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The Influence of Tectonic Faults on the Wells Productivity in the Fault-Block Structure Field of the Komi Republic

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Влияние тектонических нарушений на продуктивность скважин месторождения разломно-блокового строения Республики Коми

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Timan-Pechora Basin, Komi Republic, tectonic faults, fault tectonics, disjunctives, faults, blocks, block structure, fault-block structure, zones of increased productivity, well productivity, Silurian deposits, field development, development systems, fracturing.

The influence of disjunctive tectonics on field development is of an exploratory nature and requires further study. Development design that involves drilling production wells at poorly studied sites without a reliable geological model involving faults is a high-risk undertaking. Many researchers of fault-block structure sites have encountered the problem of significant unevenness in productivity distribution, well operation patterns, and waterlogging dynamics across the field area. After establishing the presence of a tectonic factor, attention was focused on the dependence of the distance of wells to faults on productivity and other operating factors. In general, the dependence was designated as follows: increased well productivity was noted in fault zones; for some sites, the size of the increased productivity zone was determined quantitatively and was up to 2 km. A study of the influence of tectonic faults on well productivity for one of the fields in the Timan-Pechora Basin (TPB) has been conducted. For the Silurian deposits of the TPB, a relationship was established between well productivity and a tectonic disturbance, which was a normal fault. Increased well productivity was detected at a distance of 2 km from the fault. For the first time, a dependence was found for the influence of the distance from a normal fault to production wells on the efficiency of their operation for oil deposits of the Silurian deposits, which made it possible to predict the volume of production. Based on the results of optimization of drilling of project wells based on a new understanding of the geological structure of the field and the identification of a zone of increased productivity, the cumulative production of the project cluster increased by 1.5 times as a whole for the cluster over a 15-year forecast period. The total initial planned oil flow rate increased by 1.8 times.

Ключевые слова:
Тимано-Печорская нефтегазоносная провинция, Республика Коми, тектонические нарушения, разрывная тектоника, дизъюнктивы, разломы, блоки, блоковое строение, разломно-блоковое строение, зоны повышенной продуктивности, продуктивность скважин, силурийские отложения, разработка месторождений, системы разработки, трещиноватость.

Влияние дизъюнктивной тектоники на разработку месторождений носит поисковый характер и требует дальнейшего изучения. Проектирование разработки, предусматривающее бурение эксплуатационных скважин на слабоизученных объектах без надежной геологической модели с участием разрывных нарушений, является высокорисковым мероприятием. Многие исследователи объектов разломно-блокового строения столкнулись с проблемой значительной неравномерности распределения продуктивности, характера работы скважин и динамики обводнения по площади месторождения. После установления присутствия тектонического фактора внимание акцентируется на наличии зависимости расстояния местоположения скважин до нарушений на продуктивность и другие факторы работы. В общем случае зависимость обозначается так: повышенная продуктивность скважин отмечается в приразломных зонах; по некоторым объектам размер зоны повышенной продуктивности определен количественно и составляет до 2 км. Выполнено исследование влияния тектонических нарушений на продуктивность скважин для одного из месторождений Тимано-Печорской нефтегазоносной провинции (ТПНГП). Для силурийских отложений ТПНГП установлена связь продуктивности скважин с тектоническим нарушением, являющимся разломом сбросового типа. Повышенная продуктивность скважин выявлена на расстоянии в пределах 2 км от разлома. Впервые для залежей нефти силурийских отложений выявлена зависимость влияния расстояния от тектонического разлома сбросового типа до эксплуатационных скважин на эффективность их работы, позволяющая прогнозировать объем добычи. По результатам оптимизации бурения проектных скважин на основании нового представления о геологическом строении месторождения и выделения зоны повышенной продуктивности накопленная добыча проектного куста увеличена в 1,5 раза в целом по кусту за 15-летний прогнозный период. Суммарный начальный плановый дебит нефти увеличен в 1,8 раза.

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Introduction

The accumulated experience of studying the geological structure of deposits all over the world shows that a significant part of hydrocarbon (HC) deposits in areas with developed tectonics identified at the early stages of prospecting and exploring at subsequent stages of their further exploration and exploitation become an association of smaller deposits separated from each other by faults [1–7]. The complication of the tectonic structure is also observed in the deposits of the Timan-Pechora oil and gas province (TPOGP).

The result of poor studying faults in the design of field development are fault-free simplified geological and hydrodynamic deposit model, repeated recalculations of reserves, revision of technological development indicators and selecting ineffective methods of reserve development.

If the influence of tectonic faults on oil accumulation is studied by geologists engaged in prospecting and exploration, then the influence of disjunctive tectonics on the deposit development is of an exploratory nature and requires further study.

Many researchers of fault-block structure objects have encountered the problem of significant unevenness in the distribution of productivity, the nature of well operation and the dynamics of water cut across the field area. After establishing the presence of a tectonic factor, attention is focused on the presence of a dependence between the distance of the well location to the faults and productivity and other factors of operation. In general, the dependence is designated as follows: increased well productivity is noted in fault zones; for some objects, the size of the increased productivity zone is determined quantitatively and amounts to 2 km [8–10]. The studying the influence of tectonic faults on well productivity and the determining the size of the increased productivity zone using one of the TPOGP fields as an example are carried out in this paper.

The role of tectonic complications during the deposit development

The influence of tectonic faults on the deposit development has been and is currently being studied by D.G. Afonin, Mark D. Zobak, Yu.A. Kotenev, O.N. Pichugin, P.N. Solyany, A.V. Bochkarev, V.A. Bochkarev, V.V. Nikiforov and other researchers.

The features of the developing fractured reservoirs have been studied by V.D. Viktorin, T.D. Golf-Rakht, N.P. Lebedinets and many other researchers.

Disjunctive (rupture) tectonic faults are divided into two large categories: conductive (living) and screening (healed).

Depending on the conditions of formation and secondary processes, rupture faults, on the one hand, contribute to the cracking rocks around them and the emergence of a complex relationship between macro- and microcrack systems, increasing the filtration-capacitive properties and connectivity of reservoirs; on the other hand, they can be impermeable screens for fluids and divide the deposit into isolated blocks. The tectonic factor becomes decisive for the geometrization of such deposits.

Within one deposit, as a rule, the simultaneous presence of both fault types is noted: conductive and screening. Checking the presence and degree of permeability of each fault is a complex and labor-intensive task.

Traditional methods for identifying tectonic faults include gravity and magnetic exploration and 2D seismic exploration. The introduction of advanced technologies for preparing structures using 3D seismic exploration methods reveals a more complex geological structure of hydrocarbon deposits due to the widespread development of fault tectonics. This proves that the study of disjunctive faults should be considered as the most important scientific and practical task.

If previously tectonic faults were rarely the target object of study due to the difficulty of identifying them, especially low-amplitude faults in local structures, then in recent years there has been a tendency towards increased interest in this issue: new methods of interpreting seismic exploration data for the purpose of mapping fault zones have emerged, including those based on the use of artificial neural networks [21–25].

