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The block structure and the presence of oil and gas in the Siljan impact crater

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Abstract

Morphostructural modeling of the block structure of a part of the Scandinavian crystalline shield has shown that the ring structure of the Siljan Ring impact crater is located in the center of a morphostructural node, a ring structure with a diameter of 300 km, marking a large disjunctive tectonic knot. The crater area consists of a central block, which is a granite massif, and of a surrounding mobile morphostructural boundary forming a wide small-block ring depression zone, where oil and gas shows have been revealed within the crater. This zone is regarded as the most promising one for search for migration channels and atypical shows of hydrocarbons.

Keywords: impact crater; morphostructural modeling; Earth's crust blocks; hydrocarbon shows

Introduction

Seeping of oil and natural gas on the Scandinavian crystalline shield in central Sweden, in the area of Siljan impact crater, has been known for about 300 years (Kudryavtsev, 1959; Tilas, 1740). The vivid scientific and practical interest for this structure as a possible source of hydrocarbon resources in Sweden can be explained by the following factors. Firstly, the Siljan structure was formed by a bolide that hit the Earth in the late Devonian (about 360 million years ago), accompanied by intense explosive impact (Svensson, 1971). This event not only produced a network of faults and fractures, which served as migration channels for deep fluids in the crater area, but also stepped up geodynamic and hydrothermal activity, which continued in the next geological periods.

There are 188 known confirmed impact craters (http://www.passc.net/EarthImpactDatabase) with diameters varying from hundreds of meters to several hundred kilometers, formed as a result of the impact of large celestial bodies. Impact craters are characterized by the same relief morphology inside the ring structure, the same nature of the rock disorders, and the presence of debris melted at high pressure. A characteristic feature of impact craters is the presence of mineral deposits, both syngenetic and epigenetic in the crater's area. Among syngenetic deposits formed by meteorite impact, there are deposits of diamonds, gold, nickel, copper, which can have rather large sizes (Koeberl et al., 1997). Hydrocarbon accumulations represent epigenetic deposits. Impact craters, which are associated with commercial deposits of oil and gas, are shown in Table 1 (Donofrio, 1988).

In impact craters, hydrocarbons lie mainly in lithologic traps or in buried, discarded breccia. At the same time, in Steen River impact crater hydrocarbons were found in the rocks of the Precambrian crystalline basement.

Secondly, crystalline rocks of magmatic and metamorphic origin are increasingly attracting attention as a possible reservoir of unconventional oil and gas fields in the basement or in the shields of ancient platforms. Along with numerous commercial oil and gas flows from the crystalline basement of sedimentary basins, great oil deposits in the granite massifs of the shelf zone of southern Vietnam are known (White Tiger, Dragon, Rang Dong, Ruby, and others). Oil, gas, solid bitumen shows were found in the shields of ancient platforms in all the continents. This indicates the presence of modern hydrocarbon flows in the Earth's interior outside the sedimentary

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Table 1. Parameters of the petroleum productive impact craters

Impact crater	Country	Age, Ma	Diameter, km
Ames oil and gas deposits in carbonates and granites	U.S.A.	470 ± 30	15
Avak gas deposits in sandstones	U.S.A.	3–95	12
Calvin oil deposits in carbonates	U.S.A.	450 ± 10	8.5
Chicxulub oil and gas deposits in carbonates	Mexico	65	240
Marquez oil and gas deposits in carbonates and sandstones	U.S.A.	58 ± 2	12.7
Newporte oil and gas deposits in carbonates and sandstones	U.S.A.	<500	3.2
Red Wing Creek oil and gas deposits in carbonates	U.S.A.	200 ± 25	9
Sierra Madera gas deposits in carbonates	U.S.A.	<100	13
Steen River oil deposits in carbonates and granites	Canada	91 ± 7	25

basins. All this fully justifies the issue of exploring hydrocarbon accumulations in the shield.

In this paper, the methodology of such exploration is discussed as an example of the Siljan impact crater.

The method of investigation

Modern technologies of oil and gas exploration, which are based on identification of hydrocarbon traps using seismic methods, do not really suit the search for unconventional oil and gas deposits. These traditional methods are not suitable at all for exploration of hydrocarbon accumulations in crystalline rocks. An alternative approach to exploration of unconventional deposits is aimed at the search for the migration channels of deep hydrocarbon fluids to the Earth's surface. In this regard, it is necessary to identify the currently active tectonic channels that do not lead to discharge of fluids onto the Earth's surface and into the atmosphere. Further, the lens of decompressed porous permeable rocks, the natural reservoirs for hydrocarbon accumulation, should be found in the vicinity of the channels.

The concept of the search for active migration channels of hydrocarbon fluids is based on modeling the block structure of the Earth's crust. The hierarchical level of geoblock boundaries controls the tectonic faults located at different depths. The most favorable zones for deep fluid migration into the upper part of the lithosphere are located at the intersections of block boundaries, the disjunctive knots. In the disjunctive knot areas, large and small shifts of the Earth's crust, promoting cracking and increased fluid permeability, take place.

Modeling the modern block structure of the lithosphere was carried out using the method of multipurpose morphostructural zoning developed by E.Ya. Rantsman and M.P. Glasko. The modeling technique was described in papers (Alekseevskaya et al., 1977; Gel'fand et al., 1976; Rantsman and Glasko, 2004). The concept of morphostructural zoning is based on association ofn the basic features of the terrain and the natural drainage network with neotectonic crustal movements. Blocks are identified as homogeneous morphostructural areas of the Earth's surface. On the boundaries of the neighboring blocks and in the disjunctive knots 'informative parameters' of the terrain and of the river network are changed, and the uniformity of the landscape as a whole is also changed.

The key elements of zoning are blocks of different hierarchical levels (ranks), which are the most stable areas of the territory. The boundaries between the blocks (morphostructural lineaments) are more mobile areas, compared with the blocks. The ranks of the boundaries correspond to the hierarchical levels of blocks. Zones of intersections of the boundaries of several blocks of different hierarchies (morphostructural knots) are the most active elements of the block structure. They represent fragmented areas around zones of intersections of the block boundaries. Morphostructural knots are interpreted as tectonic disjunctive knots activated in the newest and modern geological epochs. All the parts of the morphostructural model of the block structure are the elements of a single hierarchical system and cannot be interpreted independently. The morphostructural block model describes the deep structure and geodynamics of sedimentary basins, affecting migration of hydrocarbons and formation of their accumulations.

As a result of modeling the modern block structure of oil and gas basins in different regions of the world, association between the largest oil and gas deposits and morphostructural knots having a set of special features was recognized (Guberman et al., 1988, 1997).

The hydrocarbon migration channels in the crystalline rocks are most likely to occur in small-block areas at the periphery of ring morphostructures. Geochemical studies allow the presence of fluid migration and the nature of the migrating substance to be specified.

Results of modeling the modern block structure of the Siljan impact crater

The small-scale (1:1,000,000) morphostructural zoning map of Central Sweden shows that the Siljan crater belongs to a large ring morphostructural knot, formed by intersection of morphostructural lineaments—boundaries of large megablocks