. Additional criteria for the presence of a deposit are: the content of heavy metals, the V/Ni ratio, the types of bituminoids, the bituminosity coefficient, Fe2+/Fe3+.
3) The main criteria for assessing the phase saturation of hydrocarbon deposits are: the dryness coefficient of gases, the maturity coefficient of gases, the epigenetic coefficient of hydrocarbon gases, the type of HC gases, the value of butane and pentane coefficients (iC4/nC4; iC5/nC5).

Based on the results of processing geochemical data and adapted interpretation model, 11 most informative indicators were selected. Anomaly maps are constructed in the Isoline GIS (geoinformation system) based on the selected indicators. Also, a seismic project has been uploaded to the Isoline GIS, including the surfaces of discontinuous faults and structural maps. Geological and geochemical sections have been constructed in two directions (submeridional and sublatitudinal). Based on the materials obtained, taking into account the drilling results (logging, core, well testing results), a comprehensive interpretation was carried out.

The geochemical field according to the sum of the limiting HC C2-C4 is medium-contrast, medium-rugged (figure 1B and 3). A low-contrast annular anomaly is observed in the near-water part of the Astrakhan structure, and a low-contrast areal anomaly is observed in the boundaries of blocks 7–8.
Based on the results of the complex interpretation, a map of total anomalies was created, on which the contours of anomalies identified by all major geochemical parameters were placed. According to the number of matching contours and the accuracy of the coincidence, several sites with varying degrees of reliability and, accordingly, prospects were identified and a perspective production map was created (figure 4).

The most promising section 1 is allocated in the vaulted part of the southern block of the Astrakhan structure. This area is distinguished by all geochemical indicators, the contours of all anomalies practically coincide with each other and with the contours of traps No. 7, 8 (figure 3), which are highlighted on all major stratigraphic horizons. The probable phase saturation of the prospective site 1 is oil. Four more sites have been identified with a slightly lower degree of confidence.

Based on the results of the work, recommendations were developed for subsequent geochemical work on the shelf:

- it is necessary to conduct experimental work to assess the properties of bottom sediments in order to develop an optimal sampling technique;
- when conducting offshore geochemical searches for oil and gas, it is recommended to select control sites (HC fields, proven deposits) on the shelf areas with similar conditions;
• when conducting geochemical searches for oil and gas on land, samples should be taken from a depth of at least 1 m.

Based on the conducted research, we have proposed an optimal algorithm for conducting geochemical surveys at sea.

Sampling:
• sampling of bottom sediments. The work can be carried out at sea depth from 1 to 1500–2000 m. Sampling depth is 2–3 m from the sea bottom surface;
• degassing of samples immediately after sampling;
• express analysis on a mobile chromatograph.

Analytical work:
• analytical work in a stationary "town" geochemical laboratory;
• construction of maps and graphs of the distribution of geochemical parameters and coefficients (the selection of parameters for each area is individual);
• delineation of anomalous zones and interpretation of the received data.

Interpretation of results:
• geochemical zoning by phase saturation and conditions of preservation of hydrocarbon deposits.
• comparison of the results with information about the geological features of the area;
• identification of promising areas for drilling.

3. Conclusion
A comprehensive interpretation of geological and geochemical information carried out using modern software products, involving all available geological and geophysical information, allows us to obtain the most reliable results on structural and non-structural deposits, the degree of conductivity/closure of faults and the phase composition of the forecast saturation. During the work, 12 maps of the distribution of hydrocarbon and non-hydrocarbon gases in the area of study and 7 maps of the distribution of metals in bottom sediments were constructed. According to the results of the conducted research, 6 promising sites have been identified, which are ranked according to the degree of prospects, which in turn will significantly reduce the risks during further exploration.

The most informative geochemical indicators on this area were:
• helium and the sum of heavy hydrocarbons C₇⁺ for assessing the permeability of structural discontinuities;
• low-contrast annular or area anomalies C₂-C₄, C₅-₆, the sum of alkanes and cycloalkanes – as criteria for the presence of hydrocarbon deposit.

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