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Drilling challenges and technological solutions in the development of oil deposits in fractured carbonate reservoirs

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ABSTRACT

Introduction. Currently, carbonate reservoirs play an increasingly significant role in the global hydrocarbon balance. Most of the deposits discovered in recent years are fractured carbonate reservoirs. The potential for effective development of carbonate reservoirs lies in the development and application of new high-tech methods and advanced well drilling technologies. The article highlights the challenges of developing productive deposits in the Paleozoic basement of Tomsk region deposits represented by fractured carbonate reservoirs. The article considers the mining and geological conditions of carbonate reservoirs in the Paleozoic basement and the challenges that arise when using traditional drilling technologies. The article presents the results of an analytical review on the application of advanced technologies for drilling wells with horizontal completion. Some aspects of the application of nano drilling fluids for conditions of low-permeability carbonate reservoirs are highlighted. The content of the article is based on the author's research and analysis of publicly available literature. **Methods and materials.** The work is based on the generalization, systematization and analysis of factual material, scientific publications, and results of analytical studies. **Results.** Based on the generalization and analysis of geological and field data, the authors established that in the conditions of the identified group of fields, when developing fractured carbonate reservoirs, the productivity of a well depends on the number of natural cracks opened during drilling that penetrate carbonate rocks. Fault tectonics had a major impact on the development of highly fractured zones of carbonate reservoirs, which are the main reason for frequent absorption of drilling fluid when drilling wells with a horizontal end. Clustering of the well stock of the development object in carbonate reservoirs allowed to identify 3 groups of wells, opening up deposits with different filtration-capacity characteristics. It was established that the nature of the distribution of porosity and permeability depends on the development of reservoir fracturing associated with the position of tectonic faults. Analytical studies in the perimeter of Russian oil and gas companies have shown that the efficiency of well drilling technologies in fractured carbonate reservoirs is achieved through an integrated approach: detailing the geological structure of the target object, adapted drilling technology with the ability to regulate differential pressure in the well-formation system, as well as selecting optimal drilling fluids.

KEY WORDS: carbonates, fracturing, reservoir, deposit, field, productivity, drilling technology, pressure drop, nano particles, nano drilling fluids.

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INTRODUCTION

Today, the prospects for the development of Russia's resource base are closely linked to the active involvement of hydrocarbon deposits in carbonate reservoirs in the development. Carbonate reservoirs are characterized by the complexity of the structure of the void space, the ambiguous distribution of the properties of the natural fracturing of the reservoir (fracture orientation, intensity of mass exchange with the matrix), and complex mechanisms of hydrodynamic interaction with the system of tectonic faults. Uncertainties associated with the insufficient degree of study of carbonate reservoirs have a significant impact on the efficiency of their primary opening and subsequent development [4, 5].

As the experience of oil workers shows, the use of traditional well drilling technologies in such conditions is accompanied by a number of complications. When drilling wells with a horizontal end, cases of large volume absorption of process fluid in zones of high fracturing of reservoir rocks are common, which negatively affects the characteristics of the wells laid down in the project.

Geological structure and challenges for development of fractured carbonate reservoirs of the Paleozoic basement. The oil and gas potential of the Paleozoic basement of the West Siberian oil and gas province is confirmed by a number of small fields discovered in the Tomsk region [2,7]. The target horizons are confined to carbonate and clay-carbonate deposits of the Upper Devonian and Lower Carboniferous. Productive strata are represented by dense compact limestones of the cavernous-porous and fractured types. Two layers are distinguished in the structure of the deposits: M – weathering crust and M1 – carbonate platform. Figure 1 shows an example of the structure of a deposit in carbonate deposits of the Paleozoic basement.

Horizon M1 is represented mainly by limestones of the Gerasimov suite: organogenic, amphiporic, massive, fractured. Bauxite-like siliceous rocks of the weathering crust (horizon M) do not occur everywhere on these deposits [3].

The influence of active fault tectonics in the early Mesozoic and post-Jurassic periods can be traced at the research site: a sublatitudinal fault divides the deposit into two blocks (Figure 2); a large influence of natural fracturing and secondary porosity, expressed in high lateral heterogeneity of the reservoir properties in adjacent wells.

The identification and tracing of fault surfaces (Figure 3) was carried out using:

1) visual assessment – identification in the wave field based on signs of shifting phase axes, loss of correlation, and also based on changes in the pattern of the seismic record;

2) analysis of maps on the reflecting horizon M1 on cubes of seismic attributes related to the regularity of the wave pattern (coherence and covariance). High-amplitude faults are distinguished quite clearly, the position and distribution of faults with lower amplitude inside the blocks requires attribute analysis.