Tectonic heterogeneities are identified based on aerospace research data. Based on the grid of lineaments deciphered on space images, zones of increased fracturing associated with faults are identified [26]. For the purpose of studying highly detailed objects, i.e. low-amplitude faults within a field, high-resolution space images are required. The advantages of this method include its low cost compared to 3D seismic exploration.

In recent years in the south of Russia, at the fields of the Eastern Ciscaucasia (Stavropol), the authors M.V. Nelepov, K.I. Chernenko, V.M. Kharchenko et al. study the relationship between tectonic faults and associated zones of increased productivity with lineaments of the daylight surface, and develop approaches to substantiating zones of increased well productivity based on the use of satellite imagery interpretation data [11–18].

In the TPOGP signs of the existing lineaments were identified in the Permian-Carboniferous deposit of the Usinskoye field [19], and the possibility of a connection between the position of modern surface watercourses and low-amplitude tectonic faults that ensure the development of cracks in the Sakmar-Asselian deposits of the Yuzhno-Khylchuyu field is noted [20]. To check the presence and degree of faults permeability data from industrial geophysics [27–30], hydrodynamic studies: tracer studies [3, 31–36], hydraulic listening, diagnostic graphs of the indicator diagram (ID) and pressure recovery curve (PRC) [27], various analyses of the actual well operation, comparing maps of residual oil reserves, isobars and faults [32, 37–39] are used. Several methods should be used to reliably identify violations.

Based on the results of well operation, an idea is formed about the efficiency of the development system and the placement of wells in conditions of strong tectonic destruction of productive formations [37–48].

Development design which provides for drilling production wells in poorly studied objects without a reliable geological model with the participation of structure-forming, fluid-conducting and screening faults, is a high-risk event.

Development of such objects is complicated because of characteristic problems.

The most obvious problem is the disruption of hydrodynamic connectivity over the area and the reducing the influence of injection wells up to its complete absence [3, 27, 33, 35]. The location of the injection and production wells on different sides of the screening fault leads to a decrease in reservoir pressure in the selection zone and to a decrease in oil production, as well as to an unproductive increase in reservoir pressure in the injection zone - pressure redistribution does not occur.

The location of the injection well near the fault, framed by "feathering" cracks, leads to a high proportion of ineffective injection, since the injected water does not perform useful work on oil displacement, but contributes to premature flooding of production wells along more permeable layers and uneven production along the section [33, 34].

The next problem is the occurrence of crossflows between layers/objects due to vertical communication along the fault. The disjunctive fault here becomes a kind of conductive channel, due to which, under certain conditions, fluids from the underlying strata, bypassing the seal, migrate along cracks into the upper reservoir strata. This situation leads to the complexity of accounting for oil production by strata, as well as to the impossibility of controlling the flooding process, bypassing a part of the oil-containing volumes by flows, and therefore to a decrease in the coverage factor and, accordingly, the oil recovery intensity coefficient (OIC).

For objects of block structure, it is typical when in each block the bed deposits have their own water-oil contact. In the case of an incorrect concept of the geological field structure, the unification of such deposits leads to a false idea of sloping water-oil contacts, to an unreliable assessment of reserves and leaving significant reserves of recoverable oil in the subsoil during the development of fields. Thus, at the Zamankulskoye field in the Eastern Ciscaucasia, formation flooding in a well at high hypsometric elevations was perceived as complete development of the deposit over the entire area, although in the same formation in other blocks there was unextracted oil. Based on the block structure of the field, it was made a decision to test it in one of the wells, and as a result, a gushing flow of oil was obtained, although the formation was considered flooded, since in other wells at higher elevations the formation had been flooded for a long time [49].

The development of objects with a fault-block structure is not only complicated by characteristic problems, but also has a number of features, which understanding allows increasing the efficiency of field development.

Based on the results of assessing the degree of faults influence on the efficiency of well operation, some researchers note high and increased productivity of wells located in near-fault zones. Some scientists directly link increased productivity with a branched system of cracks, the so-called "feathering" fracturing which occurs within a certain distance from a tectonic fault. Complex interconnected systems of macro- and microcracks in fault zones are formed as a result of stress loads exceeding the rock's ultimate strength. That is, faults form a zone of rock crushing around them. The density of cracks and well productivity are increased in the direction of the fault [2, 4, 8, 34, 50, 51]. Some researchers, due to the insufficient level of studying the object and the impossibility of naming specific reasons associated with high well flow rates, point only to zones of increased productivity and permeability, preferring not to delve into terminological disputes.

The absence of a clear influence of the structural factor and other main geological and physical parameters, namely oil-saturated thickness, height above contact, porosity, oil saturation, specific reserves of the formation on increased productivity testifies in favor of the tectonic factor, as noted for the deposits of the Stavropol fields [11–13, 52, 53]. The confinement of high-flow wells to "linear zones of tectonic genesis" [13] is observed in general at the fields of the Stavropol Territory. For one of the objects, an example of extremely uneven production by area is given – 5 wells (25 %) extracted 45 % of all cumulative oil production. For the considered objects, it was established that wells with the highest cumulative oil production are located at the intersections of linear zones with increased productivity. Wells with low values of cumulative oil production are mainly located far from zones with increased productivity. The results of hydraulic interference tests show the connectivity of wells confined to the identified zones of increased productivity. It is assumed that the described linear structures are formed by low-amplitude faults and are associated with zones of increased fracturing and permeability.

At some fields in Western Siberia researchers have found that anhydrous production increases in the direction of the fault [2, 8, 33, 34, 50, 51].

For the U1 formation of the Kharampur field in Western Siberia [8], the distance from the fault where deterioration in well performance parameters is noted has even been determined quantitatively and is 1.5 km, and it has also been shown that there is no connection between the structural factor and productivity.

For gas deposits of the Cenomanian sediments of the West-Tarkosalinskoye and Yamburgskoye fields, an increase in well productivity by 2–4 times is noted in the zone up to 2 km from the fault [10]. The influence of fault amplitude on the production capabilities of wells is noted: the maximum values of cumulative, peak and current oil production are observed in wells confined to low-amplitude faults, the minimum ones are distinguished to micrograbens, the coefficients of decline in oil production rates by wells decrease with a decrease in fault amplitude [54]. For the Gezhskoye field in the Perm Territory the influence of the fault direction on the operating parameters of wells was also revealed.

However, the influence of fault amplitude on its permeability and the efficiency of reserves development is ambiguous. Some researchers note that in blocks characterized by large effective thicknesses, faults with a small displacement amplitude almost do not violate the hydrodynamic relationship [33]. On the other hand, in the case of the forming a capillary barrier, in other words, the so-called "friction clay", due to the occurrence of a thixotropic effect of compacting rock grains along the fault plane, even with small displacement amplitudes, the fault will be impermeable [34]. For example, for one of the fields in the Tomsk region, numerical values of the relationship between the amplitude of faults and their permeability were established, and it was concluded that the greater the fault amplitude, the stronger the friction force between the contacting surfaces, the greater the thickness of the "friction clay" layer, the stronger the screen and the less permeable the fault [55]. Researchers note the increased wells productivity in zones with low-amplitude faults, at the same time, zones adjacent to faults can be "stagnant, dead-end and poorly developed" [56]. In addition, the reliability of identifying low-amplitude faults is limited by the low sensitivity of the methods.

