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CAUSES OF FLUID ENTRY ABSENCE WHEN DEVELOPING WELLS OF SMALL DEPOSITS (on the example of the Khadum-Batalpashinsky horizon)

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A promising direction for the development of the oil and gas industry is the drilling of small hydrocarbon fields, which constitute two thirds of Russia's total hydrocarbon reserves.

When choosing an effective method of development and assessing the potential of small fields in Eastern Ciscaucasia, which are characterized by complex mining and geological conditions with abnormally high reservoir pressures and temperatures, it is necessary to determine the optimal amount of oil production taking into account the flow of edge water under elastic water drive.

The article discusses the reasons for the lack of inflows of reservoir fluids in wells during their development, which are due to complex unconventional fractured clay reservoirs in the lower Maykop deposit and the presence of loose rocks in the section of the reservoir. The results of studies of the influence of technological and geological factors on the poroperm properties of the Khadum-Batalpashinsky reservoir are described, zones of rock softening are revealed, the intervals with bottom water and their influence on the well development process are specified.

It has been established that the state of the hydrodynamic system of the field depends on the introduction of the bottom and edge waters of the sedimentation basin of the East Stavropol Depression. Oil deposits in the Khadum and Batalpashinskaya suites initially work in an elastic and then in an elastic-water drive mode.

The main reasons for the lack of inflows of formation fluids into wells are the low reservoir properties of clay fractured reservoir rocks; clogging of the fracture capacity of reservoir rocks at the drilling in as a result of penetration of drilling mud and its filtrate deep into the reservoir; inflow of formation water from an overlying aquifer with abnormally high formation pressure; the closure of cracks in the clay reservoir due to a sharp decrease in pressure caused by the lowering of the slotted filter into the well; secondary dissection of productive layers by perforation during repression on the formation in a liquid medium with the presence of a solid phase and high density.

***Key words*:** well drilling; drilling in; geological factors; geological structure of the reservoir; bituminous clay; fractured clay rocks; reservoir properties of rocks; porosity; permeability

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Introduction. A special feature of the mineral resource base of the oil industry in Russia is that for 75 percent it is represented by small deposits with recoverable reserves of less than 10 million tons. In this regard, the issue of technological and technical readiness for economically efficient development of oil fields with small stocks is of great importance [8].

Formulation of the problem. The development of small fields in Eastern Ciscaucasia, which are characterized by complex mining and geological conditions with abnormally high reservoir pressures and temperatures, with large depressions is often accompanied by the inflowing oil-field water that causes flooding of hydrocarbons, reducing their recovery and profitability of field development in general [3].

The accumulation of oil deposits in the Oligocene sediments of Eastern Ciscaucasia is associated with the presence of the Maykop oil-source strata, which is in the main phase of oil formation. The results of the study of the lower Maykop clay deposits indicate that the oil accumulation is associated with a peculiar natural reservoir.

To select an effective method of development and assess the potential of hydrocarbon deposits in this region, it is necessary to determine the optimal amount of oil drainage, taking into account the inflow of oil-field water into the reservoir from the boundary area during the elastic-water drive. The determination of ROIP will make it possible to refine the oil recovery factor and assess the degree of gravitational redistribution of oil in the area.

The lack of inflow of formation fluids in wells during their development, which occurs during the drilling of deep wells, is due to complex unconventional fractured clay reservoirs in the lower Maykop and presence of loose rocks in the section [2].

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The paleogeographic conditions of sedimentation during the Batalpashian period are characterized by the shallowing of the basin. Sedimentation over most of the territory took place at depths of 20-25 m and its conditions in the Batalpashyan period determined the poroperm properties (PP) of clay reservoir rocks. An analysis of the paleogeographic conditions of sedimentation indicates that the productive Khadum-Batalpashinskoe sedimentary strata consist of clay reservoir rocks of different PP.

Methodology. The article presents the results of laboratory studies of clay rocks of the lower Maykop and the determination of the average value of porosity according to statistical processing. Comparison of the results of determining the porosity by various methods, including saturation of the rock with liquid (kerosene), in determining the porosity by air and by the method of nuclear magnetic resonance, as well as using dynamic densitometry, is performed. The saturation graph is used, where the ordinate of the inflection point characterizes the most effective part of the pore space and is taken as the effective porosity.

