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Regularities in the development of fracturing zones in rocks of the sedimentary cover of Western Siberia, based on the results of the application of the OilRiver technology, horizontal well logging and hydrofracturing data

E.D. Glukhmanchuk, V.V. Krupitskiy, A.V. Leontievskiy*

Center for Geological Modeling LLC, Khanty-Mansiysk, Russian Federation

Abstract. The article presents known results of theoretical and experimental works, describing the regularities of the formation of fractured-block structures in platform areas. The above examples of mapping such structures in Western Siberia on the basis of the use of the OilRiver technology fully correspond to these patterns. Target drilling of the mapped fractured zones by horizontal wells indicates a mapping accuracy of 30-50 meters. According to the logging, the zones of fracturing in the Jurassic and Cretaceous rocks are confined to the zones of carbonatization, and in connection with this, when the formation is fractured 2.3 times more it is likely to get «STOP». The accuracy and completeness of the fractured zones mapping using the OilRiver technology opens up the possibility of using filtration channels to improve the profitability of oil production.

Keywords: fractured-block structures, filtration channels, fractured-cavernous reservoir, horizontal wells, carbonatization, fracturing

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In case of reservoir models construction for Western Siberia, more attention is paid to the models lithofacial characteristics, which are considered as the main factor of reservoirs heterogeneity (Bastrikov et al., 2012; Volostnov et al., 2011). At the same time, based on the results of pressure transient testing (pressure buildup curves, tracer studies, well interference testing, etc.), it is established that to a large extent in the reservoirs under development there are out-of-model highly permeable elongated filtration channels formed by rocks fracturing.

In the early stages of oilfield development, this factor leads to uneven oil production, which does not attract much attention of reservoir managers. However, with the onset of waterflooding, premature high-speed breakthroughs of the injected water significantly complicate the generation of an oil displacement front, which ultimately leads to a decrease in oil recovery ratio. Moreover, according to the results of both indicator studies comprehensive analysis (about 20,000 measurements) and oil light absorption coefficient, in 23% of all measurements the speed of water movement in the Jurassic and Cretaceous reservoirs exceeds 150 m/day, which is accompanied by a sharp drop in the speed of oil movement (Sauley et al. 2010). In general, more than 40% of measurements indicate on pre-waterflooding and water breakthroughs associated with fracturing of rocks.

It is characteristic that the fracture filtration acts not as a scattered in space factor, but as concentrated narrow filtration channels with premature water breakthrough along them. Most often, formation of such channels is associated with the rupture of productive strata caused by water injection (Surovets et al., 2015; Shpurov et al., 1997).

Localization of fractures in narrow extended zones follows from incremental faults development regularities, where these faults act as zones of fracturing in the early stages of their development (Sherman, 1977). Platform faults are characterized by grid faulting stretching independently of both layers and folds strike in the folded basement of the platforms (Gzovskiy, 1975). Fracture modeling under conditions corresponding to the platforms sedimentary cover rocks deformations shows the formation of quadrangular block-fracturing systems

*Corresponding author: Evgeny D. Glukhmanchuk
E-mail: geomodeling@mail.ru

(Fig. 1). At the same time, depending on the thickness of the deformable layer, the block sizes are stable despite the further increase in deformations (Revuzhenko, 2000). The modal nature of the block areas distribution in rocks follows the "equal areas" rule (Rats, 1970). Thus, based on the theoretical and experimental data, within the sedimentary cover of Western Siberia a regular block structure should be formed by two systems of faults.

Fracturing zones characteristics according to the results of target processing and interpretation of 3D seismic data

Fig. 1. Formation of a block structure under biaxial tension conditions (Revuzhenko, 2000)

Faults within the sedimentary cover of Western Siberia are at an early stage of their development and represent by 90-95% a set of extended fractures forming zones up to 100 meters wide. At this stage, as there is no any indicator proving the existence of an extended main seam, therefore there are no significant vertical displacements of the blocks along the faults, which prevents them from being identified in case of standard seismic data processing. Under these conditions, target processing and interpretation of seismic data within the framework of the OilRiver technology was developed and applied for stable mapping of the blocks displacements. The original feature of the technology lies in the fact that the informative parameters of fractured zones are not the absolute values of the wave field characteristics, but the heterogeneity of its structure. Only in Western Siberia, the technology was implemented to study the block-fracturing structure for more than 40 active oilfields and exploration areas. An accumulated volume of exploration and geophysical data opens up the possibility of the following generalized characterization of both fractured zones themselves and block structures formed by them.

