Reasons for the low productivity of the Bashkirian stage oil deposits on the southwestern slope of the South Tatar arch

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Abstract. Oil deposits of the Bashkirian stage of low-amplitude uplifts on the southwestern slope of the South Tatar arch are considered. It has been established that in the sections of the Bashkirian stage, only the upper two oil deposits are potentially productive. The reservoir rocks are composed of leached packstone-grainstone. The oil productivity of the upper oil reservoir is determined by the intensity of leaching of carbonate rocks and the nature of oil saturation, while the lower one is determined by the degree of oxidation of oils and the manifestation of secondary mineralization. Oxidation of oil from the lower reservoir oil deposit is associated with the penetration of peripheral stratal water enriched with sulphate ions and magnesium ions. Deposition of diagenetic calcite, dolomite and gypsum-anhydrite aggregates in previously formed leaching caverns leads to a decrease in porosity and connectivity within reservoir layers. For low-amplitude uplifts, there is a tendency for oil productivity to decrease as the proportion of diagenetic mineralization increases.

1 Introduction

The deposits of the Bashkirian stage within the South Tatar arch are among the most promising in terms of oil production. However, unlike other industrial oil and gas bearing carbonate strata of the Paleozoic, they are less accessible for development due to the high lithological and facial variability of the rocks, the complex structure of oil deposits, and the varying intensity of superimposed processes of fluid lithogenesis [1-6]. At present, the oil-bearing sections of the Bashkirian stage on the western slope and in the dome part of the South Tatar arch, where the most well-recovered oil reserves are concentrated, are relatively well studied. Geological exploration drilling in other areas of the structure yielded more modest results in oil production. Recently, oil companies have focused on the southwestern slope of the arch, where numerous small-sized dome uplifts have been identified [7]. Some of them are oil-producing, while others, despite the presence of oil intervals in core, do not produce oil inflows. The reasons for this differentiation of uplifts are not fully understood. The study of cores from wells that passed through a low-

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productive oil deposit on one of the small-sized dome uplifts made it possible to some extent to clarify the issue of low oil recovery from reservoir rocks of the Bashkirian stage.

2 Methods

The research methodology consisted of a detailed description of cores from wells that passed through the oil-bearing intervals of the Bashkirian stage. During the description, special attention was paid to identifying cap rocks and reservoir rocks, the nature of oil saturation of rocks, and the presence of secondary diagenetic mineralization. Samples were taken from various zones of oil deposits for laboratory research. The work uses the structural-genetic classification of carbonate rocks R.J. Dunham [8]. The main research method was optical microscopic analysis, which made it possible to determine the mineral composition of rocks, their structural and textural features and the sequence of post-sedimentation transformations. The studies were carried out using a polarizing optical microscope Axio Imager A2 made in Germany. An X-ray diffractometer Bruker D2 Phaser (Germany) was used as an auxiliary method. Interpretation of X-ray diffraction patterns in order to obtain information about the qualitative and semi-quantitative composition of rocks was carried out using the DIFFRAC EVA and TOPAS software.

3 Research results

The results of studies of core material showed that within the southwestern slope of the South Tatar arch, promising oil deposits for development are confined only to the tops of the Bashkirian stage sections. In the lower and middle parts of the sections, all oil deposits were destroyed as a result of the penetration of peripheral groundwater into the reservoir rocks. Analysis of core material showed a heterogeneous structure of oil deposits along the wells section, where dense cap-rocks alternate with decompacted oil-saturated limestones. Within the low-amplitude uplifts of the Bashkirian stage, the two upper oil-bearing intervals are potentially productive (Figure 1). However, they cannot always provide acceptable oil inflows. This is due to both the different intensity of leaching of reservoir rocks and the natural flooding of oil reservoirs with groundwater.

In the contours of most low-amplitude uplifts, the upper reservoir is characterized by uneven oil saturation. Uniformly oil-saturated limestone layers alternate with spotty-banded intervals. The productivity of a deposit is determined by the ratio in the section of decompacted and relatively dense layers. The lower reservoir is characterized by more uniform oil saturation. The productive interval has a thickness of 2.5 to 4.0 m. The oil reservoir within the studied low-amplitude uplifts has undergone natural flooding processes of varying intensity, which determines their oil productivity.

