SUBSTANTIATION OF THE FAULT-BLOCK STRUCTURE FOR EFFECTIVE ADDITIONAL EXPLORATION AND DEVELOPMENT OF THE WEST-KOMMUNARSKY FIELD

M.A. Lobusev, A.V. Bochkarev, G.Yu. Rachkova*
Gubkin Russian State University of Oil and Gas (National Research University), Moscow, Russia

Abstract. While the seismic exploration and methodological geological interpretation of geological data for drilling various wells and other types of research are improved for a significant part of the fields being developed in the Samara Region, the reliability of the structure of geological and recoverable oil and gas reserves increases. The complication of the structure and multiple recalculations of reserves at a number of fields are due to the introduction into the development of undiscovered to the required conditions of complex geological fields and licensed areas. The example of the West-Kommunarsky field shows how its geological structure becomes more complex as its study becomes more extensive. Thus, the oil reservoir in the Lower Paschian sediments, according to the created integrated model, has horizontal positions, but with different levels of water-oil contact in adjacent blocks separated by downthrows. The justification of disjunctive dislocations, which have been planned but not tracked due to their uncertainty in seismic data and determination of their main characteristics, was performed by stratigraphic correlation of well sections using the rules of projective geometry and confirmed by other traditional methodical methods. With each new tectonic movement along the strike-slip, a near-faul fracture of rocks is formed parallel to it, as a reflection of geodynamic stresses and energy-intensive processes in the downthrows and strike-slips of rocks along the fault plane. Near-fault regular changes in the fracturing of rocks and the dependence of well productivity on their location relative to the disjunctive make it possible to predict the latitudinal reservoirs zonation in near-fault area: fractured, porous-fractured, fractured-porous and porous types. Such a dialectical process of movement towards a real model of the field ensures the reliability of revised reserves and updated technological documents for the development of fields.

Keywords: strike-slip, disjunctive dislocations, well productivity, fault-block model, water-oil contact
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Introduction

The reliability of geological and recoverable oil and gas reserves structure increases with the improvement of seismic exploration means and geological interpretation methods for drilling wells of various purposes and other types of research for the significant part of the fields under development in the Samara Region. The complication of the structure and multiple recalculations of reserves at a number of fields are due to the introduction into the development of fields and licensed areas unexplored up to the required conditions and complicated in the geological structure (Ashirov et al., 2001). As a result, the structure of complex hydrocarbon reservoirs is specified (sometimes drastically) at the stage of development due to the drilling of a large number of production wells. Such a dialectical process of movement towards a real model of the field ensures the reliability of specified reserves and updated technological documents for the development of fields.

Brief geological description of the field

The field is confined to the western side of the Buzuluk depression at the regional level along the surface of the crystalline basement and the terrigenous Devonian. Deposits of the Devonian, Carboniferous, Permian, Neogene and Quaternary ages, located on the surface of the crystalline basement of the Archaean age, participate in the geological structure of the field. The total thickness of the sedimentary cover reaches 3290 m. The productive Staroskolskian and Pashian horizons are composed of sandstones interbedded with siltstones and clayey rocks. Sandstones are quartzous, fine-grained. The productivity of sandstones is associated with the formations D-I, D-II, D-III. The reservoir under consideration in the DIII formation (total thickness 11.0 ... 31.4 m) lies at an average depth of 3187 m.

*Corresponding author: Anatoly V. Bochkarev
E-mail: anatolybochkarev@gmail.com

The West-Kommunarsky field is located within the Kinel district of the Samara region. A detailed study of the features of its geological structure was carried out with the goal of creating, as far as possible, a reliable geological and hydrodynamic model and justifying the real indicators in the forthcoming technological documents for its development.