According to the results of fracture-block structures mapping based on the use of the "OilRiver" technology there was revealed the prevailing development of a single fractured zones generation consisting of two systems (Glukhmanchuk et al., 2016; Glukhmanchuk et al., 2014). As a result, quadrangular blocks with a close distribution of block areas (Fig. 2) dominate in the oilfields block structure. It is also characteristic that the size of the blocks (700-800 meters) is ½ of the sedimentary cover thickness for the Apt-Cenomanian time of tectonic deformation activation. This characteristic of block structures is due to the known geomechanical dependence of their size on the depth of the competent layer (in this case, the depth of crystalline basement). Rarely at the same time, two generations of faults may occur within some oilfields. The second generation is represented by arcuate elements curved towards the east. Their maximum development is identified within the uplifts. Elements of the northwestern and northeastern strike are less deformed, more extended and, as a rule, limited by sub-latitudinal elements (Fig. 3). Sub-latitudinal elements are much longer, with maximum intensity of suture characteristics, and therefore are often accompanied by secondary non-extended elements.

As a result of two faults generations participation in the formation of the block structure, the distribution of the block areas is changed significantly (Fig. 2). The increase in the number of blocks of the smallest area in

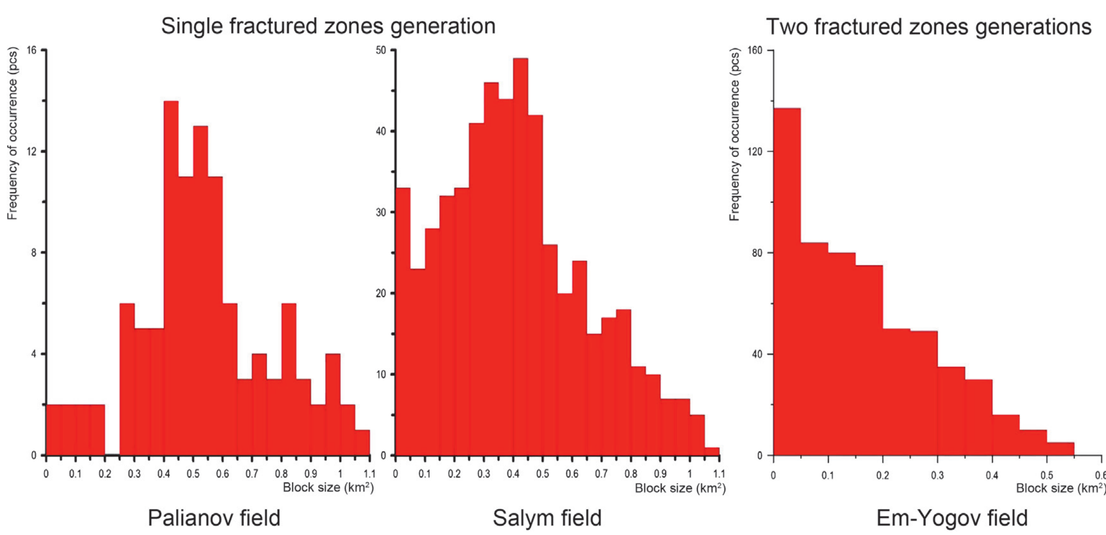

Fig. 2. Histograms of block area distribution

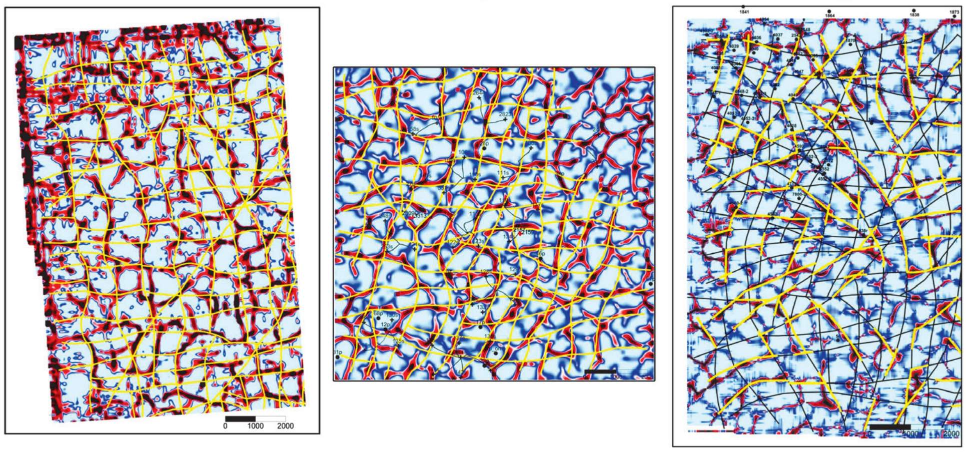

Fig. 3. The oilfield's block-fracturing structure and its relationship with wave field inhomogeneity structure

these conditions occurs due to formation of triangular shape blocks.

The presented figures show the fragmented intensity of fractured zones in the structure of the wave field inhomogeneity. Comparison with the well logging data showed that the maximum values of heterogeneity are confined to the most hydrothermally developed, as a rule, carbonatized fault nodes and areas of fracturing zones.

