Cost Estimate for Exploration of Oil and Gas Fields in the Arctic Zone

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Abstract. In the paper, the oil and gas exploration methods and technologies have been compared. It is noted that the use of modern computer technologies and mathematical models ensure progress in the search and exploration of hydrocarbons. Contact and remote exploration methods and technologies have been outlined. Among contact ones, the field and analytical methods have been compared, and among remote ones, geomorphological and structurometric techniques and computer geodynamic simulation (CGDS) developed by the authors have been successively analyzed. Based on expert analysis, it has been concluded that remote-sensing methods are significantly cheaper (3-10 times). Geomorphological and structurometric remote-sensing methods are based on GPS images, i.e. they use the ‘top view’ technology. On the contrary, the CGDS technique implements the ‘view from inside’ technology based on a system of geodynamic models. It does not require preliminary fieldwork, and its application may be focused on poorly developed, complex areas such as the Arctic zone.

1. Introduction
In recent years, easily recoverable reserves of oil and gas fields have been rapidly depleted, the conditions for their production have become more complicated, and fierce global competition often leads to a sharp drop in hydrocarbon prices. Compliance with the rapidly changing breakeven conditions requires new search and exploration methods and technologies in this area. According to the authors, modern computer technology and geodynamic models should ensure significant progress [1-6]. The proposed tools can significantly increase the efficiency of the oil and gas complex by reducing costs at the search and exploration stages. This is especially true for the Arctic zone, where the oil and gas production costs are quite high.

Let us compare the specifics of implementation and the cost of modern oil and gas exploration methods, i.e. contact (field, analytical) and remote ones (geomorphological, structurometric, and the authors’ approach - CGDS).
2. Comparison of Oil and Gas Exploration Methods and Technologies

The available range of the hydrocarbon deposit search and exploration methods and technologies is constantly being improved. The *conventional search scheme* always requires complex geological and geophysical *field* studies and ultimately, drilling operations. The *geological group* of techniques comprises geological surveys, generating geological cross-sections, and hydrogeological methods. The *geophysical group* includes seismic, gravimetric, electrometric, magnetometric, thermometric, radiometric, spectrometric, electromagnetic, and other methods. The worldwide average implementation of this scheme is the most expensive one [7], i.e. 3-5 thousand USD/km² plus at least 10 thousand USD/km² for choosing the drilling locations using a 3D seismic technique (and years to perform). As a result, conventional methods are advantageous only for exploration conditions of large and medium oil and gas-bearing structures laying at shallow depths.

The next expensive ones are *analytical* methods [8] identifying hydrocarbons in various geological environments by direct or indirect signs. Their cost is determined by expensive hardware and the need for field studies, i.e. deep soil sample (core) drilling.

Let us conditionally attribute the field and analytical methods to the *contact* ones since their implementation requires drilling, sampling, and other special operations at the potential field location.

It is known that the Arctic zone has fairly large oil and gas deposits, including onshore, offshore, and oceanic ones. However, the search for hydrocarbons by only field and analytical methods is estimated as extremely complex and expensive due to a combination of environmental, climatic, and geological factors, as well as vast areas of potential exploration.

Attempts to search for small or deep hydrocarbon deposits make conventional approaches ineffective. Thus, among the total number of exploratory wells in Russia and continental Europe, the share of productive ones is about a quarter, and in the USA, it is one fifth. The actual cost of USD 3-7 million for drilling a single productive well is added by USD 10-28 million for drilling empty wells without hydrocarbons [7].

All this has led to the development of new scientific techniques oriented to the search and exploration of hydrocarbons by cheaper and at the same time more accurate methods. Herewith, it is obvious that universality, profitability, and efficiency are simultaneously unattainable, and some optimization is required when combining various methods. The authors see it in the integrated application of the entire range of techniques and the creation of new ones.

In this regard, the *remote-sensing* oil and gas exploration methods are relatively new ones. They are characterized by more active use of modern mathematical simulation and prospective information technologies.

This way, great hopes are assigned to a group of *geomorphological methods* [9] based on the identifying and visualizing various indirect signs of the presence of hydrocarbons (color, tone, various structures, heat fluxes in different spectral ranges, anomalies in the hydrographic network structure, etc.) manifested on Earth both onshore and offshore. Predicting hydrocarbon deposits by these methods is based on the results of computer interpretation of GPS images in different spectral ranges.

In simple terms, the geomorphological method implements the research algorithm ‘landscape analysis - morphological analysis - morphographic analysis’. The GPS images are interpreted as follows:

- the first stage - the landscape analysis results (identified structures, i.e. circular, linear, and arched relief elements associated with deep faults, changes in topography, anomalies in the hydrographic network pattern, etc.) are systematized, classified, and prepared for the second analysis stage,
- the second stage - the terrain hypsometry is performed, i.e. leveling the elevations of the identified tectonic structures signs (lineament, rings, relief and hydrographic network pattern peculiarities, etc.) possibly associated with the hydrocarbon deposits,
- the third stage - morphographic indicators with a morphometric representation are digitalized as contour maps, equipotential curves, etc. Using them and the algorithmic procedures developed, an
experienced expert searches for similarity, replication of the pattern observed in areas with known hydrocarbon deposits.

Obviously, the main drawback of geomorphological methods is the fuzziness, vagueness of their results, high dependence on skills, experience, special knowledge, and scientific intuition of the GPS image interpreter. Also, the landscape analysis method included in this chain does not allow qualitative prediction of deep structures since it is only applicable to shallow deposits.