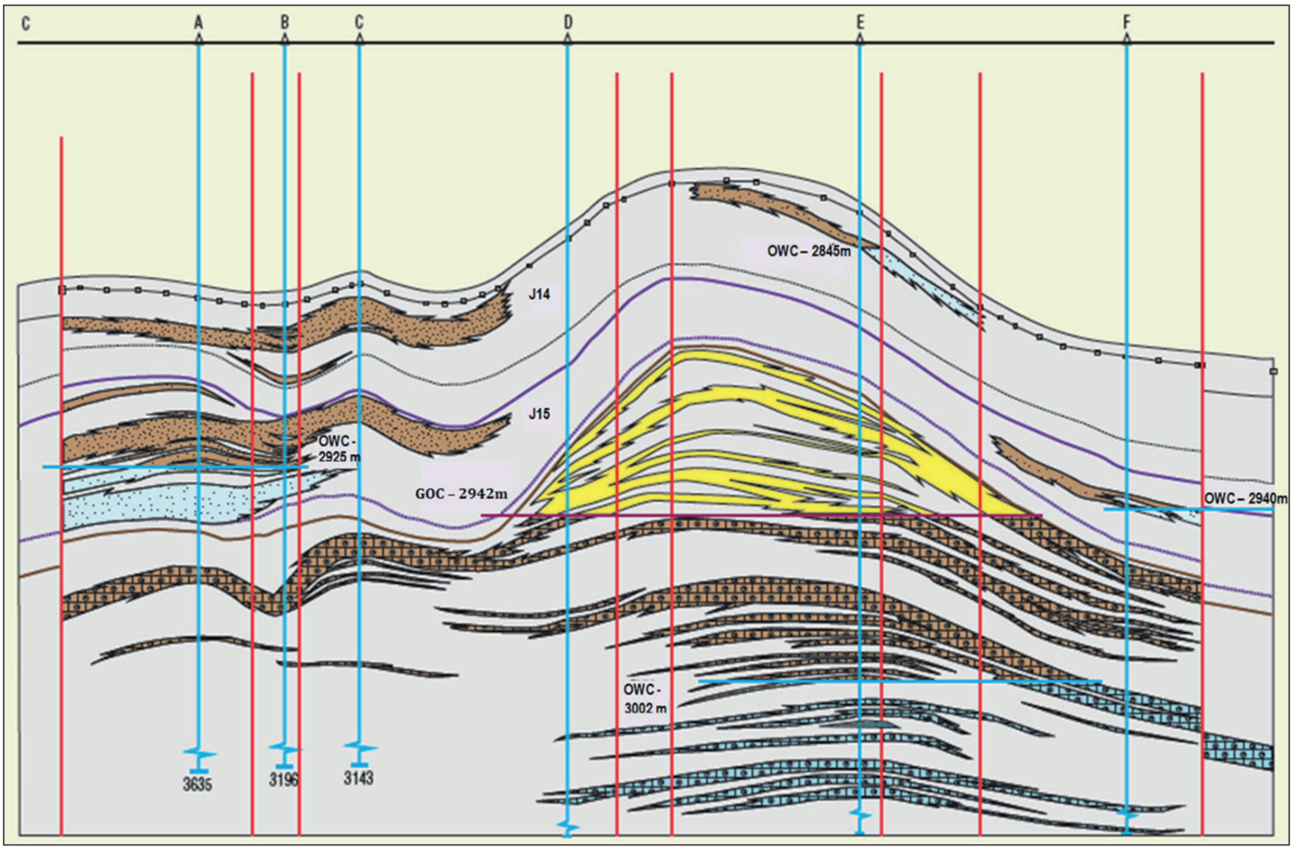

Fig. 1. **Geological section of the N deposit**

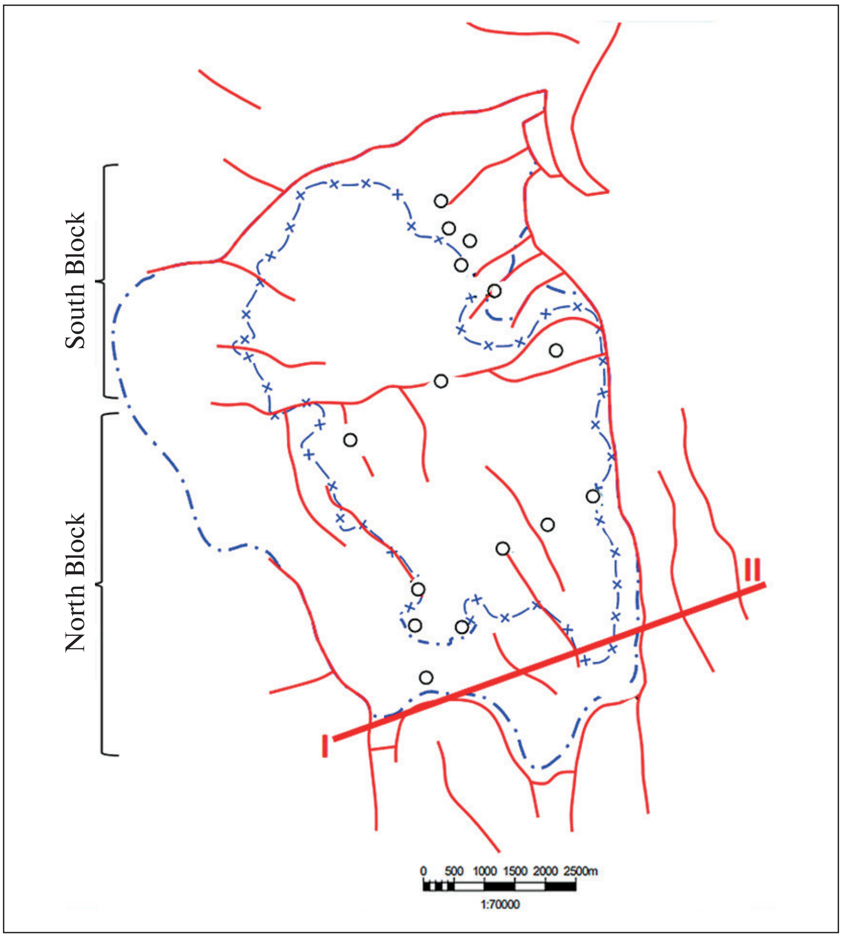

Fig. 2. **Scheme of tectonic disturbances of the deposit in carbonate reservoirs of the M1 formation**

The reservoir rocks of the N field are hydrophobic, therefore, at high water saturation, water will "move" along the crack system and will not penetrate into the matrix. The process of drainage of the matrix block will occur when the external pressure difference exceeds the capillary pressure (Figure 4). Establishing the critical size of the matrix block, i.e. the minimum size at which gas or water will "bypass" the block and oil will remain inside this block, plays a significant role. The calculations performed indicate the impossibility of gravity drainage of oil by water. The values of the height of the matrix blocks vary in the range from 0.01 to 5 m [3].

One of the difficult tasks in this group of fields is the division of fractured reservoirs into lithotypes. Prediction of filtration-capacitive properties based on the results of inversion is physically impossible due to the low quality of material processing (high background of multiple waves, high proportion of noise component).

Based on the application of the methodology of geological and geophysical data integration, creation of DFN models, attribute analysis of seismic exploration results for the N field, a conceptual model of reservoir properties was created, reflecting a high degree of difference in the properties of the matrix and fractures (the difference in permeability and fractures from 1 to 3 orders of magnitude), which allows for a more accurate description of fluid displacement. The fault model of the site was detailed, taking into account screening faults, and a model of dual porosity and permeability of the M1 formation was built [3, 5].

The authors have classified the well stock of the N field using cluster analysis, on the basis of which 3 groups of wells were identified, penetrating deposits with different filtration-capacity characteristics. As a result of clustering, it was established that the nature of the distribution of porosity and permeability depends on the development of fracturing of reservoirs associated with the position of tectonic faults.

The wells of the first group open undisturbed blocks of organogenic-detrital pelitomorphic limestones. Based on the comparison of the group with the results of classification according to the method of R.A. Nelson [6], this group falls into the areas of type 1 and 2 of the collector, the main void space of which is determined by fracturing.