Fracturing zones characteristics according to log interpretation in horizontal wells

With such block sizes, a large part of horizontal wells with a length of a wellbore horizontal section up to 1 km crosses fracturing zones. As a result, the average specific indicator movement speed towards horizontal wells is 2.7 times higher than the indicator movement speed towards directional wells (Bakhtiyarov et al., 2007). Wells are studied by various well logging methods having different resolutions in terms of the fractured zones characterization. In this case, there were analyzed the results of standard logging, methods of high-frequency induction logging isoparametric sounding (VIKIZ) and FMI.

In Cretaceous porous reservoirs (AS layers) with high reservoir properties, fractured zones are characterized by VIKIZ and gamma-ray logging (GR) as a part of porous reservoir including 4 carbonatization intervals within well section of up to 140 meters length (Fig. 4). Porous reservoir compaction occurs due to its secondary carbonatization, which, together with the presence of filtration channels, determines fractured zones as flow-diverting zones.

Two horizontal wells were drilled into the Upper Jurassic rocks (Yu_0 reservoir, Bazhenov formation) after conducting the fracture-block structure mapping within the oilfield (Fig. 5). The first, sub-latitudinal, was drilled directly along the fractured zone and crossed the fault node. Standard and gamma-ray logging in the well is characterized by extreme instability, which indicates the numerous intersections of the carbonate bodies by the well. This effect is most intense when the well trajectory completely coincides with the fractured zone in the fault node. When the well is located up to 50 meters from the fractured zone, the instability of the recording disappears and it acquires a standard form. From this, we can conclude that the width of the fractured zone in the rocks of the Bazhenov Formation is up to 50 meters.

The second horizontal well drilled sub-meridionally intersected two fracturing zones in perpendicular