The dependences of the measured resistances of the samples on the effective porosity and total porosity of saturation are analyzed. A clearer is the functional relationship of clay resistances from their effective capacity, and not from the full saturation capacity. The conductivity of the sample in the directed orthogonal strata is dominated by the most effective interlayer void capacity, rather than the total porosity of the clays. The boundary value of porosity is also important. In order to predict the effective porosity of the lower Maykop clays, the dependence of the effective porosity on the resistivity in the saturation interval has been constructed.

Discussion. According to the results of studying the lithological features of the lower Maykop deposits, a conclusion was made about the wide sideritization of these rocks, including clays, previously characterized as «noncarbonated», since the mass determination of carbonate content by the standard (volumetric) method did not allow obtaining reliable data on the degree of sideritization of rocks. The results of special studies to determine the content of siderite in rocks have shown the presence of siderite in almost every sample. This is also confirmed by X-ray analysis.

The quantitative content of siderite in clays varies from 6.2 to 37.2 %. In general, there is a tendency to decrease the effective porosity with increasing content of siderite. The nature of this ratio is similar to the ratio of the coefficient of porosity Cp and carbonate content ($CaCO_3$). However, this does not allow us to assume that the presence of siderite negatively affects the reservoir properties. Perhaps even the opposite. Thus, there is a tendency to a decrease in the content of residual water (hence, an increase in the effective porosity) with an increase in the amount of siderite. The noted sideritization of rocks allows us to make an important conclusion about the possibility and necessity of intensifying oil inflows from clay reservoirs by means of hydrochloric acid treatments.

The research results showed that at a temperature of 100 °C, the complete dissolution of clay carbonates takes 50 minutes. The time required for the dissolution of clay carbonates, compared with limestone, increased by 16.6 times. An increase in the concentration of acid from 18 to 36 % practically does not produce any effect, although the degree of dissolution of carbonates increases.

Based on the above, it can be concluded that an increase in the effectiveness of hydrochloric acid treatment of clays can be achieved by: restoring the reservoir temperature of the bottom hole (after cooling the flushing) before pumping the acid; an increase in the reaction time of the acid with the rock from 30 minutes (adopted for limestones) to 5-8 hours; multiple (3-5 times) treatments.

According to the results of laboratory studies of clay rocks of the lower Maykop (Khadum and Batalpashinskaya suites), the average values were determined: porosity 11.28 % (standard deviation is 1.43 %, asymmetry – 0.24) and density $2.4 \cdot 10^3$ kg/m^3 (standard density deviation – $0.038 \cdot 10^3$ kg/m^3, asymmetry – 0.29).

There is a relationship between the porosity of clay rocks and their density, which is expressed by the equation

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$$m = 23.88(2.88 - d), \quad (1)$$

where m – porosity, %; d – volume density, multiplied by 10^3 kg/m^3, with correlation coefficient γ = = 0.65 (calculated by the average values for individual wells).