Since the density of cracks increases in the fault direction, not only the productivity of wells should increase in the same direction, but also the wells productivity after carrying out measures to intensify oil inflow. It is noted that the maximum efficiency of hydraulic fracturing (HF) is achieved in zones affected by faults [2, 34].

One of the promising methods of influencing the formation is drilling horizontal wells with multi-stage hydraulic fracturing. However, the efficiency of this technology may decrease in the case of higher facies variability of the formation properties. In the case of using this technology, it is necessary to clarify such uncertainties as the length and direction of the horizontal section of the production wellbore, the density of the well drilling grid, the distance between the points of hydraulic fracturing (HF) operations in the well [2, 34].

Several types of fault influence on development, both negative and positive, can be observed simultaneously at one site in individual parts of the deposit.

The result of poor studying faults in the design of field development are fault-free simplified geological and hydrodynamic deposit models, repeated recalculations of reserves, revision of technological development indicators, selection of ineffective methods of reserve development.

It should be noted that the impossibility of adequately adapting models to the development history as a whole should be regarded as an indicator that some features of the geological structure are not taken into account [3, 4].

A good example of the need to consider complete geological information on disjunctive faults and their permeability is the modeling of the Vatyegan deposit section of the UV-1 formation [3], where disjunctive faults identified according to 3D seismic exploration data were not initially taken into account by field development specialists. The standard "template" approach to designing a development system led to complications in the process of field development.

The results of 3D seismic exploration interpretation were re-analyzed by the authors and supplemented by an analysis of tracer studies which confirmed the presence of the identified tectonic faults. A geological model was built. A block structure was obtained. A hydrodynamic model was built in the selected block where the convergence of the result with history was obtained at 99 % after the first calculation without any adaptation. Thus, the calculation results once again confirmed the presence of faults in the studied area and the assumption of their impermeability, i.e. the presence of a block structure with barriers to the movement of reservoir fluids between the blocks.

Thus, for objects complicated by the influence of disjunctive tectonics, based on the results of a review of Russian and world experience, characteristic development problems were formulated:

• violation of the hydrodynamic connection between injection and production wells;

• advancement of the water injection front along tectonic faults and no impact on the producing environment;

• local water breakthroughs along highly permeable layers;

• vertical flows between layers;

• uneven distribution of injected fluid;

• significant variability in well productivity and flow rates, reservoir properties;

• failure to confirm the geological structure based on drilling results.

Recommendations for organizing development systems

In Russia, the greatest attention to the issue of organizing development systems for objects with a complex block structure is currently paid to the fields of Western Siberia; the problem has also been studied by researchers in the Stavropol Territory, Samara Region, Perm Territory and the Komi Republic.

First of all, researchers emphasize that within the development object, areas formed by screening faults should be considered as independent development elements, and within these allocated blocks individual grids for the placement of injection and production wells must be formed. This will allow the most efficient approach to drilling the deposit with the most optimal number of wells and the most efficient development of the deposit with subsequent planning of geological and technical measures. It is also recommended to monitor the development of hydrocarbon reserves within the allocated blocks [2, 4, 8, 27, 33, 34, 51].

It is proposed to use the technology of non-stationary (cyclic/pulsed) impact on the reservoir inside individual development blocks under the condition of a complex fracture-pore type of reservoir, that is, in the presence of a pore "matrix" and a network of fractures. Cyclic flooding is proposed in the following stages: a cycle of pumping the working agent and stopping highly watered production wells – water is introduced into low-permeability oil-saturated pores of the matrix; starting production wells and stopping injection wells – a redistribution of reservoir pressure occurs which allows water in the matrix to displace oil into highly permeable areas [33].

Due to the fact that areas near low-amplitude faults are characterized by increased fracturing and productivity, the maximum efficiency of hydraulic fracturing is noted in the zones of fault influence [34].

Meanwhile, in order to increase the success of water inflow restriction measures, it is necessary to exclude from consideration wells where excess water enters through cracks and faults [57]. At the field, the network of cracks formed as a result of the geodynamic activity of tectonic elements has a certain direction. The direction of fracturing must be taken into account while designing the development of deposits, namely when forming a reservoir pressure maintenance (RPM) system, planning the direction of horizontal well sections and hydraulic fracturing.

The direction of the horizontal well must be planned perpendicular to the main direction of the fractures in order to increase the coverage area due to the influx of hydrocarbons through the system of fractures intersecting the direction of the horizontal well. While performing hydraulic fracturing, the hydraulic fracture will be formed mainly in the direction of the existing natural fracture system. Therefore, the direction of the natural fracture system should be taken into account while locating the injection and production wells in addition to the standard parameters: the location of the well relative to the water-oil contact, the boundaries of substituting reservoirs or other production wells. The direction of the natural fracture system will also affect the location of the injection and production wells. If the injection and production wells are located parallel to the main system of fractures, then water will quickly break through the cracks to the production well, without ensuring the coverage of the formation by the effect. If the injection and production wells are located perpendicular to the main direction of the fractures, the injected water will flow away along the fracture system to the side, without having a significant impact on the area near the production well [13, 14, 50]. Thus, while deciding on the location of injection wells, it is necessary to take into account the direction of the fracturing the object, as well as additional features of the object.

Many researchers determine the most optimal location of production wells near low-amplitude faults. And the location of injection wells in the near-fault fractured zone or fracture system negatively affects the nature of the reserves development.

Table 1

Problems of developing TPOGP fields which are complicated by disjunctive tectonic faults

Typical development problems	Percentage of fields where problems are observed, %
Violation of hydrodynamic connection by area	14
Breakthrough nature of flooding	19
Vertical connectivity, flows between layers/objects;	4
Low efficiency of the RPM system and Pre reduction	17
Uneven production, difficulties in recording production, formation of stagnant zones	12
Uneven distribution of the injected liquid;	9
Significant variability in productivity factors and well flow rates, reservoir properties: local areas with abnormally high reservoir properties and/or low well productivity	9
Failure to confirm geological structure based on drilling results	12
Gas breakthroughs through highly permeable channels	4

If injection wells are already located in the near-fault fractured zone and the negative development scenario has already been realized, it is proposed to stop injection or transfer injection wells to production. The main favorable factor here is the powerful systemic effect, which neutralizes the expected negative consequences of transferring wells from RPM to production. Zones adjacent to faults may be stagnant, dead-end, and poorly developed, and therefore require special analysis and attention.

The use of recommendations for organizing injection considering fault-block tectonics is relevant not only while designing new fields but is also advisable while transforming the flooding system at later stages, since in the practice of field development it is usually difficult to immediately form a selective system, since the structural features of the field are specified during drilling. In addition, at later stages, the development system must be rebuilt according to the changed distribution of reserves in the reservoir [50, 58].

Tectonic complications of TPOGP deposits

The Timan-Pechora oil and gas basin is one of the five largest oil and gas basins in Russia and it is of strategic importance in the fuel and energy complex of North-West Russia. The region has significant potential for expanding the raw material base of the oil and gas industry.