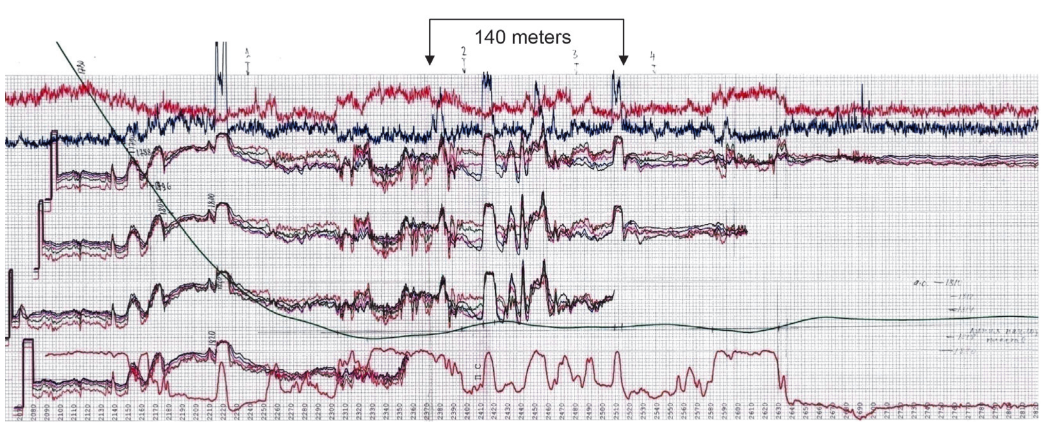

Fig. 4. Fracturing zones in Cretaceous sediments (AS reservoir) according to horizontal well logging data

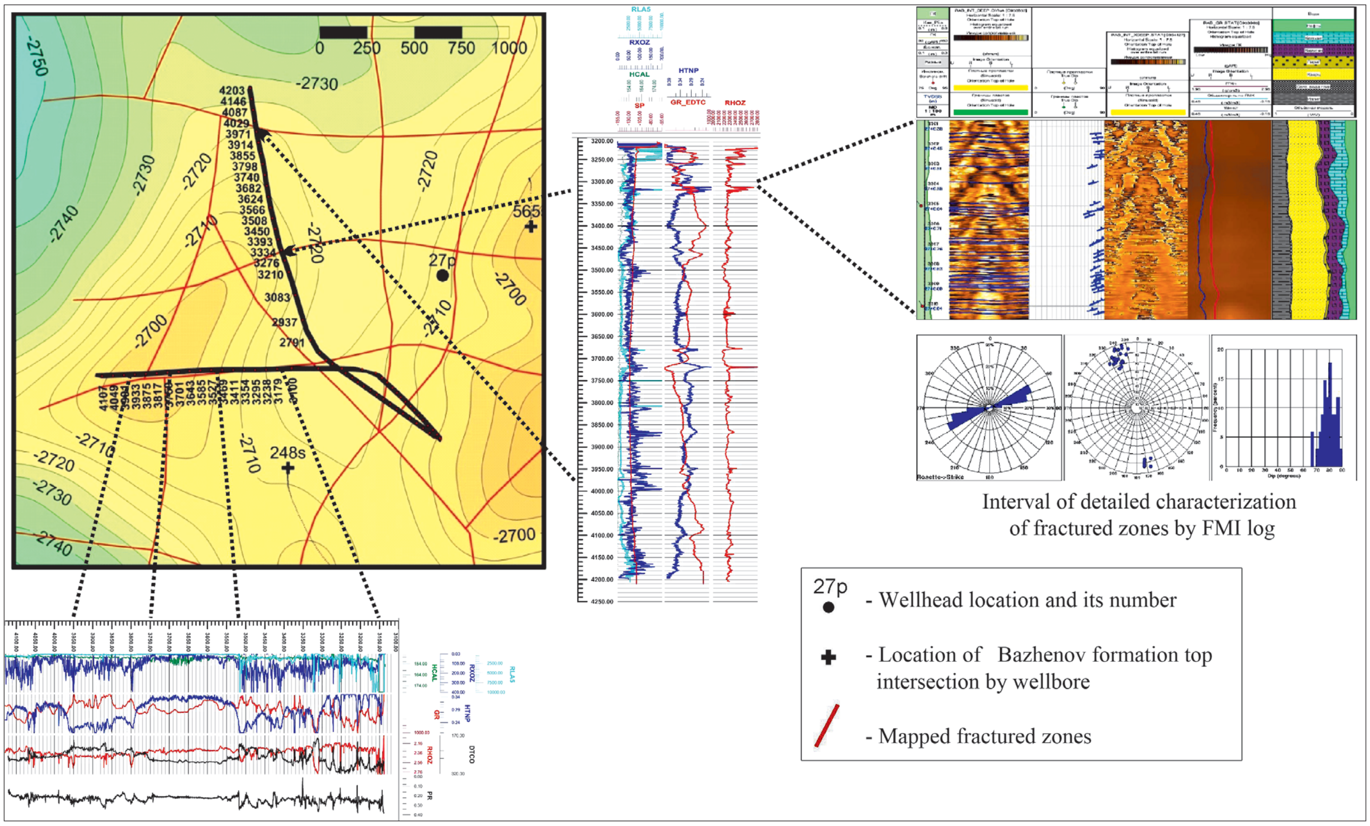

Fig. 5. Fracturing zones in the rocks of the Bazhenov formation according to horizontal well logging data