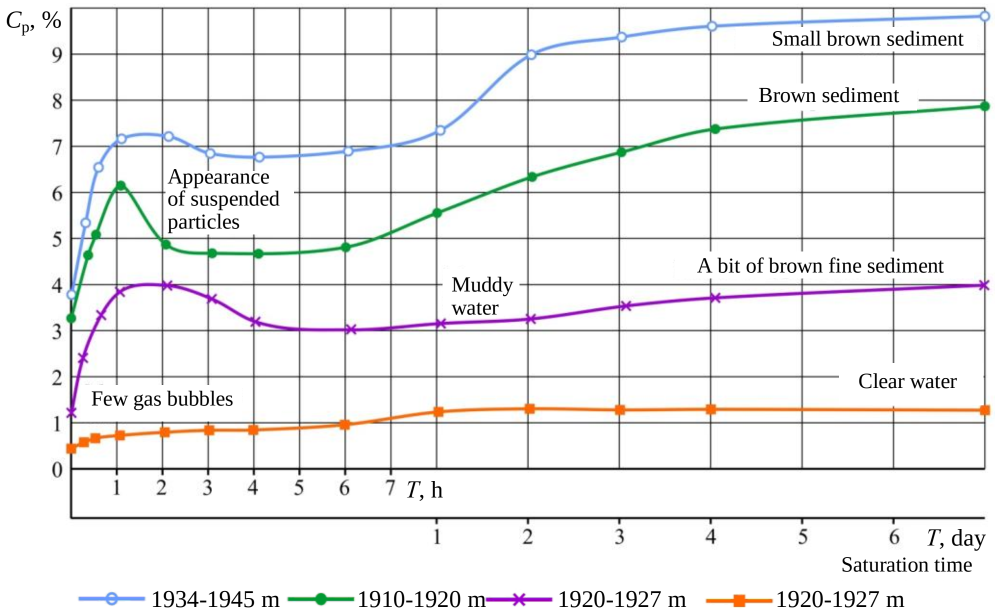
The nature of the distribution of average values of the density of rocks of the Batalpashinskaya suite, in general, is consistent with the distribution of porosity, but a direct relationship is not always observed. The maximum value of the density of the rocks of the Batalpashinskaya formation is (2.48-2.41)10^3 kg/m^3, and the minimum (2.30-2.31)10^3 kg/m^3.

From the graph of changes in the current porosity of clay rocks in the well (see figure), it can be seen that the first type of rocks, according to densitometry, has a maximum saturation porosity of 6.8-9.7 %, while the effective porosity is 0.78-0.83 from the maximum. The second type of rocks (transitional) in the configuration of the curve resembles the previous type but differs in smaller values of the maximum porosity in densitometry (5.2-5.8 %, rarely up to 7.8 %). The effective porosity is 0.31-0.51, rarely 0.77, from the porosity of saturation. The third type of rocks is characterized by low values of maximum porosity by densitometry (1.7-5.8 %), effective porosity is 0.31-0.42, rarely 0.66 of the maximum.

It was revealed that the distribution of the free oil saturation coefficient in the section of the lower Maykop sediments is closely related to the residual water saturation coefficient. The high content of residual water is predetermined by the mineral composition of the rocks (clay minerals) and the structure of their void spaces (very fine pores and interplate, interlayer spaces). Due to the significant content of bitumoids, the rocks are usually hydrophobic to some extent, which affects the amount of residual water saturation, causing the latter to decrease with increasing degree of hydrophobization.

The results of work on the lower Maykop clay deposits show that the oil accumulation here is associated with the peculiar structure of the natural reservoir. This, in particular, show the results of testing wells. Within the established oil-bearing fields, wells with industrial oil inflows (25-100 m^3/day), low-flow rates (5-7 m^3/day), low-throughput (0.01-1.5 m^3/day) and non-flowing. In addition, in a number of wells, inflows of water with varying amounts of oil, inflows of water and oil were obtained with further rapid water flooding.

As is well known, a natural reservoir in the classical sense is a reservoir with certain poroperm parameters, limited by fluid seals that do not have an effective capacity and permeability. The clayey natural reservoir has a number of specific features: reservoir rocks are represented by thin-layer mudstones enriched with organic matter and sulfides; poroperm system consists of a permea-



Graphs of changes in the current porosity of clay rocks in the well ble conductive fractured part and a weakly permeable and impermeable porous matrix; there are both horizontal and vertical and inclined cracks; there are no sharp boundaries between the reservoirs and the fluid seals [14].

A characteristic feature of fracture zones, noted on the outcrops of Paleogene sediments, is the parallelism of the lines of the vertical fracture zones [1]. In this regard, of particular interest is the difference in the composition of oils from the fractured and block parts of the reservoir (see table) and the permeability of the conducting channels between the wells both within the fractured zones and between fractured zones separated by blocks.