The Timan-Pechora oil and gas province is located within the Komi Republic and the Nenets Autonomous Okrug of the Arkhangelsk Region. One of the features of the TPOGP field geological structure is the tectonic factor. Tectonics here is not only the basis for oil and gas geological zoning of sedimentary basins, determines the process of forming oil and gas deposits but also affects the fields development: its efficiency and technological indicators.

Based on the results of the analyzing the TPOGP fields, it is noted that 49 % of the fields are complicated by disjunctive tectonic faults. According to the analyzing development of TPOGP fields complicated by disjunctive tectonic faults, 47 % of the fields have typical development problems caused by the influence of disjunctive tectonics listed in Table 1. The listed problems are similar to the problems formulated based on the results of generalizing Russian and world experience.

The solution to the problem of the tectonic disjunctive faults influence on the developing TPOGP oil fields is currently of an exploratory nature, the number of methodological recommendations for organizing development systems for objects with a complex TPOGP block structure is extremely limited [20, 31, 59]. In the works [20, 31], the reservoir pressure maintenance system is analyzed, the influence of tectonic faults on increased well productivity is not studied.

Thus, the degree of studying the influence of tectonic complications on the development of TPOGP fields is insufficient to form our own recommendations for development design. Based on a review of Russian and international experience, the direction of the search in this study was chosen to be the analyzing the influence of tectonic disturbances on the increased wells productivity and the search for quantitative characteristics for one of the TPOGP fields.

Characteristics of the geological structure

The TPOGP considered field is large in size and reserves, multi-layer, very complex in geological structure which is associated with high lithological and petrographic heterogeneity of reservoirs and the development of disjunctive tectonics. The size of the field is 11 × 30 km, the oil-bearing area is 135,000 thousand m^2, the total thickness is 153 m, the oil-saturated thickness is 43 m.

Based on lithological features, the deposit suites are divided into packs represented by interbedded secondary dolomites, areas of highly fractured and thin-layered argillite. According to core data, horizontal permeability is twice as high as vertical which predetermines the movement of fluid mainly along the layers. Permeable layers do not have a regular distribution in the section even within one suite due to the discontinuous and lenticular structure of the reservoir.

Development of the field is complicated by the block structure, the boundaries of the blocks are faults of submeridional orientation of the normal fault type, the which amplitude fades along their strike.

Carbonate deposits of the Upper Makarikha subsuite (S1mkr), Sandiveyskaya (S1sn) and Veyakskaya (S1vk) suites of the Lower Silurian (S1), located at a depth of 3.3–4.2 km, combined into one production facility, are industrially productive. They contain light, low-viscosity, highly undersaturated gas oil.

Table 2

Geological and physical characteristics

Parameter	Formation		
	S1mk	S1sn	S1vk
Average total thickness, m	50.9	49.4	53.1
Average effective oil-saturated thickness, m	15.1	11.9	15.9
Porosity coefficient, fractions of units.	0.086	0.090	0.100
Oil saturation coefficient, fractions of units.	0.708	0.702	0.637
Permeability according to GIS, μm^2	0.005	0.006	0.007
Permeability by core, μm2	0.038	0.021	0.038
Sandiness coefficient, fractions of units.	0.36	0.31	0.41
Dismemberment, units	10.3	9.0	9.1
Displacement coefficient (by water), fractions of units.	0.699	0.570	0.673

The deposits have a reservoir or incomplete reservoir type, arched, tectonically and stratigraphically screened, tectonically disturbed and lithologically limited. The geological and physical characteristics of the productive field formations are presented in Table 2.

According to the oil and gas geological zoning, the field belongs to the Kolvavis oil and gas region (OGR) of the Khoreyverskaya oil and gas area (OGA) and is confined to the Sandivey uplift complicating the southwestern part of the Khoreyverskaya depression.

The area of the field is confined to the junction zone of two large tectonic elements of the first order – the Kolvinsky megaswell of the Pechora-Kolvinsky aulacogen in the west and the Khoreyverskaya depression of the Khoreyversko-Pechora-Sorskaya syneclise in the east.

Within the area of the fiel, as well as in the main area of the southern part of the Khoreyverskaya depression, only Silurian deposits outcrop under the surface of the pre-Franian erosion, which section completeness varies from the lower Makarikha suite to the upper Veyak suite and the Upper Silurian.

The complexity of the structure and the multi-stage development of the Kolvin megaswell which is an inversion structure determined the widespread occurrence of tectonic faults in the area reflecting the most important stages of tectonic activity – pre-Frasnian, Frasnian, pre-Visean, Upper Permian-Triassic [60]. The above-mentioned tectonic stages in the modern structural plan of the deposit along the Silurian part of the section are reflected by a fault series of predominantly submeridional and northwestern orientation, along which largest amplitude the area is divided into six blocks. The greatest amplitude of displacement (about 2000 and 1500 m) is characteristic of the Kolvin system faults. In general, the amplitude of displacing the main part of the faults does not exceed the first hundred meters. By the beginning of the late Devonian transgression, the formed blocks were eroded to different depths depending on the sign and amplitude of their displacement by this time [61]. The pre-Franian stage of activation is associated with the formation of another fault system – the Kharyaginskaya which faults are characterized mainly by a submeridional strike and can be traced in the central part of the deposit (Fig. 1).

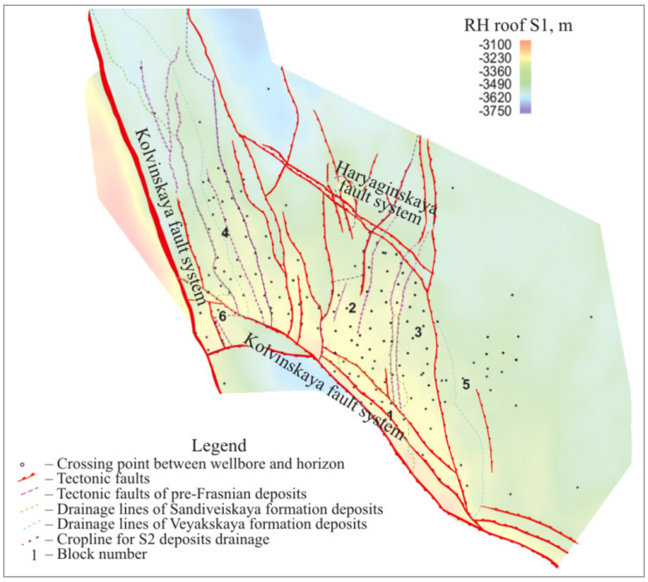

Fig. 1. Structural map by reflecting S1 roof horizon

Current development state

The field was put into operation in 1989. The maximum recovery rate was reached in 1998 and amounted to 4.3 % of the IRR. Reserve development is 45 %. Current water cut is 52 %. Current oil recovery factor for the field as a whole is 0.191 shares of units with a design value of 0.421 shares of units. The accumulated parameter of the oil recovery factor is 0.67 shares of units. The field is at stage III of development.

The dynamics of the main technological indicators of development are shown in Fig. 2.

In the conditions of a complex geological structure with a large number of tectonic faults and inactive oil-water contact, it was established that injection wells are the main source of water cut in the production of production wells at the field.