direction. In the standard logs, these zones are expressed as areas of rocks carbonatization having width of 1.5-2 meters (Fig. 5). According to FMI log, the fractured zone consist of up to 25 sub-vertical fractures, the strike and position of which completely coincides with the strike of the mapped fractured zone. The given examples characterize the fractured zones of Bazhenov formation as hydrothermally developed and carbonatized areas mapped by using OilRiver technology with accuracy of tens of meters.

In case of horizontal wells drilling within previously mapped fractured zones, sub-perpendicular to the Tyumen Formation rocks, fractured zones are characterized by well logs (gamma-ray methods, acoustic and density logging) as intervals edged with vertical carbonate bodies (Fig. 6). At the same time, the most intensive

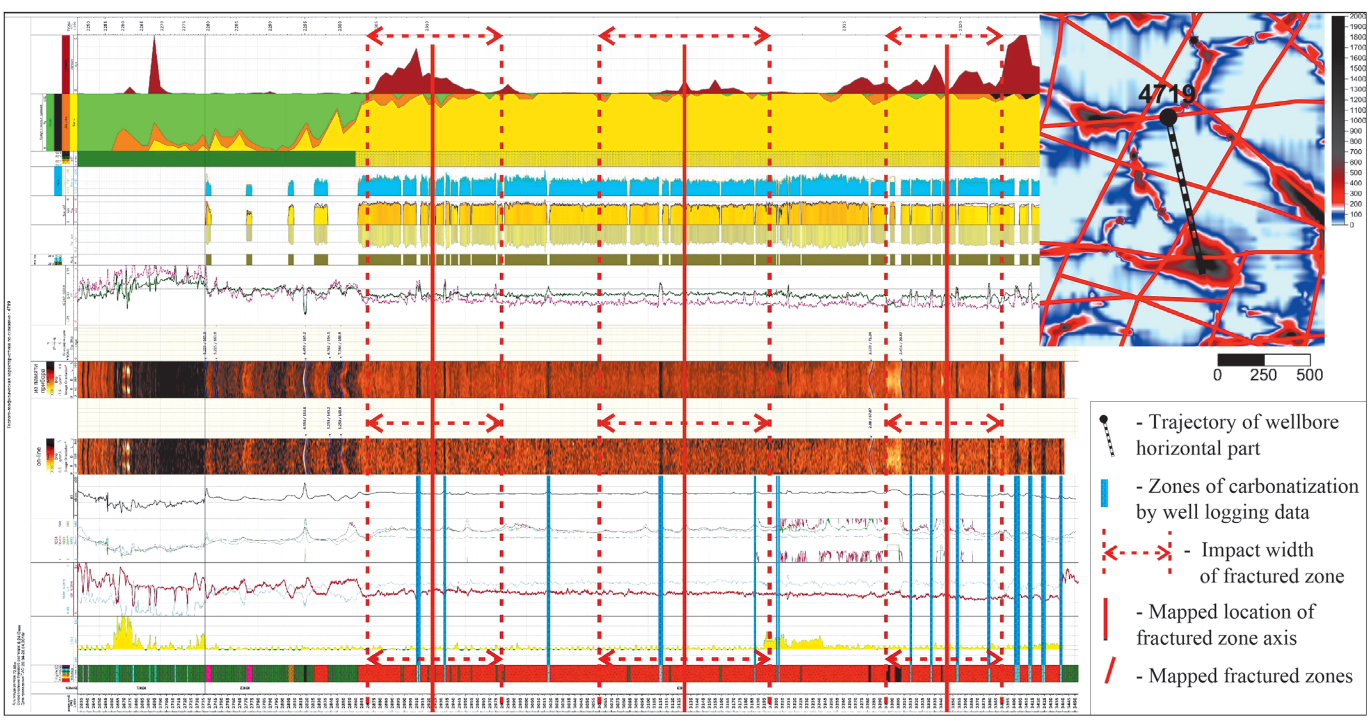

Fig. 6. Fracturing zones in the rocks of the Tyumen formation according to horizontal well logging data

