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# Shale strata development problems and origin of the Bazhenov Formation fractures in the southeast of the West Siberian Plate

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**Abstract**

Shale strata development is one of the most promising trends for the hydrocarbon production increase within the West Siberian petroliferous province. The lack of understanding of fracturing mechanism, which is crucial for steady well production during hydraulic fracturing or drilling of horizontal wells, substantially restricts the choice of process capabilities for effective development of such horizons. This paper considers the Bazhenov Formation fractures based on the core data. The role of open and mineralized fractures (their slope angles, density, and specific surface) in the structure of bituminous shales is considered. Paleomagnetic orientation of the core samples with open fractures is implemented, and litho-petrographical description of the strata is made. The obtained results indicate that the planetary paleotension system of rocks controls the origin of open fractures in the Bazhenov Formation. Therefore, their spatial orientation and autogeneration capability can be used during the development of the bituminous shale strata.


*Keywords:* fractures; paleomagnetic orientation; Bazhenov Formation; pore pressure; hydraulic fracturing

## Introduction

The shale oil problems are governed by the individual understanding of the lithologic structure of bituminous shale strata and by the technological approaches to well drilling and development. As practice shows, there are no universal methods. In each specific case, the observed lithologic heterogeneity of the section must be taken into account during the hydrocarbon resource development. In modern economic conditions, when the activity of oil-producing enterprises is territorially and informatively limited, these "understanding" and "approaches" are based on a limited particular factual material and lead to different, sometimes contradictory, conclusions for different areas.

The most important issue in the effective development of shale strata is understanding of the formation of fractured zones in bituminous shales during drilling of horizontal wells, hydraulic fracturing, and subsequent operations.

In the most economically recoverable Bakken shale strata, the performed hydraulic fracturing in the Middle Bakken carbonate-siliceous member made it possible to form a vast zone of technogenous fractures. This zone is a system gathering oil from bituminous clays overlying and underlying the Middle Bakken member (Glaser et al., 2013).

In contrast to the Bakken strata, where the carbonate-siliceous bed reaches 30 m in thickness, similar deposits of the Bazhenov Formation are thin and are "dispersed" throughout the section. The number of their beds significantly decreases from the central part of the basin to its periphery, which is due to the paleogeographic conditions of accumulation of the Bazhenov Formation (Predtechenskaya et al., 2006). All this calls for particular criteria for the development of wells in different facies zones.

Under limited conditions for the origin of technogenous-fracturing zones in the Bazhenov Formation deposits in the southeast of the West Siberian Plate, special attention should be focused on studying the open fracturing in the deposits, caused by the spatial distribution of the natural horizontal-stress field. The tension stress is the most significant for further investigation. Natural tension stress cannot form a system of open fractures, because there is no free space for them. The existence of space, however, is a prerequisite for their formation. Shale strata are favorable for this process. First of all, the Bazhenov Formation deposits have numerous isolated micropores filled with oil, in which the pore pressure considerably exceeds the hydrostatic pressure.

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When a technogenous fracture forms, oil migrates from nearby micropores owing to the difference in the pore pressure and fracture pressure, which results in free space in the micropores. This effect in the tension zone of shale strata leads to the formation of a vertical tensile fracture, which, in turn, can cross the tension zone of rocks. This gives an impetus to the autogeneration of vertical fracturing, whose duration and scale of development will depend on the intensity of hydrocarbon outflow from the micropore space and on the density of the tensile field.

The possibility of this process in the Bazhenov Formation deposits in the southeast of the West Siberian Plate can be assessed from the results of study of well core fractures.

The fractures in the above area were most extensively studied by the Siberian Research Institute of Geology, Geophysics and Mineral Raw Materials (SNIIGGiMS) in the 1960s and 1970s (Mikulenko et al., 1972). They analyzed the fracturing in the Bazhenov and Georgiev Formations by examining 111 structures within the vast southeastern part of the West Siberian Plate (Fig. 1).