The features of the fracture structure of rocks show that among vertical cracks, cracks with an opening of 10-20 μm predominate, slightly less cracks with an opening of 5-10 μm, the distribution pattern is close to lognormal. The data obtained as a result of direct study of the fracturing of clay rocks suggests that in the section of the lower Maykop there are separate intervals with a satisfactory capacity (up to 2-7 %), fairly high and very high permeability (up to $534955.3 \cdot 10^{-15}$ m^2).

Separating unconventional fractured reservoirs in the Khadum and Batalpashinskoe formations presents considerable difficulties. According to the field geophysical studies (electrical survey – ES, self-potential method – SP, neutron γ-logging – NL, gas logging), it is practically impossible to distinguish reservoir rocks. The decompressed zones in the Oligocene section can only be distinguished using a set of methods, which include acoustic (AC) and density logging, caliper survey, thermometry, and the method of laterolog probe (LP) [6, 14, 15]. According to the AC, the reservoir is characterized by an abnormally increased acoustic wave travel time (up to 500-600 μs/m). According to it, in the Oligocene section, layers with increased porosity are distinguished, and according to the caliper survey data, the permeable fractured formation is marked by an increase in the diameter of the well, which indicates that the section is cavernous.

Thermometry makes it possible to isolate the intervals of increased fracturing, which, due to the penetration of drilling fluid, which has a lower temperature than the reservoir (120 °C), are marked by a decrease in temperature by 2-5 °C. Subsequent temperature measurement records a decrease in temperature of a lesser magnitude, since after clogging of the formation, the infiltration of the filtrate decreases or stops. It should be noted that in wells where there are no permeable formations, temperature anomalies are not observed.

Rocks from oil-saturated intervals and rocks from intervals attributed to unproductive by average values of petrophysical parameters (porosity, density) do not differ. However, productive wells are characterized by a smaller scatter of average porosity values (10.72-12.22 %) as compared with non-productive ones (8.9-13.85 %). As noted by many researchers, the contrasting parameters of the values of density parameters in the section of clay sediments can serve as a criterion for their oil content.

An analysis of the relationship between the reservoir productivity and the petrophysical parameters of the reservoir rocks allows us to conclude that capacity in wells with low productivity is most likely due to fracturing. In highly productive wells, the influence of the useful volume of the matrix is noticeable. If the contrast of petrophysical parameters can be a criterion for the oil-bearing capacity of a section in a particular well, then the homogeneity of the rocks composing it [12, 14] can serve as a criterion for determining the productivity of an individual interval. This feature, in our opinion, confirms the fact of the impact of secondary physicochemical processes. Under their influence, the petrophysical parameters of rocks are leveled in accordance with new thermodynamic conditions. The amount of bound and free oil in the clay reservoir of the lower Maykop deposits is directly dependent, firstly, on the physical-chemical state of the surface, and secondly, on the reservoir properties of rocks [9, 10].

The results of experimental studies suggest that the mechanism and direction of construction

Physical-chemical properties of oil in fractured and block parts of the reservoir, %

Composition	Fractured zones	Blocks
Resins	4.6-9.7	5.7-9.4
Asphaltenes	0.35-0.96	0.2-1.7
Paraffins	6.5-10.6	6.4-19.2/1*
Gasoline fractions	25-29	20-29

* Average content

of a polymolecular layer of water are determined, on the one hand, by the distance from the solid surface, on the other, by the degree of surface hydrophobization and the actual occupancy of hydrocarbons of the adjacent hydrophobized sites. Closer to the surface, the forces of interaction with the substrate predominate. As one moves away from the surface into the depths of the void space, the forces of attraction between the adsorbed water molecules begin to predominate. Polymolecular layers formed on monolayers begin to be completed not only in the vertical, but also in the lateral directions. If the neighboring hydrophobic sites are not occupied at this moment by polymolecular layers of hydrocarbons, the polymolecular layers of water will begin to finish building them in a horizontal direction until merging with adjacent layers. This was exactly the situation under the conditions of the experiment: the hydrophobized surface areas were not occupied by polymolecular layers of hydrocarbons, as is the case in natural conditions of the reservoir. With a low degree of surface hydrophobization, the volume of polymolecular adsorption of water does not depend on the hydrophobicity coefficient Hc, which can be explained by the lightened conditions for the manifestation of the action of hydrogen bonds between water molecules of adjacent hydrophilic sites located relatively close to each other. Since the distance over which the molecular field of the substrate acts is approximately the same everywhere, the volume of the resulting polymolecular layer will also be of the same order. In this case, the hydrophobized surface areas are buried under a continuous layer of strongly bound water. As the degree of surface hydrophobization increases, the merging of adjacent polymolecular layers becomes more difficult.