carbonatization is observed in fragments of the zone with high wave field structure heterogeneity in the interval of the Tyumen Formation. It is also characteristic that gas anomalies are confined to the mapped fractured zones, indicating migration of light hydrocarbons into the reservoir.

Five drilling mud absorption intervals were observed in dense and even clay sediments of the Tyumen Formation while a horizontal well have been drilled along a fractured zone. Measured absorption intensity of 5-7 m^3/h complicated the drilling of a well along the fractured zone indicating the presence of open fractures. Intense carbonatization of rocks (10 meters wide) in this well is observed in the fault node, to which, as before, is referred the wave field structure heterogeneity anomaly (marked on the map in red and black, Fig. 7). Thus, within the Tyumen formation, fractured zones are a combination of both open fractures and rocks carbonatization areas.

Fracturing zones characteristics according to the results of hydraulic fracturing in horizontal wells

Comparison of 153 hydraulic fracturing results in layers of the Tyumen Formation with mapped fractured zones showed that the chance of a screenout at hydraulic fracturing distance of 50 meters from the zones axes increased 2.3 times from 12 to 27%. At the same time, low (less than 90 atm) pressures of fracturing closure at a distance of up to 100 meters from the zone axis are found 53% more often, which ensures maximum stability of flow rates. The average flow rate from one perforated (effective) meter within the reservoir in these wells is 1.5 times higher. In general, according to the results of hydraulic fracturing characteristics analysis in fractured areas, there should be noted the rocks consolidation (carbonatization) impeding the development of technogenic fractures.

Conclusions

A generation of fractured zones consisting of two systems forming quadrilateral blocks of similar sizes is predominant at the oilfields within the central part of Western Siberia. Triangular blocks are additionally formed in case of second generation occurrence causing both the decrease in block sizes as well as modality of their areas distribution deficiency.

Fractured zones in the Jurassic and Cretaceous rocks have a width of up to 100 meters and are characterized by both fractures and enclosing rocks partial carbonatization.

According to results of hydraulic fracturing, the chance of a screenout is increased in case of hydraulic fracturing within fractured zones of Tyumen formation, which means that the carbonatized parts of fractured zones are a hardened medium in which the formation of technogenic fractures is significantly difficult.