Thus, the rather high cost of obtaining high-quality images of the Earth's surface using satellites, planes, or drones combined with the vast Arctic zone areas, the complexity of arranging their flights in the conditions of the available aerodrome infrastructure and insufficient coverage of the Arctic zone space by artificial satellites, as well as the vagueness of processing criterial images to identify hydrocarbon deposits make geomorphological methods expensive and not actually useful for most of the Russian North. However, with the development of the required GPS infrastructure and a dramatic improvement in the analysis algorithms due to the use of artificial intelligence models, these techniques could justify the prospectivity attributed to them.

Despite the geomorphological method application is currently limited, a remote approach to predicting the mineral deposits continues developing. Thus, to expand the capabilities of analyzing data on the remote Earth sensing and increase the accuracy of their computer processing, indirect signs are increasingly being used to interpret various images of potential hydrocarbon deposition areas. To identify the links between hydrocarbon deposits and the ground surface image, photogrammetric and photometric processing of digitized images, their scaling, correction, contrasting, filtering, etc. are applied.

However, efficient algorithms and programs for processing GPS materials to predict and estimate hydrocarbon deposits still have not been created. In no small part, this is due to the gap in the computer image analysis techniques.

This situation has led to the development of structurometric analysis algorithms [10-12]. It is a variety of spatial geomorphological techniques for analyzing multispectral space data to solve the problems of searching and evaluating oil, gas, and other mineral deposits.

The technique is also based on studying traces of the effect of weak acoustic waves from lithospheric minerals on the ground surface. Over millions of years, hydrocarbon deposits continuously transmitting the Earth’s energy by low-power acoustic waves have led to a noticeable rearrangement of terrestrial landscape and formed numerous circular formations on the surface. Using such physical prerequisites, a computerized method has been developed for analyzing and predicting various characteristics and parameters of oil and gas deposits located at sufficiently large depths of up to 20-25 km.

However, like all other problems of structurometric analysis, the solution of this problem creates many difficulties. They are specified above for the Arctic zone concerning geomorphological methods.

The complexity of the circular structure interpretation is also added, which requires attributing almost every image pixel to one or another circular structure reflecting a 3D model of the geological structure of the area of beddings with special properties. Each of these beddings passes the image interpreting procedure. Then, the conclusion is made whether the structure identified is promising for the oil and gas search and contains an acceptable amount of hydrocarbons.

The methods and techniques of processing the GPS images, automated interpretation, and cartographic simulation used in the structurometric analysis are the essence of integrated computer technology. It combines original image interpretation software packages, specialized geoinformation systems, graphical data representation modules, etc. For a simpler understanding, the geomorphological and structurometric analysis methods can be attributed to the ‘top view’ ones when searching for hydrocarbons considering the Arctic zone difficulties specified.

3. Principles for Implementing a New Computer Geodynamic Simulation Technique

To improve the existing remote-sensing methods, overcome the oil and gas exploration difficulties noted, and reduce the costs of its implementation, the paper authors have created and justified a new
technological approach, i.e. ‘view from inside’. It is based on the computer geodynamic simulation – the CGDS technique [13-20]. Fundamentally, the approach is based on a set of proprietary geodynamic models that allow calculating stresses, strains, and displacements caused by the migration of seismic deformation energy in the Earth’s solid throughout the entire lithosphere.

The common algorithm of the technique proposed includes four stages:

- providing the computer simulation system with the required information about the geodynamics of the area studied,
- calculating the stress, strain, and displacement indicators throughout the entire lithosphere, including offshore and onshore parts, in the hydrocarbon deposit prediction area using the model complex,
- calculating a set of differential operators reflecting the stress, strain, and displacement change vectors in the Earth’s lithosphere in the hydrocarbon deposit search area,
- choosing areas where differential operators acquire a special vector orientation tested on a representative number of regions and indicating the presence of hydrocarbon deposits. By changing the vector orientation, the deposit boundaries and area, the productive strata depth, and estimated volumes of oil, gas, and gas condensate reserves in the deposit as a whole can be determined.

It is important that the CGDS is related to the remote oil and gas exploration techniques and does not require preliminary fieldwork. Also, it is oriented to both poorly developed areas such as the Arctic zone and under-explored parts of the Earth. By economic indicators, the CGDS is incomparably more effective than all contact methods using gravity, seismic and magnetic exploration, exploratory drilling, as well as analytical ones. In terms of costs, the new development is also cheaper than geomorphological and structurometric methods requiring expensive GPS images.

In particular, this is supported by a comparison of the methods considered using an expert assessment performed with the assistance of experienced specialists in the field of oil and gas exploration. The relative search and exploration costs per a productive well, obtained by the experts are as follows: field geological and geophysical surveys - 10 RU; analytical studies – 5 RU; geomorphological methods – 3 RU; structurometric methods – 2 RU; the QGDM technique – 1 RU.

For the QGDM, the primary informational support is the available world databases on the Earth's lithosphere. Using only these Internet databases, previously unexplored areas can be quickly typologized for potential oil and gas reserves. Then, with additional review of more detailed information, the main deposit characteristics can be estimated.

4. Conclusions
1. Comparison of existing oil and gas exploration methods and technologies has shown that the main progress in the search and exploration of hydrocarbons is associated with the use of modern computer technologies and mathematical models.
2. Contact and remote-sensing methods and technologies for the search and exploration of hydrocarbons can be outlined. Among the contact methods, these are field and analytical ones, and among the remote methods, these are geomorphological and structurometric ones and computer geodynamic simulation.
3. Remote methods are 3-10 times cheaper in their implementation compared to contact ones. Herewith, geomorphological and structurometric remote-sensing methods are based on expensive GPS images, i.e. they use the ‘top view’ technology.
4. The computer geodynamic simulation technique implements the ‘view from inside’ technology based on a system of geodynamic models. It does not require preliminary fieldwork and is focused on poorly developed, complex areas such as the Arctic zone.

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