Previously, when the degree of the field exploration was insufficient, the formations in question were modeled in a plicative variant with an inclined water-oil contact (immersion in the west direction). According to the data of seismic prospecting, north-north-eastern strike faults, confining the reservoir in a structural-tectonic trap, are clearly identified and reflected in the resulting structural maps. Presumably, this fault is accompanied (feathered) by disjunctive dislocations with insignificant amplitude of rocks displacement along the dislocation plane. Fragmentary tracking of these faults, as well as small amplitude of their displacement in the dislocation plane, were below the sensitivity threshold of the seismic survey equipment at some sites. For this reason, most of the disjunctive dislocations are not represented on maps by reflective horizons (Fig. 1).

After drilling exploration and production wells, the geological structure of the field was repeatedly clarified in view of more complex (block) structure of oil deposits. The process of multivariate study of deposits began and continues including manual and computer reconstructions of the structural plans of the sedimentary cover, including the fault-block version presented below.

The ratio of structural plans of the basement and the platform cover

The crystalline basement has played a decisive role in the formation of the sedimentary cover tectonics, composed of highly metamorphosed, magmatic and sedimentary rocks of the Archean and Lower Proterozoic. The basement is divided by numerous faults into blocks of various shapes and sizes. Two ancient orthogonal systems of dislocations are distinguished – of sublatitudinal and ex-meridian strike – in the sediments of the basement and the platform cover within the area of the study. The movement of blocks along faults directly or indirectly affects the formation of such tectonic structures as graben-like troughs and horst-like raised zones (Fig. 2). A number of signs of fracture tectonics and tectonic movements of rocks along faults have been established (steep fall of rocks, repetition of horizons in a section, development of jointing in rocks, occurrence of volcanic inclusions among sedimentary deposits, presence of linear magnetic and gravitational anomalies, etc.). The presence of pronounced disjunctive dislocations is established throughout the section of the terrigenous deposits of the Devonian in the zones of Devonian graben-like troughs (Shashel, 1998).