The second group is confined to the areas of development of tectonic disturbances and is represented by

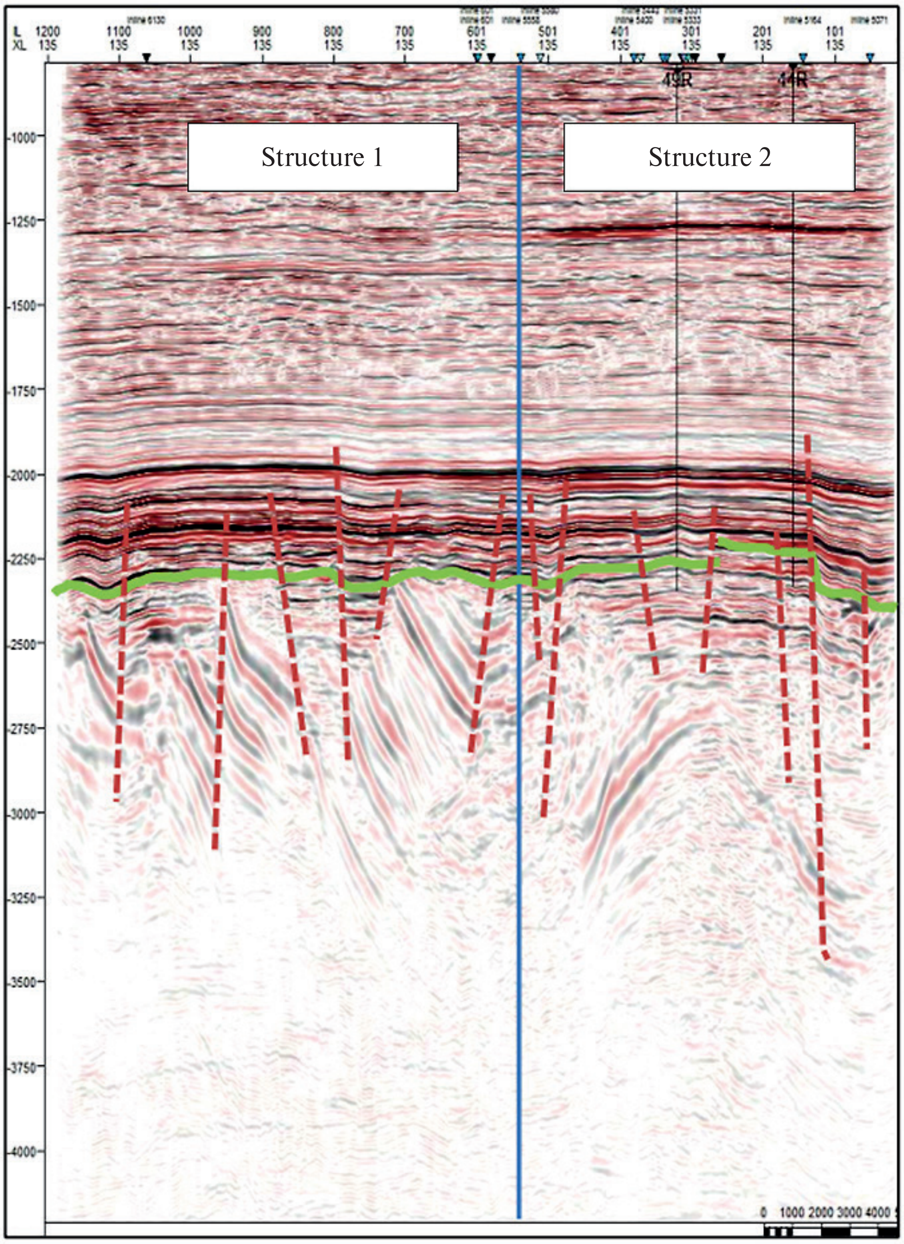

Fig. 3. **Seismic cube after specialized processing**

fractured varieties of organogenic-detrital limestones. According to Nelson's classification, this group corresponds mainly to type 3 and partially to type 4 collectors, the filtration of fluid of which occurs through pore channels.

The third group is also characterized by the development of fractured reservoirs, the fractures themselves being predominantly filled with calcite. For this group of wells, mainly 4, as well as 2 and 3 types of reservoirs are distinguished according to Nelson's classification. Thus, this group is characterized by the most complex structure of the void space, formed by both fractured and sediment matrix.

Based on the generalization and analysis of geological and production data, the authors have established that in the conditions of the analyzed group of deposits, during the development of fractured carbonate reservoirs, the number of natural cracks opened by drilling is closely related to productivity.