The reservoir rocks in both oil deposits are packstone-grainstones. Limestones are 80-85% composed of organic residues, 15-20% - cementing mineral matter (Fig.2). Organic remains 0.1-0.5 mm in size, dominated by 0.1-0.25 mm, of medium degree of preservation, represented by fragments of algae in the form of peloid-lumpy microgranular aggregates (70%), whole foraminifera shells (30%), rare valves of brachiopods and segments of crinoids. The shaped elements are densely located in the volume of the rock, their edges touch each other, which indicates the active hydrodynamics of the aquatic environment. Organic remains are cemented with calcite cement. There are two generations of cement: syngenetic and epigenetic. Syngenetic cement of the pore type, microgranular in structure, partially leached from the intergranular space, is noted in the form of rims along the periphery of organic residues. Epigenetic cement is distributed unevenly, crustification, pore and clot-nest-like type. Crustification cement forms rims around organic residues, is

 https://doi.org/10.1051/e3sconf/202449803010

composed of calcite scalenohedrons, pore cement forms single monograins filling previously formed leaching pores, clot-nest-like cement forms aggregates up to 2.0 mm in size, composed of fine-grained calcite. Among the diagenetic minerals, rare pyrite aggregates about 0.05 mm in size are noted, metasomatically developing on calcite cement. Limestone contains 10-15% pores. Leaching pores are formed due to the leaching of organic residues and calcite cement, communicating, forming winding intersecting channels up to 0.1 mm in size, filled with oil.

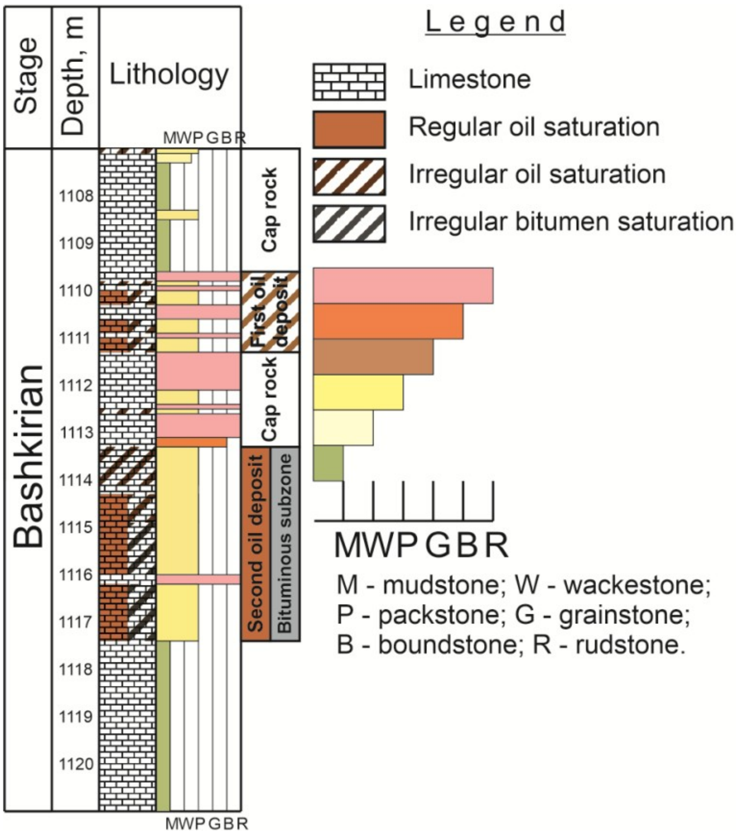

Fig. 1. Structure of the Bashkirian stage oil-bearing low-amplitude uplifts.

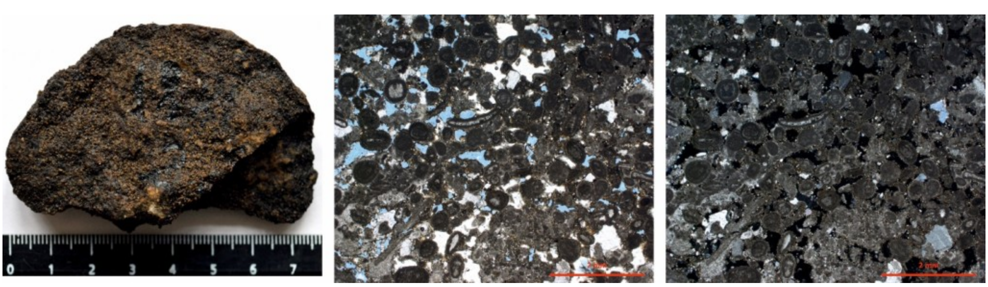

Fig. 2. Photo of sample and thin section (NL/PL) of oil-bearing packstone-grainstone.