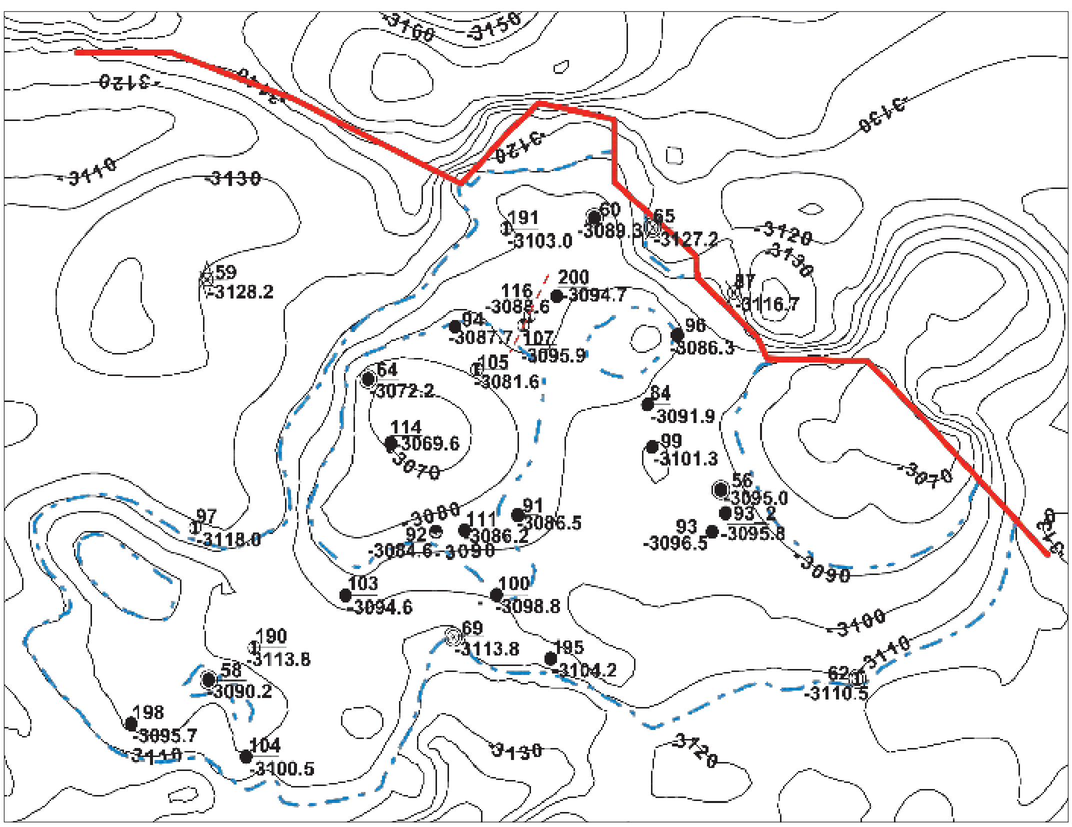

Fig. 1. Structural map for the roof of the productive formation D-III of the Starooskolskian horizon in a plicative version. 1 – external and internal contours of oil content; 2 – downthrows

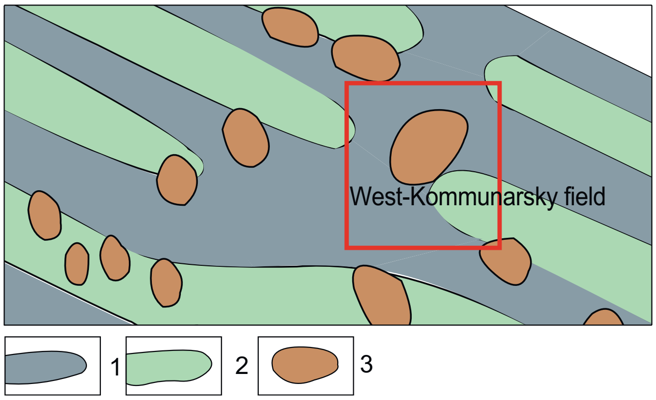

Fig. 2 – The map fragment of the tectonic and oil geological zoning of the Samara region (the area of the West-Kommunarsky field). 1 – Devonian graben-like troughs; 2 – horst-like raised zones; 3 – oil fields

The main tectonic factor controlling the morphology of structural elements of grabens are narrow, linear, sublatitudinal and parallel strike-slips, which limit it and are the sides. The fault planes of strike-slips are directed towards each other and have a steep fall, being extensions of disjunctives in the basement.

As shown by similar studies in other regions, a joint approach to the modeling of hydrocarbon deposits from the viewpoint of geology and development makes it possible to more accurately approach the modeling of reservoir boundaries, the estimation of hydrocarbon reserves and the optimal location of producing wells (Bochkarev, Bochkarev, 2016; Karpov, 2011; Kopylov et al., 2015; Lobusev et al., 2014b).

New geological model of the deposit

As the drilling volumes increased and new modifications of geophysical works were applied, the structure of the field became more complex than it seemed at the early stages of the research. The structural-tectonic field composition is clarified below by analyzing the resulting seismic survey materials along the reflecting horizons as close to productive strata as possible, and by using standard methods for establishing and tracing discontinuous faults (projective geometry, profiles, etc.) (Bochkarev, Bochkarev, 2016; Karpov, 2011).

When sediments were correlated, particular attention was paid to those parts of the deposit section where a sharp change in the thickness occurred in a narrow inter-well space along the linear zones of uncertain interpretation (loss of sensitivity) of disjunctive tectonics from seismic data. The analysis involved 35 wells. In the places of the proposed monitoring of faults, adjacent pairs of wells were put on different sides of the dislocations. A pair of wells No.107-116 and No.127/2-56 was chosen as an example of the downthrow and graben-like structural elements.

The regional reference A "ostracod limestone" served as a comparison line for linking the analyzed strata, differing in lithological composition from the above and below underlying sediments, consistent in thickness and area and clearly recorded in the logging diagrams. The boundaries of roof and base of the compared productive formations are identified on the geological profiles of selected pairs of analyzed wells (Fig. 3).