For a quantitative assessment of reservoir parameters, hydrodynamic studies of wells were carried out [4], the results of which, taking into account the above, made it possible to refine the petrophysical model of the Khadum and Batalpashinskaya reservoirs: the average effective net weight determined by the data of the inflow profile study is 7.5 m; secondary porosity of reservoir rocks ranges from 1.7 to 2.5 %; free oil saturation averages 15.0 % of effective porosity; reservoirs are argillite-like clays, reservoir rocks are composed of horizontally oriented thin, even, sometimes lenticular overlapping layers, and are divided by a network of horizontal (58.5 %), inclined (31.3 %) and vertical (10.2 %) cracks in which the main volumes of oil are concentrated; the collector differs from the non-collector by increased values of total porosity (up to 16.27 %) and lower values of density (2.35-2.4 g/cm^3); the residual water saturation of clays by mass determinations varies within relatively narrow limits (70-85 %); the average value of permeability of the reservoir is $5.23 \cdot 10^3$ μm^2; hydroconductivity of 3.39 μm$^2 \cdot$ cm/(mPa·s); water conductivity of 0.044 m^2/day.

The interpretation of the pressure recovery curves showed that the Khadum-Batalpashinskoe deposits are of fracture-pore type, due to the impact on clay mudstones of low-amplitude tectonic disturbances that are clearly visible in time sections [13].

For intersecting seismic profiles, decompacted zones can be noted, which are favorable for obtaining oil inflows [1]. The connection with the oil saturation of the intervals distinguished by the amplitude-frequency characteristic is confirmed by the results of testing the Batalpashinskaya suite in wells where industrial oil flows are obtained. For a limited number of analyzes of the dynamic characteristics of the wave field on seismic profiles, it is possible to identify areas that are promising for the supplementary exploration of the oil-bearing potential of the Batalpashinskaya suite.

When drilling, it is necessary to exclude areas unfavorable in the oil-bearing ratio, which are singled out in aggregate in areas of seismic profiles with a negative dynamic characteristic of the wave field and materials of drilling and testing [6, 11].

In wells that have produced oil inflows, productive intervals are confined to zones of fractured mudstone-like clays. The development of the wells was carried out according to standard methods by reducing the density of the fluid that fills the well by replacing it with water, followed by aeration. Only single wells were developed without additional stimulation of inflow using oil-acid reservoirs and hydrochloric acid treatment of the productive formation. The remaining wells required double and triple formation treatment. In a number of wells drilled in the study area, after repeated treatment of the reservoir, the inflows were not obtained due to the fact that these wells are located

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in compacted clay zones that do not have fracture zones, as well as due to the deep penetration of drilling fluid filtrate during drilling in areas with a higher degree of fracture. However, it should be noted that the hydraulic fracturing carried out in the well not only did not give the desired result, but the flow rate obtained before it was carried out, significantly decreased. Probably, from the impact of water, the clay rocks of the productive formation swelled up, which led to the closure of existing cracks, and after conducting multiple oil-acid treatments of the formation, a positive result was obtained in increasing the productivity of the well. Of the 140 wells tested in the Khadum-Batalpashnskaya deposits, only 48 had industrial oil flows. The main part of the wells that gave a positive result was developed after repeated acid treatments of the reservoir; therefore, wells that were not subjected to intensification cannot be assessed as unproductive. Since a very complex mosaic-located reservoir in the Khadum and Batalpashinskoe formations is installed within the field, and the results of testing wells that were not subjected to intensification cannot be unambiguously estimated, the boundaries of their distribution carried out from the test results of drilled wells require further clarification.