Productive formations are represented by reservoirs with various types of void space, characterized by significant heterogeneity and variability of filtration and capacity properties. In this regard, local water breakthroughs along highly permeable layers are typical, which reduce the efficiency of the applied impact system.

The implementation of the reservoir pressure maintenance system began in 1991 in block 1.

In the initial period of the reservoir pressure maintenance system organization, a breakthrough nature of water cut was observed in the wells of block 1. Until 1996, the water cut was less than 5 % with a production of 11 %. A significant increase in the volume of injected water in 1999–2000 led to a sharp water cut in the production and a decrease in oil production.

By 2000, with a ratio of production to injection wells of 5:1, the water cut reached 48 % with a production of 23 %. The mass shutdown of high-water-cut wells has reduced and somewhat stabilized the average annual water cut since 2003.

Until 2011, there was a further gradual increase in water cut to 70 %. In the period 2012–2016, water cut was stabilized by conducting geological and technical measures (GTM) at 63 %. Then, water cut increased again to 71 % in 2018. Since 2020, due to the involvement of new areas in development and the disposal of water-cut wells, water cut at the field has been reduced to 52 % in 2023 with a production of 45 %.

In general, there is a significant difference between the reservoir pressure values in the extraction and injection zones at the field. For individual production wells, the reservoir pressure is significantly lower than the initial pressure, and for injection wells, it is significantly higher than the initial pressure. One of the reasons for the low efficiency of the reservoir pressure maintenance system is the location of injection wells near tectonic faults, which leads to the movement of part of the injected water along the faults and to the disruption of the hydrodynamic connectivity of the wells and the absence of the influence of the injection well on the producing environment.

The implementation of the reservoir pressure maintenance system in the northern sections of all blocks shows low efficiency. The accumulated injection by wells, accumulated and current fluid and oil withdrawals from wells located in the northern parts of the field are less than in the southern ones. In the northern parts of the blocks, there are also zones with reduced reservoir pressure, while in the southern part of the field the energy situation is more favorable.

Stock development analysis

One of the quick ways to diagnose the structure of a reservoir is to assess the degree of heterogeneity of well operation, as proposed by Nelson [24, 62]. His criterion can be formulated as follows: if 5 to 15 % of producing wells provide 50 % of the accumulated oil production, then such an object should be classified as a highly fractured formation. At the studied field, 16 % of the wells that were in production took 50 % of the accumulated oil production.

Analyzing well selections in the section of suites, it can be noted that the highest selections are shown by wells that have opened the Veyak deposits (Fig. 3). The Veyak deposits, along with the Makarikha deposits, are characterized by the highest productivity characteristics (Fig. 4).

Unevenness of production by blocks is noted (Fig. 5). Block 5 is the least developed.

In block 1 the value of selections corresponds to the water cut – this is explained by the satisfactory operation of the reservoir pressure maintenance system. In blocks 2 and 3 outpacing rates of well production water cut are noted.

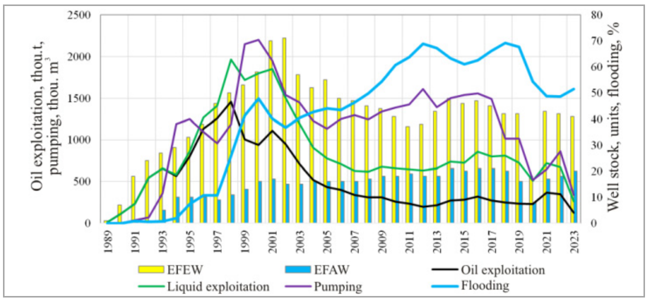

Fig. 2. Field development schedule

In blocks 4 and 6 the levels of selections from the lower reservoirs exceed the values of water cut of the product.

Most of the field has been drilled (Fig. 6).

Block 5 contains reserves that are not covered by the production grid. The existing potential of the field must be realized through a comprehensive analysis of the features of the geological structure.

Studying the influence of tectonic disturbances on increased well productivity

The problem of significant unevenness in the productivity distribution, well operation characteristics and water cut dynamics over the field area identified for fault-block structure objects by various researchers is also noted at the studied field.

In this regard, the hypothesis of the tectonic factor influence on the increased productivity of the field's wells was further tested.

First of all, the influence of the main geological and physical deposit parameters such as porosity, oil saturation, oil-saturated thickness on the value of cumulative production and the maximum oil flow rate by wells was considered. The distribution of cumulative production was also analyzed taking into account the time of well operation. The dependencies were constructed for the whole deposit and an analysis was also performed by suites and by main blocks. In general, it can be said that reliable dependencies characterizing the presence of the main geological and physical parameters influence on oil production and flow rates were not obtained for the field.

To study the relationship between well productivity and the tectonic factor, the distribution maps of cumulative oil production by wells were analyzed (see Fig. 3). The dependences and maps of maximum oil flow rates (Fig. 7, *a*) were constructed, as well as specific maximum oil flow rates reduced to 1 meter of oil-saturated thickness (Fig. 7, *b*).

It can be noted that wells with increased productivity are attracted to the Kolvin system fault with amplitude of up to 1500 m which limits the field from the southwest (the fault is called F2 in the geological model and further in the text). This is especially evident on the well flow rate maps (see Fig. 7). It can also be noted that two zones by flow rates are distinguished in the area: the flow rates are higher in the left part of the field. Examination in the section of the suites showed that different flow rate levels are confined to different suites: wells with maximum flow rate values extract oil from the vk suite.

To plot the dependencies, cubes of the distance of well bed intersections to the faults were constructed: to the F2 fault (Fig. 8, *a*) and to the nearest fault. The distances from each well to the nearest fault were plotted to test the theory of the possible influence