To correlate the D-III formation of the Staroskolskian horizon, Mullin clays and "ostracod limestone" were used as the reference surface, which are clearly traced throughout the area and have a specific configuration of the logging curves. The pack 1 (Fig. 3) is mainly represented by clayey rocks and siltstones. The pack 2 corresponds to the D-III formation, which is represented by sandstones and siltstones and is allocated confidently on the background of enclosing rocks. The overlying layer of clay (pack 3) serves as the cover of the D-III formation. The thickness of the D-III formation varies from 22.8 to 37.6 m. The pack 4 corresponds to the regional benchmark "ostracod limestone", for which high indications of resistance and neutron gamma-ray logging are typical, as well as reduced values of gamma-ray logging. The upper part of the Zhivetskian formation is represented by clayey deposits (bundle 5), which are characterized by regional consistency. These deposits are distinguished by high values of gamma-ray and self-potential, low resistance in the logging diagrams. Deposits of the Pashian horizon, mostly composed of sandstones and siltstones with interlayers of clay, are divided into packs 6 ... 9. The pack 6 includes reservoirs of the D-II formation, the pack 8 – reservoirs of the D-I formation. The section between the formations D-I and D-II is represented by a clay pack confidently allocated by logging diagrams (pack 7). The cover of formation D-I is clay (pack 9).

The method of projective geometry, proposed by the Canadian geologist T.B. Heights, based on the rule of the "complex ratio of four points", as well as other methodical techniques, was applied in this work in order to establish and confirm in the inter-wellbore space of disjunctive dislocations represented by downthrows and strike-slips. The absolute marks of the roof and the base of the same formations in two adjacent wells were analyzed, between which a disjunctive was assumed. Points that are in a projective relationship form a bundle of straight lines intersecting in accordance with the Heights law at a single point M, called the design center; and the connection of "four points" is the desired temporal chronostratigraphic correlation of the sections of two neighboring wells (Bochkarev, Bochkarev, 2016; Kopylov et al., 2015; Lobusev et al., 2014a).

The projective four-point ratio method identifies section intervals that have different thicknesses in the investigated wells. At the same time, an increase in thickness is observed in the lowered block, which is typical for consedimentary downthrows.