The effect of drilling fluid filtrate at the drilling in on the permeability of productive formations is analyzed. A particularly significant decrease in well productivity occurs with a large radius of penetration of drilling fluid filtrate. For the conditions of primary dissection of productive fractured formations, the size of the filtrate penetration zone is determined according to the equation [5]

$$f(r/r_0)=\frac{4kt\Delta P}{m\mu r_0^2}, \qquad (2)$$

where $f(x)=x^2(\ln x^2-1)+1;\quad x=(r/r_0)$; r – fluid permeate penetration radius, m; r_0 – well radius, m; k – bedding permeability, μm ^{2} (the permeability of fractured reservoir rocks of the Batalpashinskoe and Khadumskoe suite has been determined based on the processing of indicator diagrams and bottom hole pressure recovery curves recorded during hydrodynamic studies of wells and assumed to be 0.01 μm^2); t – total time passed after opening of this interval, h; ΔP – overbalance, MPa; m – reservoir porosity, fr. unit (adopted on the basis of laboratory studies of the core equal to 0.17); μ – drilling fluid viscosity, mPa · s.

The total time is calculated by the equation

$$t=t_{\text{total}}-\frac{h-h_0}{V}, \qquad (3)$$

where t_{total} – total time of pay drilling, h; h – depth of the current face, m; h_0 – depth of the roof, m; V – mechanical drilling speed of this interval, m/h.

Repression is determined by the equation

$$\Delta P=\rho gh-P_0-(P_1-P_0)\frac{h-h_0}{h_1-h_0}, \qquad (4)$$

where ρ – drilling fluid density, kg/m^3 (the interval of the Batalpashinsky and Khadum deposits was opened by drilling with a density of 1500 kg/m^3); g – acceleration of gravity, g = 9.8 m/s^2; P_0 – formation pressure in the roof of the seam, MPa; P_1 – formation pressure at the bottom of the seam, MPa; h_1 – depth of the reservoir floor, m.

The calculations show that at the drilling in of the Batalpashinskaya and Khadumskaya suite the mud filtrate penetrates into the reservoir at a distance of about 7 m. The size of the zone of contamination of the bottom hole zone is confirmed by the LP data. The non-illuvial thickness of the Batalpashinsky reservoir, which is 4–8 m, is rather clearly distinguished by an eight-meter gradient probe.

Analysis of the results of drilling and testing of a number of wells drilled in this area shows that the main reason for non-production of oil are unsuccessful results of drilling in the productive strata located near the wells where previously an open flow was obtained during drilling with active oil and gas inflow.

Conclusion. An analysis of the above data allows us to conclude that if objects located above the Batalpashinskaya BM are attached to the Batalpashinsky oil interval, we get false or negative testing results.

If the drilling in of unconventional fractured clay reservoirs of thin and frequent alternation in the Khadum-Batalpashinskaya deposits is performed on depression or equilibrium, then an objective picture of oil-saturated and water-saturated interlayers in the cross-section can be obtained.

The main source of water inflow is the bottom and marginal waters, which are part of the sedimentation basin of the East Stavropol Depression. There is reason to assume that in wells located inside the oil-bearing contour, the source of water inflow is the overlying thermal aquifer [7].

It has been established that the state of the hydrodynamic system of the field depends on the introduction of the bottom and marginal formation waters. Oil deposits in the Khadum and Batalpashinskaya formations initially work in an elastic and then in an elastic water-pressure mode.

Thus, the main reasons for the non-flow of fluids are:

• low poroperm properties of clay fractured reservoir rocks;

• colmatation of the fracture capacity of reservoir rocks during drilling in as a result of penetration of drilling mud and its filtrate deep into the reservoir;

• testing of the Batalpashinsky horizon together with the overlying aquifer with abnormally high reservoir pressure (in connection with which the inflow of produced water is obtained);

• closure of cracks in the clay reservoir due to a sharp decrease in pressure caused by the lowering of the slotted filter into the well;

• secondary drilling of productive layers by perforation during repression on the formation in a liquid medium with the presence of a solid phase and high density.

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