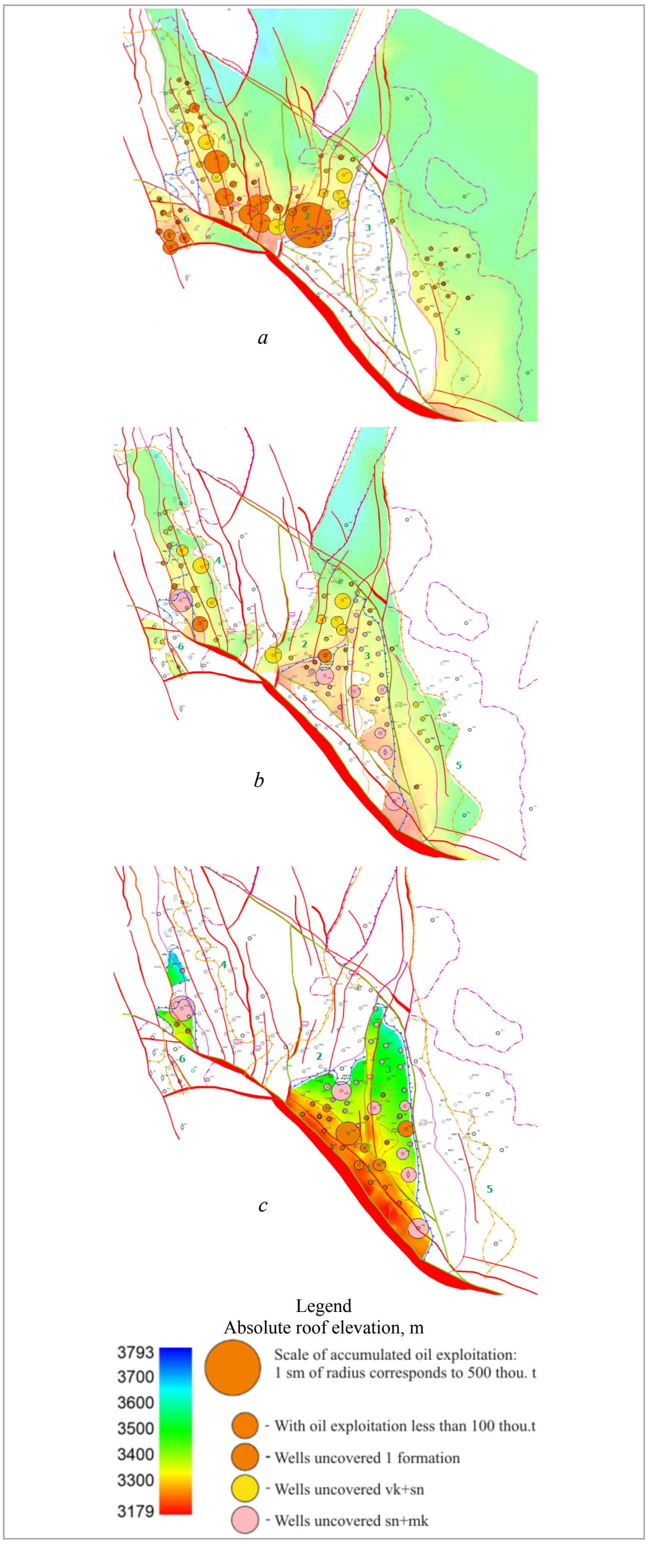

Fig. 3. Accumulated oil production by suites:
a – Veyakskaya; *b* – Sandiveyskaya; *c* – Makarikha

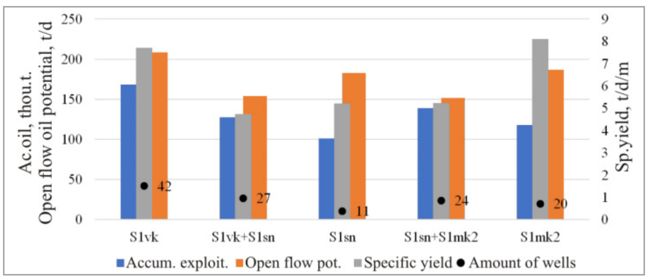

Fig. 4. Comparison of well indicators by suites

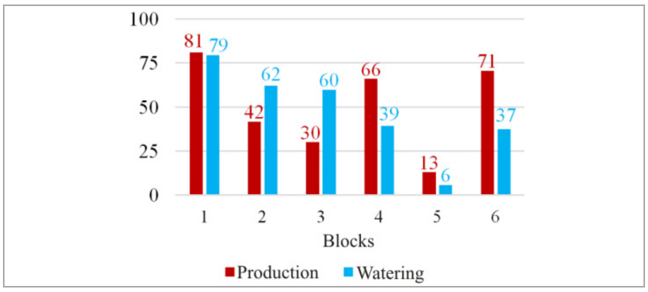

Fig. 5. The ratio of the selection parameters
from the IRR and water cut by blocks

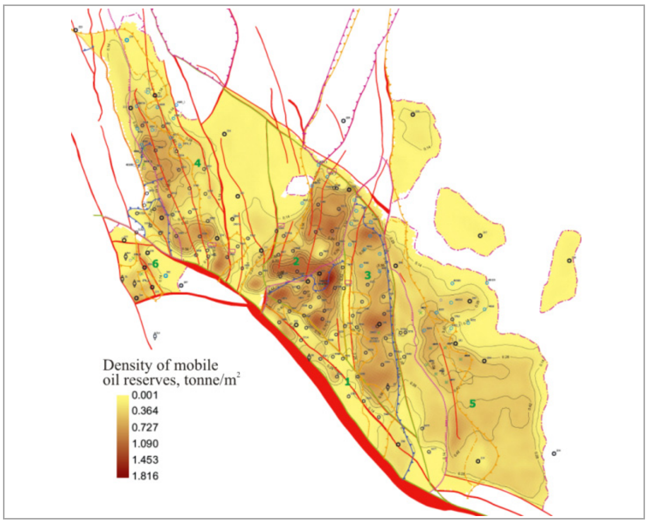

Fig. 6. Map of the distributing the density
of current mobile oil reserves

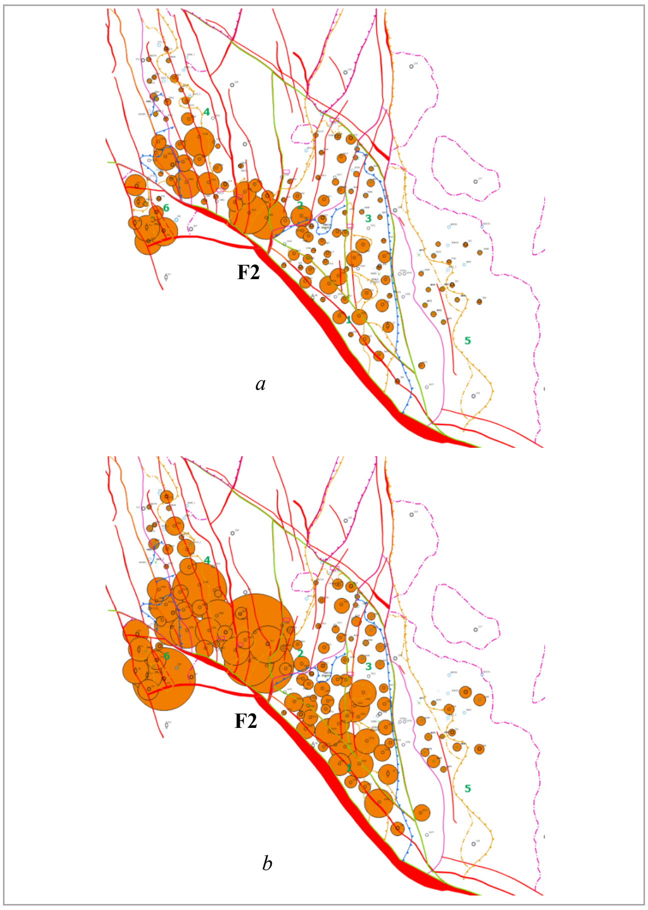

Fig. 7. Map: *a* – maximum oil flow rates;
b – specific maximum oil flow rates

of the nearest fault on well productivity (Fig. 8, *b*). No influence of the distance to the nearest fault on productivity was revealed.

In Figure 9 the dependences of cumulative oil production on the distance to fault F2 and the dependences of the maximum and specific oil flow rates on the distance to fault F2 show a trend towards an increase in parameters with a decrease in the distance to the fault. In Figure 10 the flow rate dependences are plotted separately for the deposits of each suite. Since the sampling allowed it, wells were selected in which production was carried out only from one suite. According to the data in Figure 10 a zone of increased productivity was identified for the vk and sn deposits at a distance of 2000 m from fault F2, while no zone of increased productivity was identified for the mk deposits.