In the process of studying the deposits of the N field by the traditional drilling method, a certain number of problems were identified:

- high mud losses caused by extensive reservoir fracturing;
- cavings and well walls collapses; - presence of sticking hazardous zones;

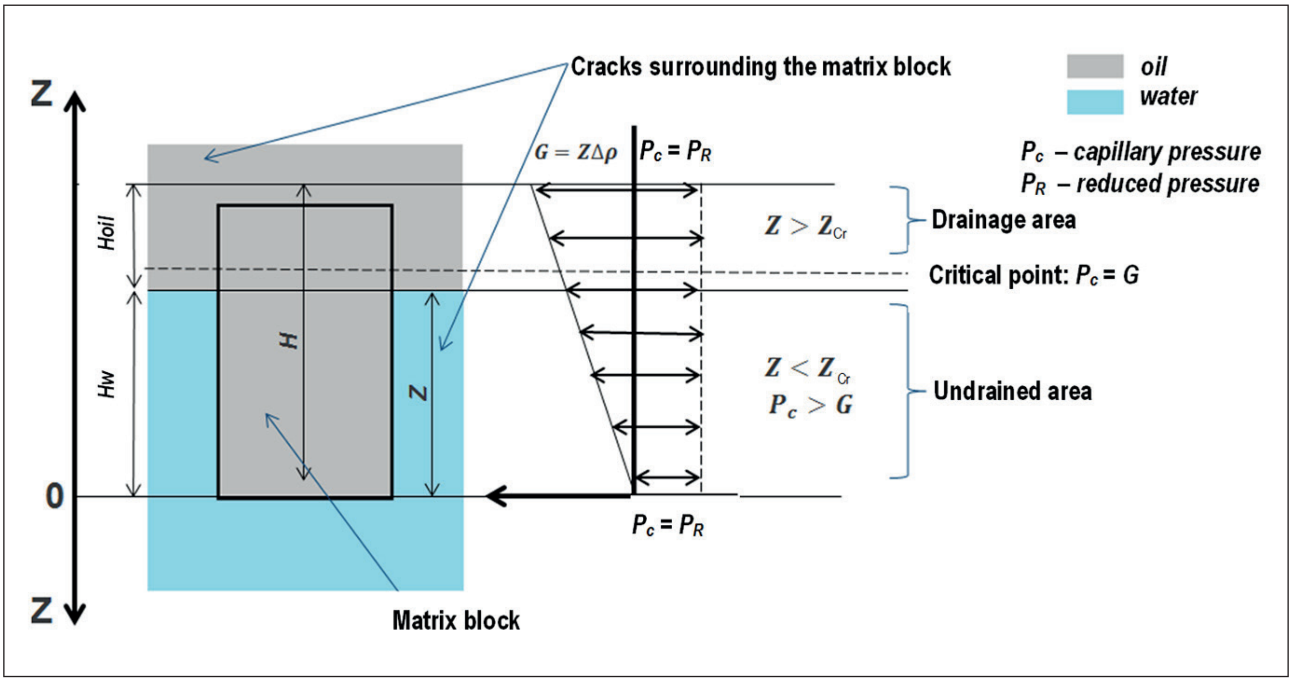

Fig. 4. **Gravity drainage scheme in the matrix block**

– low rates of penetration per bit and mechanical drilling speed due to increased oppressive pressure on the well bottom [8-10]. The unsuccessful experience in developing carbonates was subsequently studied in detail and taken into account when drilling a neighboring field with similar conditions, which made it possible to avoid many errors and complications [3].

Advanced well drilling technologies for the development of oil deposits in carbonate reservoirs.

As experience with traditional well drilling has shown, the main reason for frequent absorption of drilling fluid is a developed fault system and the associated high fracturing of the reservoir. The flow of drilling fluid into the reservoir cracks occurs due to the large pressure difference in the well and in the formation. The volumes of drilling fluid absorption are so large that further drilling becomes impossible (loss of signal from geosteering equipment, strong heating of the bit). Under these conditions, it is possible to open only 1–2 reservoir cracks. In addition, the high speed of fluid movement along the system of cracks inside the formation created the risk of water breakthroughs to the wells. This fact was taken into account by specialists of PJSC Gazprom Neft when developing similar objects in carbonate reservoirs [1, 3].

In recent years, the company has made significant progress in the development of fractured carbonate reservoirs of the Urmano-Archinskaya group of fields. High drilling efficiency is achieved through an integrated approach: detailing the geological structure of the target object, using advanced drilling technologies with the ability to regulate differential pressure in the well-formation system, as well as selecting optimal drilling solutions.

In zones of intense fracturing, corresponding mainly to areas of tectonic fault locations (example in Fig. 2), the main goal is to open the maximum number of fractures intersecting the formation. This task is difficult to accomplish when drilling directional wells. One of the main problems with directional drilling with design parameters that take into account the optimal angle of entry into the target productive formation (on average 10–15°) is the poorly predictable probability of opening several formation intervals with increased fracture permeability at once. Therefore, the most optimal drilling option was adopted for the carbonate reservoirs of the Paleozoic complex. First of all, they began to drill mainly wells with horizontal endings, which allowed to significantly increase productivity due to the opening of a larger number of cracks in the formation [13]. This technology made it possible to enter the upper intervals of the formation, covered by weathering crust rocks at an angle of 60–70°, with subsequent drilling on a casing column on a tail pipe with a natural drop in angle at full reservoir capacity [23].