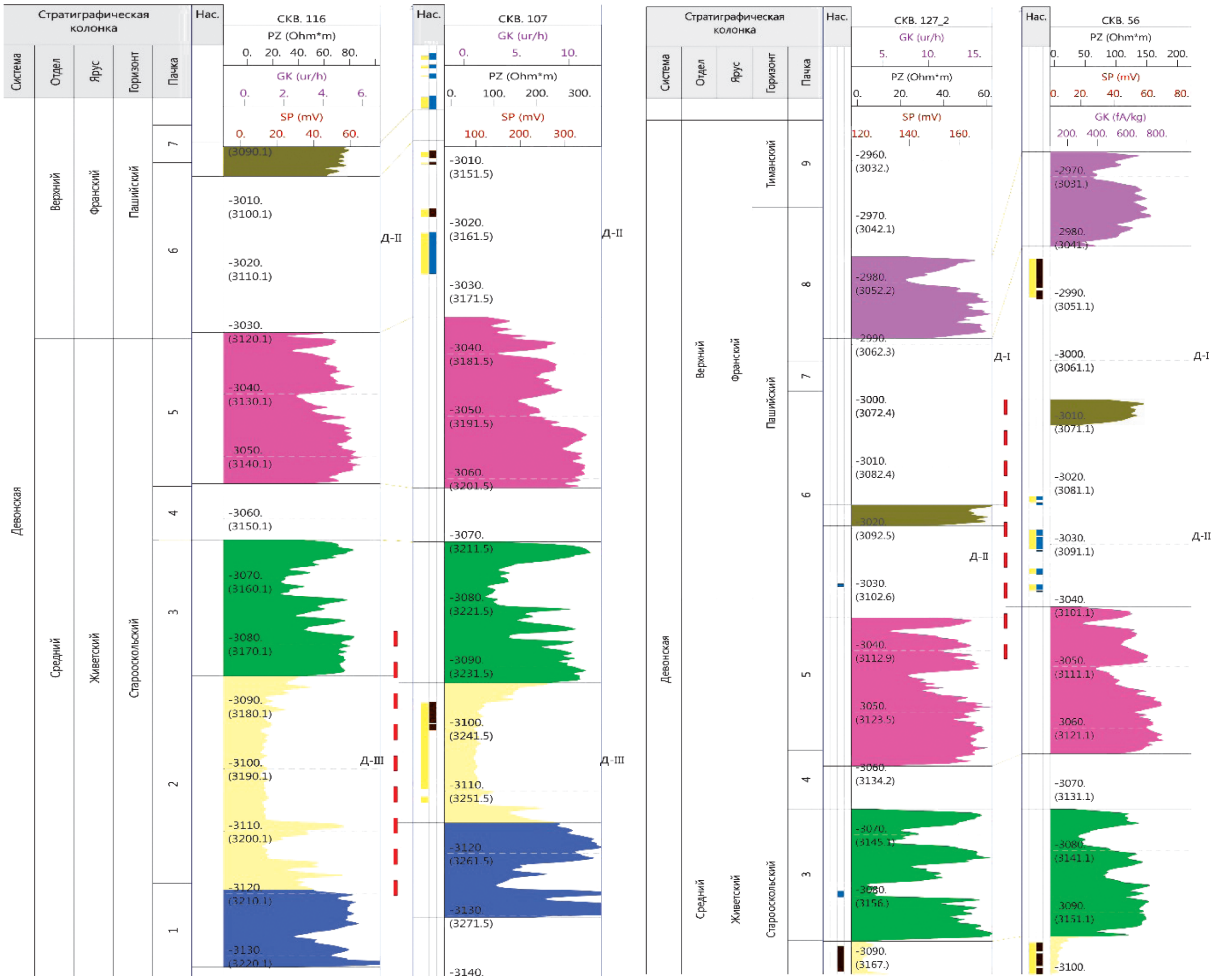

Fig. 3. Correlation of the chronostratigraphic reference marks of the productive formation D-III in pair wells No. 116 – No. 107 and No. 127_2 – No. 56

The presence of two projection centers M1 and M2 as a result of joining chronostratigraphic references, is a direct indication of tectonic dislocations. According to the four points connection rule, only one design center M is obtained at best for a pair of wells between which there is no discontinuous dislocation. The results of the correlation of productive formations D-III and D-II are shown in Tables 1, 2. The correlation analysis of the section according to the rule of the projective ratio of four points is shown on the example of two pairs of wells Nos. 116-107 (on the left for the productive formation D-III) and Nos. 127/2-56 (on the right for the D-II formation) (Fig. 4). According to the principle of projective geometry, as a result of the connection of chronostratigraphic references, two design centers M1 and M2 for the analyzed pairs of wells were obtained in each considered case, which indicated the presence of a dislocation between the given wells. Section and analysis of formation continuity in wells Nos. 107 and 116 and in wells Nos. 127/2 and 56 are shown in Fig. 5 and 6. For the first pair of wells, the displacement amplitude of rocks in the fault plane was 8 m, for the second – 11 m.

As a result, within the area of the field, small-amplitude disjunctive dislocations were confirmed, as planned by seismic prospecting and identified by geological data. As the drilling volumes increased and new modifications of geophysical operations were applied, a more complex structure of the field began to be revealed than was imagined at the early stages of the research. On the fragment of the map along the basement disjunctive dislocations, horsts and grabens have the same strike as the rocks fracturing revealed in the cover deposits according to different data (Fig. 2, 7).