Since no zone of increased productivity was identified for the mk deposits, in Figure 11 wells operating on mk deposits are excluded. According to the dependences of the maximum and specific oil flow rate for vk and sn deposits, zones with different productivity are identified, boundary is noted at a distance of 2000 m from the F2 fault between these ones. In the 700–2000 m zone the flow rates for all wells exceed 160 t/day and 5 t/day/m, while in the zone further than 2000 m, most measurements are within the range of up to 263 t/day and up to 7.8 t/day/m. The exception is one well that stands out from the general trend, located at a distance of 2838 m from the F2 fault; it has not yet been possible to understand the reason for its exclusivity.

For the vk suite deposits in Figure 10 the one of increased productivity at a distance of 2000 m from the fault is clearly distinguished. The specific flow rate in the high productivity zone for vk deposits exceeds the values in the 2000–8000 m zone by an average of 3 times and for the most productive well – by 7.8 times. For sn deposits, the difference in specific flow rate is 2.4 times (Fig. 12, 13).

In order to substantiate the flow rates of new wells, the dependences of the specific maximum oil flow rate on the distance to the F2 fault were individually calculated for each of the vk and sn formations (Fig. 13). In the zone further than 2800 m for vk and from 2000 m for sn the value of the specific maximum flow rate is assumed to be constant and in the zone up to 2800 m for vk and from 2000 m for sn it increases proportionally to the well productivity. Here, the assumption is taken into account that in the immediate vicinity of the fault, productivity decreases again which is confirmed in the graphs (see Fig. 13).

The obtained dependencies were used to justify the flow rates of the project cluster wells located partially in the high productivity zone of the poorly drilled block 5. In addition, the optimization of the cluster wells consisted of adjusting the location and purpose of the wells. A comparison was made with the flow rate calculation based on the current understanding of the geological structure without taking into account the high productivity zone ("base" calculation). The average initial oil flow rate of new wells of the cluster increased by 2.6 times – from 42.8 to 112.9 tons / day. Based on the results of an additional assessment on the GDM, the average initial flow rate of new wells was up to 65.8 tons / day, i.e. increased relative to the "base" by 1.5 times. The planned oil production levels for the wells of the new cluster were calculated on the hydrodynamic model of the deposit (HMD). Based on the results of a comparison with the "base" calculation, the cumulative oil production increased by 1.5 times for the cluster as a whole over the 15-year forecast period. The total initial planned oil flow rate increased by 1.8 times.

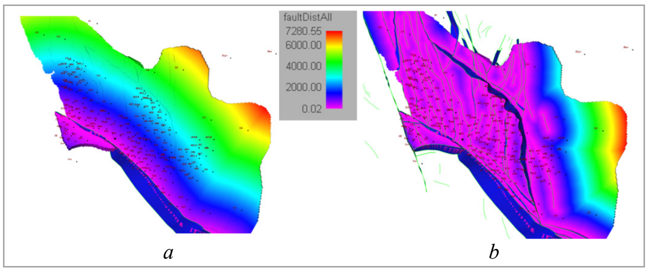

Fig. 8. Distance cube: *a* – to regional fault F2; *b* – to the nearest fault

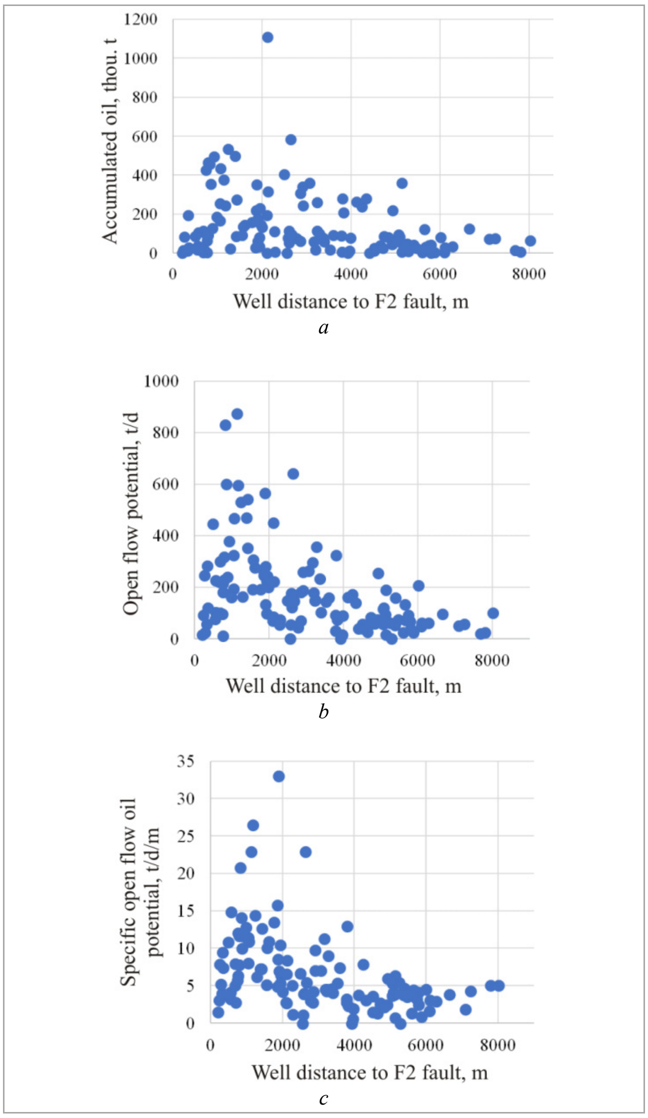

Fig. 9. Dependence of cumulative oil production on the distance to fault F2 in the field as a whole (*a*); dependence of maximum (*b*) and specific (*c*) open oil flow rates on the distance to fault F2 in the field as a whole

Conclusion

1. Analysis of Russian and world experience has shown that for objects of fault-block structure there is a relationship between increased well productivity and the