The technology of drilling on a liner and casing string has been known to mining companies for many years. Due to its advantages over traditional drilling (reduced drilling time and elimination of complications), it is widely known and is considered a progressive method of well drilling. Prevention of complications in the wellbore is achieved by simultaneous drilling and casing of the wellbore with casing pipes directly during the drilling process. As experience in drilling in carbonates has shown, the length of an open hole with a liner diameter of 127 mm averaged 260 m, while the number of absorptions and other complications was reduced, which affected the average duration of well drilling (up to 20 days per well, with traditional drilling – 35 days) [23].

The advantage of casing drilling technology is the possibility of continuing drilling below the liner in the event of tool sticking [23].

As a review of sources in the open press has shown, the Company has gained successful experience in drilling horizontal wells using the Underbalanced Drilling (UBD) technology [13–18]. A schematic description of the UBD technology is shown in Figure 5. This technology is based on the principle of creating a negative pressure differential, in which the reservoir pressure exceeds the pressure of the liquid column in the wellbore. Under these conditions, the filtrate or killing fluid from the drilling mud does not enter the formation and does not worsen the filtration and capacity characteristics of the formation [12, 14, 15]. This approach eliminates most of

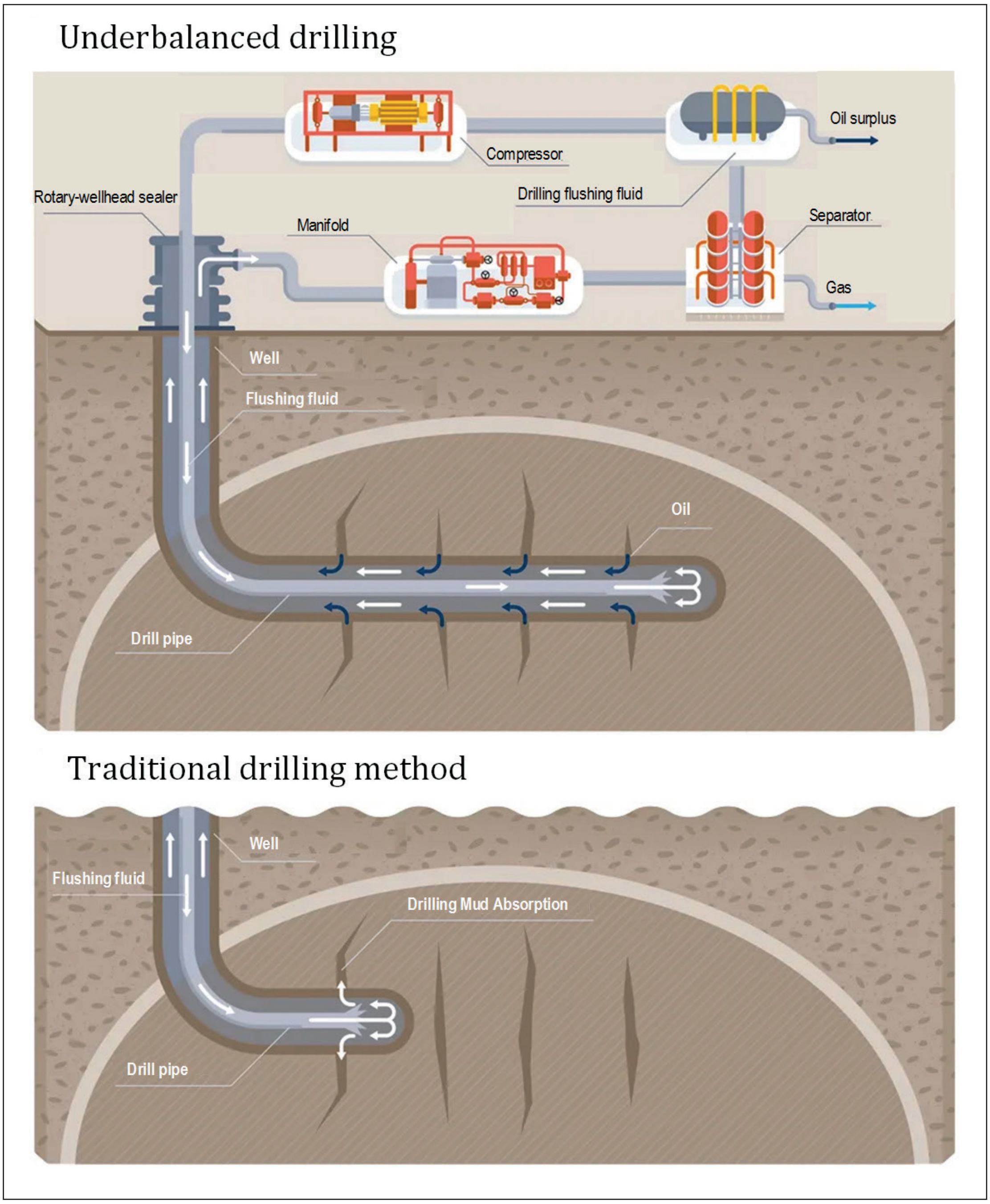

Fig. 5. **Schematic description of Underbalanced Drilling technology [13,14]**

the problems associated with traditional drilling, mainly due to the ability to regulate a given differential pressure in the well-formation system [16, 17, 20].

The main advantage of this solution is the ability to open a greater number of oil-producing cracks than with traditional methods of drilling wells with horizontal tailing-in.

Selection of drilling fluids for primary drilling of low-permeability carbonate reservoirs.

It is known that during the drilling process, finely dispersed phases of various components of terrigenous deposits penetrate into the pores of the formation along with the filtrate of the drilling mud, creating colmatation screens inside the reservoir and a filter cake on the walls of the well, which helps to reduce the permeability of the bottomhole zone of the formation.