Two blocks can be allocated in a large scale: northern (A) and southern (B), separated by micrograben (II) (Fig. 7, 8). The slip in the dislocations of graben II was 750 m, and the graben itself was also recorded by the presence of "structural shoulders" and the contraction of

Chronostratigraphic references	Legend	Depth of absolute marks of references by wells, m	
		well 116	well 107
Cover roof for the formation D-III	A/A1	-3063.3	-3070.1
Roof of the formation D-III	B/B1	-3084.9	-3092.5
Bottom of the formation D-III	C/C1	-3119.1	-3114.9
Bottom of the clay formation of Vorobyovsky horizon	D/D1	-3131.5	-3130.5

Table 1. The correlation results for the productive formation D-III (wells No. 116 – No. 107)

Chronostratigraphic references	Legend	Depth of absolute marks of references by wells, m	
		well 127/ 2	well 56
Cover roof for the formation D-II	A/A1	-3015.9	-3006.0
Roof of the formation D-II	B/B1	-3019.3	-3010.6
Bottom of the formation D-II	C/C1	-3034.5	-3040.2
Bottom of the clay formation of Mullinsky horizon	D/D1	-3058.7	-3064.0

Table 2. The correlation results for the productive formation D-II (wells No. 127/2 – No.56)

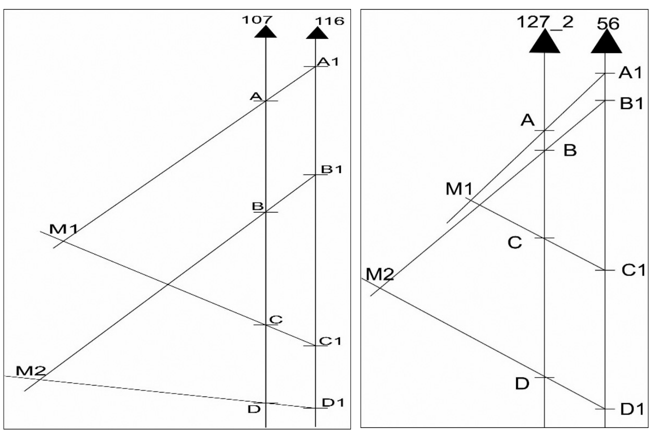

Fig. 4. Checking the correlation of the section according to the projective ratio rule of "four points" for the wells No. 116 – No. 107 (on the left for the productive formation D-III) and No. 127_2 – No. 56 (on the right for the D-II formation)

multiple isohypes (Bochkarev and Bochkarev, 2016). The presence between the enlarged blocks (A and B) of graben (II) divides the once unified field into two unconnected oil clusters. The northern block is 21 m above the southern one by the maximum hypsometric levels on the structural plan, which causes different levels of water-oil contact for the same productive formations: in the northern – minus 3103 m, in the southern – minus 3112 m (Fig. 7, 8). In the grabens productive deposits are replaced by pelitic material and productive formations are represented by non-reservoirs (porosity decreases to boundary values and less, the effective oil-saturated thickness is zero) (wells 65, 87, 69, 97). Well 190 penetrated the downthrow at the level of the productive formation, penetrating it only partially (2.2 m).

Long-term disjunctive dislocations at the level of productive formations are accompanied by zones

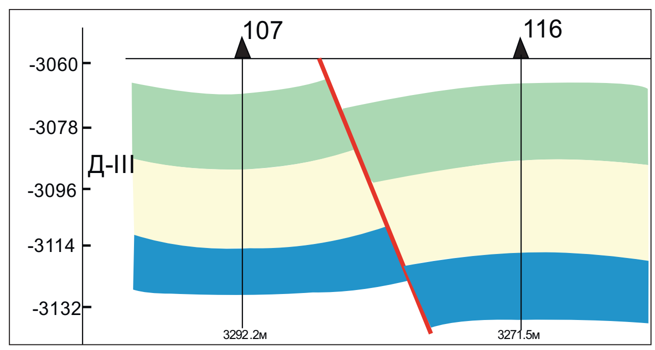

Fig. 5. Geological section through the wells 107 and 116 and the proposed downthrow location for the productive formation D-III