Technogenic fractures within the fractured zones

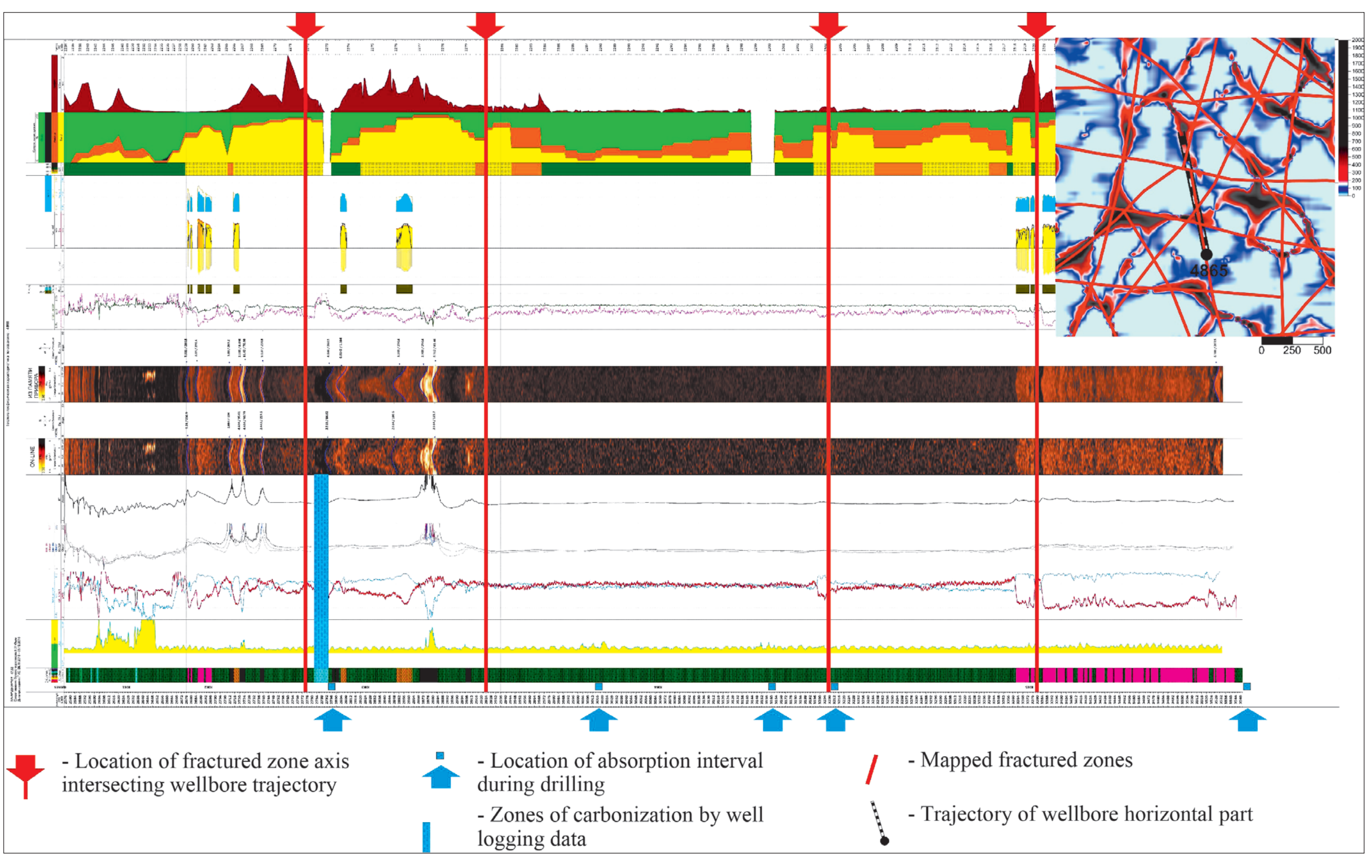

Fig. 7. Fracturing zones in the rocks of the Tyumen formation according to horizontal well logging data

are characterized by generally lower closure pressures, which provides a one and a half increase in average specific production rates. From this, it follows that the main reason for the decrease in the flow rates of technogenic fractures is their closure.

Comparison of horizontal wells drilling results with data on block-fracturing structures previously mapped by 3D seismic shows a discrepancy in matching of fractured zones of not more than 50 meters. Such accuracy along with the completeness of mapping creates a reliable basis for the effective hard-to-recover reserves development in case of fractured reservoirs as well as reliable background for reservoir pressure maintenance optimization by the placement of production and injection wells adapted in accordance with filtration channels location. According to the results of applying this principle when choosing the location of more than 30 producing wells in fractured cavernous reservoirs of the Bazhenov formation and the basement in a number of oilfields, was proven the possibility of cost-effective oil production for the most complex hard-to-recover reserves.

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About the Authors

Evgeny D. Glukhmanchuk – PhD (Geology and Mineralogy), Director General, Center for Geological Modeling LLC

Chekhov st., 16, build. 4, Khanty-Mansiysk, 628012, Russian Federation

Vladimir V. Krupitskiy – Chief Researcher, Center for Geological Modeling LLC

Chekhov st., 16, build. 4, Khanty-Mansiysk, 628012, Russian Federation

Andrei V. Leontievskiy – Chief Researcher, Center for Geological Modeling LLC

Chekhov st., 16, build. 4, Khanty-Mansiysk, 628012, Russian Federation

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