Based on the summary results of the studies, the researchers drew the following conclusions:

(1) Fracturing is observed in the rocks of the Bazhenov and Georgiev Formations in 88 of 111 analyzed local uplifts, i.e., in 80% of the uplifts.

(2) Tensile fractures make up 95% of all analyzed fractures. Tectonic compression fractures with signs of slip are minor, and fractures of other types are still scarcer.

(3) Open free tensile fractions make up 55% of all the examined ones, and open mineralized fractures, 45%.

(4) Analysis of the distribution of the slope angles of fractures shows that 80% of the free open fractures are vertically oriented and 18% have a near-vertical orientation (80º–90º). A similar orientation is observed for 20% of the mineralized tensile fractures. The rest mineralized fractures are characterized by slope angles of 20º–60º. The different orientations of the free open and mineralized fractures suggest their different genesis.

(5) The fracturing density, estimated over 38 structures and marking the ratio of the number of fractures to the length of the extracted core column (m), varies from 1.50 to 0.25 fract./m.

(6) The specific surface of the fractures (the ratio of the fracture length (m) to the product of the length and radius of the extracted core column ($m^2$)), studied in 88 areas, can be described by the function $y = 107.47x^{1.39}$ with a quadratic correlation coefficient of 0.9331, where $x$ is the number of analyzed areas. The specific surface area of fractures in these areas varies mainly from 10 to 0.1 $m/m^2$.

As follows from the above data, vertical free open tensile fractures detected in the deposits of the Bazhenov and Georgiev Formations are widespread within the southeastern part of the West Siberian Plate (points 1, 2, and 3). They are unevenly distributed both within the area (point 4) and throughout the section (point 5), which indicates different areal oil potentials of these deposits. Different oil productivities of similar shale strata are also revealed during their commercial exploitation (Glaser et al., 2013). For the first 90 days of persistent recovery, the cumulative oil production in different wells in the Bakken shale oil field varies from 10,000 to 80,000 barrels.

## Methods

To study the regularities of the spatial occurrence of free open tensile fractures within the study area, we sampled cores from the Lower Cretaceous deposits and the deposits of the Bazhenov, Georgiev, and Vasyugan Formations.

We took and analyzed 37 core samples from the Upper Jurassic sandstones of the horizon $J_1$ (18 samples), shales and carbonates of the Bazhenov and Georgiev Formations (13 samples), and Lower Cretaceous sandstones and shales (six samples) in 25 wells drilled in 18 areas (Table 1). All studied free open tensile fractures are of vertical orientation; some samples have two systems of fractures (Katylginskaya area, well 105; Igolskaya area, well 508; etc.).

We determined a paleomagnetic orientation of the samples and the fracture strikes in them and carried out lithological and petrographic studies of oriented thin sections.

The paleomagnetic method is used for the spatial core orientation because of the specific origin of natural remanent magnetization in rocks, which usually consists of two components:

(1) Primary remanent magnetization, formed at the same time as the rock (in sedimentary rocks its direction is preserved);

(2) Viscous magnetization, induced by the present Earth's magnetic field and coinciding with it in direction.

Viscous and primary magnetizations make up natural remanent magnetization, which is measured in core samples with the required accuracy. Viscous and primary magnetizations differ significantly in the degree of resistance to external effects, such as heating and alternating magnetic fields (Krasnoshchekova and Merkulov, 2014; Merkulov and Krasnoshchekova, 2002).

Processed results of demagnetization experiments are used to calculate vector differences characterizing the direction of viscous magnetization induced by the geomagnetic field of the same direction. Viscous magnetization in the studied samples is acquired during the present Brunhes geomagnetic epoch; therefore, its direction (azimuth and inclination) generally fits the geographic coordinate system (Krasnoshchekova and Merkulov, 2014).

The obtained directions are controlled by checking the coincidence of the inclination of the viscous magnetization vector with the inclination of the present geomagnetic field at the sampling point, which is made by comparing the bedding elements in the oriented samples. The angular error of the inclination measurement is 3º–8º. The propagation of fractures in the samples is also determined in this coordinate system (Fig. 2).