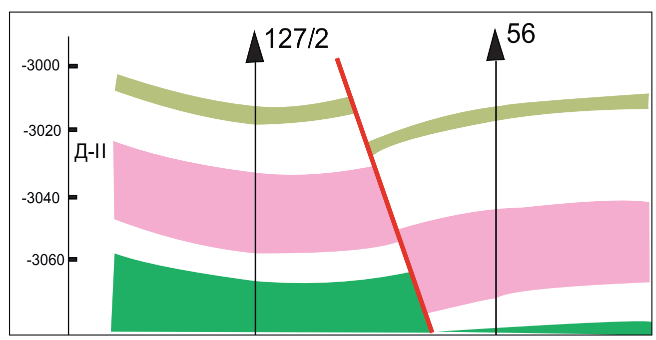

Fig. 6. Geological section through the wells 127/2 and 56 and the proposed downthrow location for the productive formation D-II

of abnormally high tectonic stresses, which, due to confined areas of normal-fault increased fracturing and maximum oil production rates, are an important area of geological exploration for oil in the region (Shashel, 1998). The role of cracks in the reservoir properties of D-II formation of the West-Kommunarsky field predominates so much that a purely fractured reservoir type can be diagnosed for them.

With each new tectonic movement in the strike-slip,

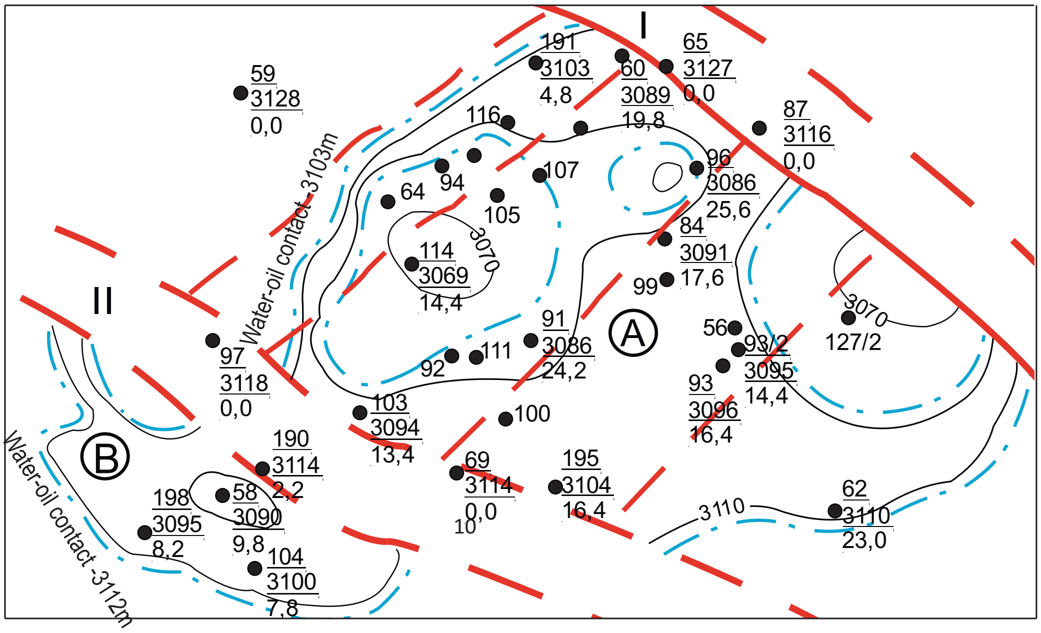

Fig. 7. The fault-block model 2D for the roof of the productive formation D-III of the West-Kommunarsky field