The use of nanoparticles as an additive prevents the penetration of solid particles into the formation and promotes high-quality opening of a low-permeability reservoir.

Some advantages of using nano-drilling fluids:
— reduced friction of drill pipes against the borehole walls;
— reduced filtration losses of drilling fluid;
— improved conditions for cuttings removal;
— strengthening of borehole walls when passing through weakly cemented rocks;
— changing in the wettability of rocks and reducing likelihood of equipment corrosion.

In the work [21] it was shown that the addition of nanoparticles of silicon, aluminum, and titanium oxides to the drilling fluid leads to a significant improvement in the transport of cuttings. The concentration of particles in the solutions varied from 0.25 to 4 wt.%, and their size from 5 to 190 nm. It was found that with a decrease in the size of the nanoparticles and an increase in the wellbore inclination angle, the positive effect of the additive increases (Figure 6).

In the work [22] it is shown that even small additions of nanoparticles significantly improve the rheological characteristics of drilling fluids, and the effect of the additive depends not only on the concentration, but also on the size and material of the nanoparticles. At the same time, the addition of nanoparticles changes not only the viscous, but also the elastic properties of drilling fluids and makes these characteristics more stable depending on the temperature.

In relation to the mining and geological conditions of the occurrence of oil-productive strata of the fields of the Tomsk region with pronounced fracturing of the reservoirs, Gazprom Neft uses water-based drilling fluids that have the ability to lose rheological properties in a static position. One of these systems causes a screening effect due to an increase in the viscosity of the liquid at low shear rates, preventing the destruction of the wellbore walls in unstable formations.

DISCUSSIONS

Development of fractured and carbonate reservoirs is associated with a number of difficulties. Fractured reservoirs are highly heterogeneous, which complicates forecasting and management of development. The nature and density of fractures, their relationship with the pore space, as well as the properties of the host rocks have a strong influence on the filtration and capacity properties. Car-