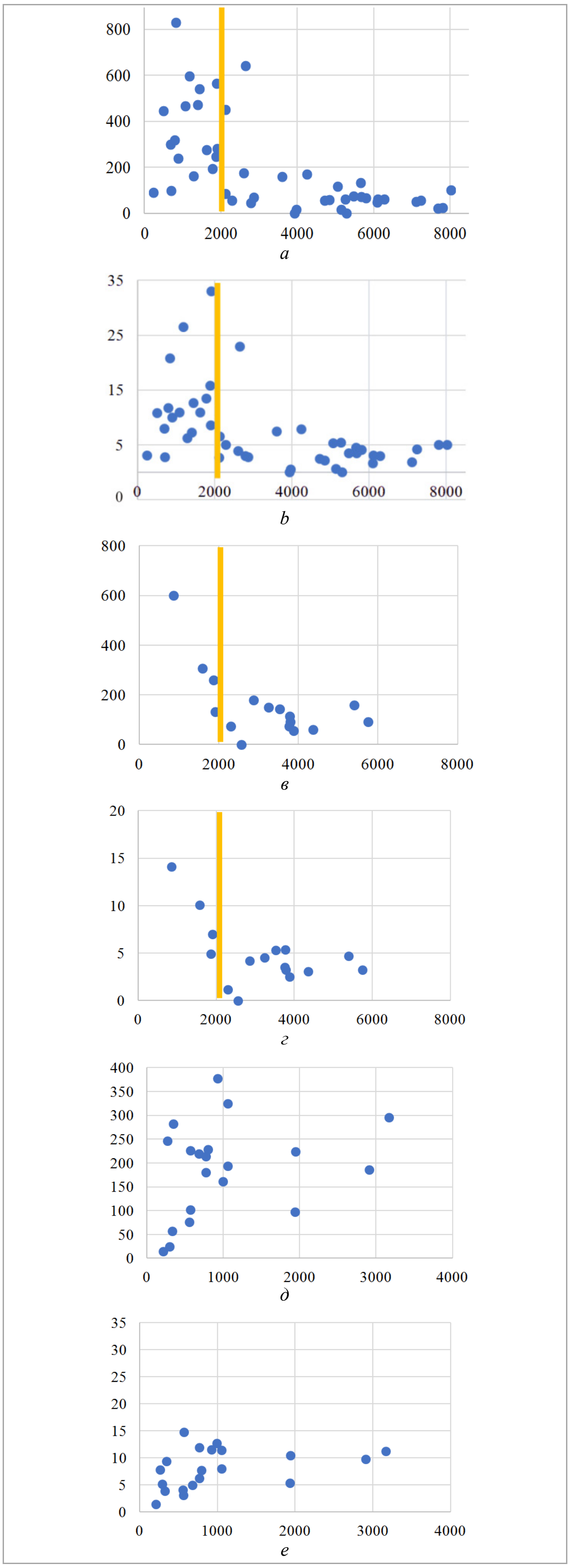

Fig. 10. Dependences of maximum and specific open oil flow rates on the distanceto the F2 fault in the suites of the Field: *a* – maximum flow rate, vk; *b* – specific open flow rate, vk; *c* – maximum flow rate, sn; *g* – specific open flow rate, sn; *d* – maximum flow rate, mk; *e* – specific open flow rate, mk

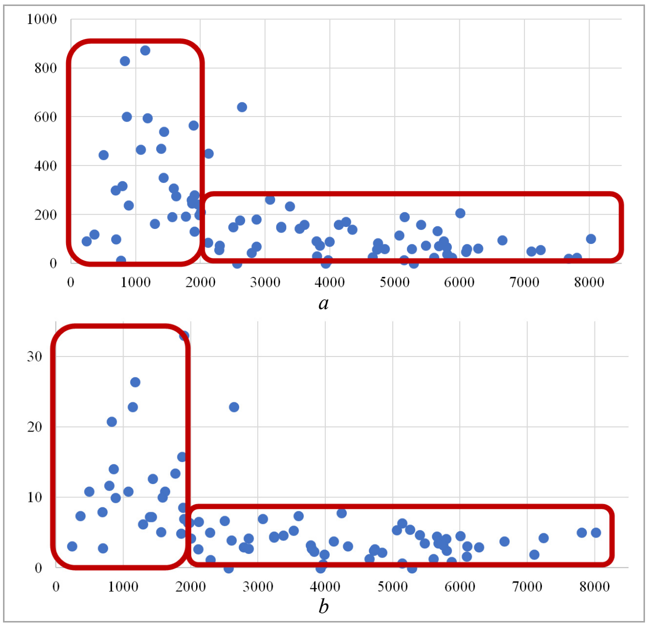

Fig. 11. Dependences between maximum (*a*) and specific open (*b*) oil flow rates and the distance to fault F2 for deposits vk and sn

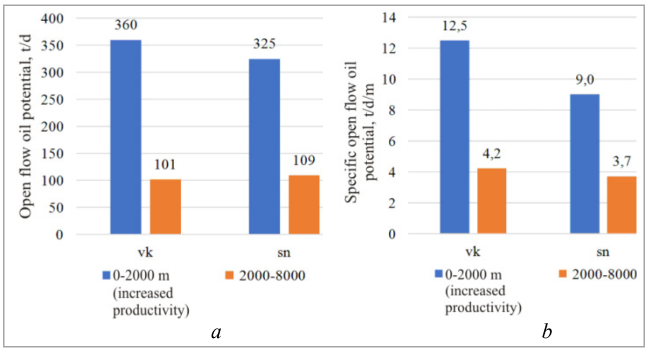

Fig. 12. Comparison of average values of maximum (*a*) and specific open (*b*) oil flow rates for the identified zones

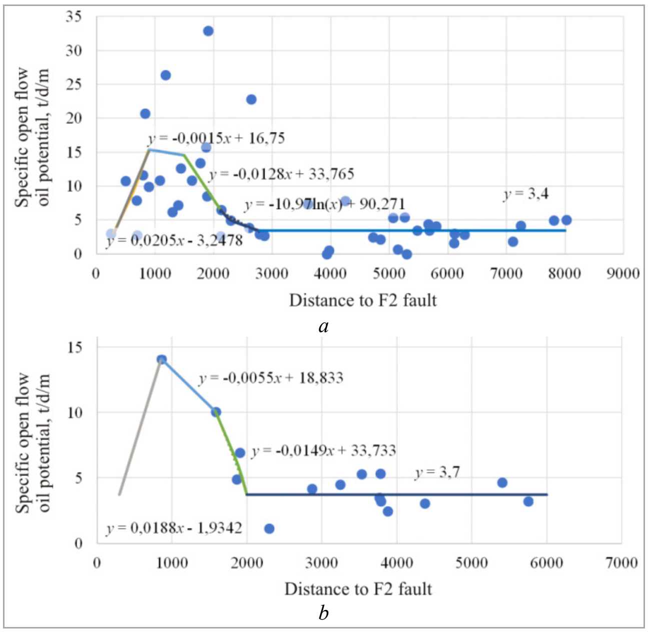

Fig. 13. Dependence of the specific open oil flow rate on the distance to the fault: *a* – for VK deposits; *b* – for sn deposits

distance to the tectonic disturbance for objects of fault-block structure. For some objects the size of the zone of increased productivity is determined quantitatively and is up to 2 km.

2. Development problems typical for tectonically fragmented objects are noted at TPOGP fields. In this regard, the experience of studying the influence of the tectonic factor on field development was used to study the selected TPOGP field. The influence of tectonic disturbances on well productivity was studied and a search for quantitative characteristics was performed.

3. Based on the results of the studying the influence of tectonic disturbances on increased well productivity of the studied field, the presence of a zone of increased productivity was revealed at a distance of 2000 m from the F2 fault which is a normal fault for vk and sn deposits. For mk deposits a zone of increased productivity was not revealed.

4. For the first time, the influence of the distance from the normal fault to the production wells on the efficiency of their operation was revealed for the Silurian oil deposits of the studied TPOGP field.

5. Based on the new understanding the geological structure of the field and the identifying a zone of increased productivity, recommendations were developed for optimizing the drilling new wells.

6. Based on the results of the optimizing the design cluster, the accumulated oil production increased by 1.5 times for the cluster as a whole over the 15-year forecast period. The total initial planned oil flow rate increased by 1.8 times.

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