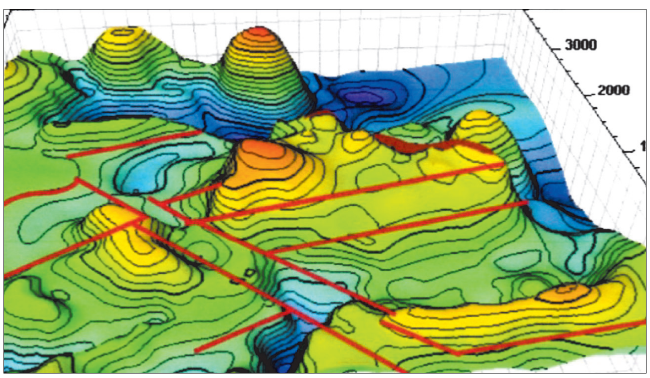

Fig. 8. Geological model 3D for the surface of the productive formation D-III in the fault-block structure of the West-Kommunarsky field

normal-fault fracturing of the rocks is formed in parallel, as a reflection of geodynamic stresses and energy-consuming processes in the strike and slip of rocks along the fault plane. This is evidenced by the effectiveness of creating a branched system of cracks in hydraulic fracturing (Golf-Rakht, 1986; Karpov, 2011; Kopylov et al., 2015).

Ashirov K.B. and others in the studied fields of the Samara region indicate an active flow of light oil through the zones of fault fragmentation into the deposits, the presence of which is fixed in normal-fault wells (Ashirov et al., 2001). Along with this, the studies of regular changes in the physical properties of rocks (decrease in porosity, increase in density and fracturing of rocks) and growth in well productivity towards the disjunctive dislocation have been initiated in sandy-siltstone reservoirs, which makes it possible to predict, in parallel to the disjunctive strike, the consistent zoning of reservoir types: fractured, porous-fractured, fractured-porous and porous types (Bochkarev, Bochkarev, 2016).

Conclusions

1. In-depth tectonic analysis and attracted methods for detecting low-amplitude dislocations made it possible to identify, and in some cases confirm downthrows previously identified from seismic data and to substantiate the fault-block structure of the West-Kommunarsky field. A system of Devonian graben-like deflections of the northeastern strike, genetically related to the horst-graben structure in the basement, has been allocated.

2. Horizontal levels of water-oil contact in the allocated enlarged blocks of the field are justified. It is pointed out that it is possible to form a normal-fault natural fracturing of rocks; its effects on the formation of various types of reservoirs (fractured, porous-fractured, and fractured-porous) are emphasized. Noting the important role of disjunctive dislocations in the structure of fields, it is necessary to attract additional methods for their study (gravimagnetic and tracer studies, hydrodynamic wells and results of reservoir pressure measurements in adjacent blocks, the results of recording the image of micro-lateral logging in wells on the FMI device and cross-dipole broadband acoustic logging, and others) in order to clarify their location and to reveal the patterns of change in rock properties and the productivity nature in normal-fault areas on the considered and other fields in the region.

3. The obtained results should be taken into account when specifying development projects, hydrodynamic modeling and choosing methods of bed stimulation.

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About the Authors

Mikhail A. Lobusev – Deputy Head of the Department of General and Oil and Gas Field Geology, Associate Professor

Gubkin Russian State University of Oil and Gas (National Research University)

Russia, 119991, Moscow, Leninsky Prosp., 65

Tel: +7 (962) 991 79 79

e-mail: mlobusev@gmail.com

Anatoly V. Bochkarev – Professor of the Department of General and Oil and Gas Geology, Academician of the Russian Academy of Natural Sciences

Gubkin Russian State University of Oil and Gas (National Research University)

Russia, 119991, Moscow, Leninsky Prosp., 65

Tel: +7 (968) 765 43 00

e-mail: anatolybochkarev@gmail.com

Galina Y. Rachkova – Student

Gubkin Russian State University of Oil and Gas (National Research University)

Russia, 119991, Moscow, Leninsky Prosp., 65

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