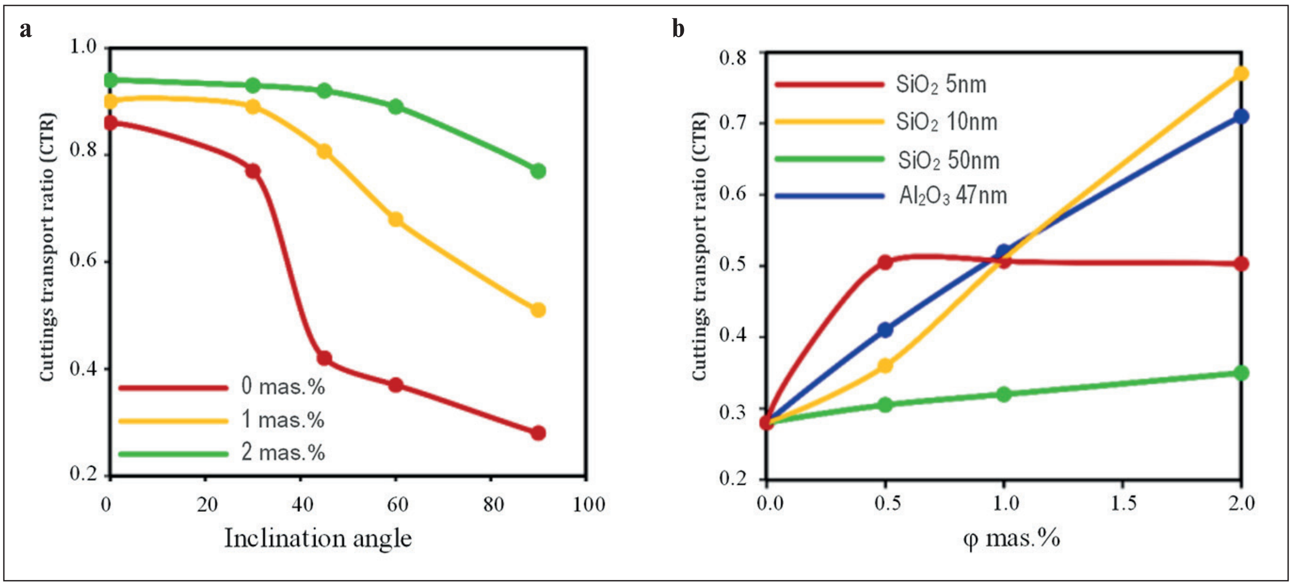

Fig. 6. **Dependence of the efficiency coefficient of sludge removal on:** a) the well inclination angle for different concentrations of nanoparticles; b) the concentration of nanoparticles of different materials and sizes [22]

bonate reservoirs are also characterized by a complex structure and heterogeneity. Complex rock textures, the presence of caverns, caves, internal and external permeability barriers make forecasting the filtration regime difficult. Unpredictability of fluid behavior in such reservoirs leads to ineffective drainage, and forecasting reserves and calculating reserves is difficult.

The prerequisites for the absorption of drilling fluid during drilling of wells of the Urmano-Archinskaya group were too high density of drilling fluid (1.06 g/cm^3) in combination with poor quality of wellbore cleaning. In this regard, the characteristics (minimum density) of the used drilling fluid were revised taking into account the real "drilling window" – the pressure range between the pore pressure and the formation hydraulic fracturing pressure, the absorption onset pressure and the collapse pressure were identified, which made it possible to draw a conclusion about the real drilling window. Ultimately, optimal approaches were developed within the drilling strategy.

Firstly, at the stage of drilling carbonate deposits of the Paleozoic basement with pronounced fracturing and cavernous reservoirs, a new drilling scheme and well completion technology were implemented [18].

Secondly, the technology of well underbalanced drilling (UBD technology) was successfully tested.

Thirdly, research is underway to select technologies for high-quality concealment of low-permeability carbonates and preservation of their primary filtration-capacitive properties.

CONCLUSION

Based on the generalization and analysis of geological and field data, the authors established that in the conditions of the identified group of fields, when developing fractured carbonate reservoirs, the productivity of a well depends on the number of natural cracks opened during drilling that penetrate carbonate rocks. Fracture tectonics had a major impact on the development of highly fractured zones of carbonate reservoirs, which are the main reason for frequent absorption of drilling fluid when drilling wells with horizontal tailing-in.

Clustering of the well stock of the development object in carbonate reservoirs allowed to identify 3 groups of wells, opening up deposits with different filtration-capacity characteristics. It was established that the nature of the distribution of porosity and permeability depends on the development of reservoir fracturing associated with the position of tectonic faults.

Analytical studies in the perimeter of Russian oil and gas companies have shown that the efficiency of well drilling technologies in fractured carbonate reservoirs is achieved through an integrated approach: detailing the geological structure of the target object, adapted drilling technology with the ability to regulate differential pressure in the well-formation system, as well as selecting optimal drilling fluids. Due to their high specific surface area and size, nanomaterials help improve the filtration and rheological properties of the drilling fluid.

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CONTRIBUTION OF THE AUTHORS

A.V. Melnikov – formation of the concept of scientific research, formulation of scientific conclusions.

Sh.Kh. Sultanov – formation of the concept of scientific research, final approval of the version for publication.

A.A. Makhmutov – formation of the concept of scientific research and summing up.

A.V. Chibisov – analytical research, preparation of scientific publication.

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