Cap-rocks, which are dense bridges between oil deposits, are represented by mudstone that has undergone weak ferruginization. Due to scattered inclusions of goethitehydrogoethite clots, the rocks acquired a brownish tint. The limestones are composed predominantly of pelitomorphic and microgranular calcite aggregate, which contain rare inclusions of organic remains of algae, ostracods and calcispheres. Aggregates of iron hydroxides are localized in the intergranular space of rocks. Limestones are cut by suturostylolite sutures, the cavities of which are filled with greenish-gray clayey material. Extended subvertical karst cracks are made with similar material. Based on a combination of characteristics, mudstones were formed in stagnant conditions of salinizing lagoons, where the vital activity of benthic communities was suppressed. The most unpretentious marine organisms survived. Weak ferruginization and the presence of karst manifestations indicate that the limestones emerged from below the level of the Bashkirian paleosea, being exposed to the processes of hypergenesis [9]. Despite this, carbonate cap rocks are characterized by very low porosity (2-3%). The pores are intergranular, subcapillary in size.

According to optical microscopic and X-ray studies, reservoir rocks of oil deposits contain various diagenetic minerals. The most common are aggregates of newly formed calcite. Most of them fill previously formed cavities of leaching caverns; isolated nest-like aggregates up to 2.5 mm in size are less common. Grains and aggregates of pyrite are also common, metasomatically replacing structural elements of limestones. Some of the pyrite aggregates develop on organic remains, and some on clear-grained calcite cement. Sulfate and dolomite diagenetic mineralization is less developed. Sulfate minerals form large (up to 5.0 cm) bluish-gray aggregates composed of short-prismatic or columnar grains of anhydrite and gypsum. They fill both the cavities of intergranular leaching cavities and metasomatically replace organic residues. Dolomite occurs in the form of single rhombohedral grains and relatively small aggregates developing along the walls of pore and caverns or on microgranular calcite cement. Diagenetic minerals, as a rule, worsen the capacitance-filtration characteristics of reservoir rocks by complicating the structure of the void space and narrowing the filtration channels.

4 Discussion

The obtained results show that the oil-bearing capacity of low-amplitude uplifts of the Bashkirian stage on the southwestern slope of the South Tatar arch is determined by both sedimentation factors and processes of superimposed fluid lithogenesis. During sedimentation in sections of the Bashkirian carbonate complex, eustatic fluctuations of the Bashkirian paleosea created the prerequisites for the formation of reservoir rocks, bounded above and below by layers of dense limestone. Packstones with potentially high reservoir properties accumulated during transgressive development cycles of the marine basin, while mudstones accumulated during regressive cycles, when shallow-water sedimentation conditions prevailed in the coastal zone [10]. The upward migration of water-oil fluids along the most permeable layers of carbonate rocks contributed to the selective dissolution of microgranular calcite cement from packstone-grainstones [11-12]. Mudstones, which initially had subcapillary porosity, turned out to be more resistant to aggressive fluids, subsequently becoming fluid-resistant rocks. The directional movement of fluids from bottom to top contributed to the formation of reservoir rocks with different petrophysical properties within low-amplitude uplifts. Packstone-grainstones in the lower and middle parts of the sections, exposed to more acidic fluids, acquired relatively high porosity and permeability. Less acidic fluids have reached the carbonate rocks of the upper parts of the sections with potential good reservoir properties. As a result, the local packstone-grainstones were subject to relatively little selective leaching. Thus, in the lower and middle parts of the Bashkirian stage sections, reservoir oil deposits with uniform oil saturation were formed, and in the upper parts - with uneven spotty-banded oil saturation. In the latter case, the productivity of an oil reservoir will be determined by the proportion of decompacted, oil-saturated layers of carbonate rocks in the oil-bearing interval.

The location of low-amplitude uplifts on the slope of the South Tatar arch contributed to the gradual penetration of formation waters from closely located troughs into decompacted reservoir rocks. Penetrating into oil deposits, peripheral stratal waters oxidized the oil, which led to an increase in the partial pressure of carbon dioxide in pore solutions. An increase in CO_2 in the system caused increased dissolution of calcite in carbonate rocks and an increase in the content of Ca^{2+} and Mg^{2+} ions in solutions. The latter was probably introduced as part of the edge waters [13]. During cyclic drops of CO_2 in reservoir systems, aggregates of diagenetic calcite and dolomite were precipitated from pore solutions, filling the space of pore caverns [14]. Calcitization occurred in several stages. The first generation of diagenetic calcites is represented by fine-grained aggregate intergrowths developing after organic remains and primary microgranular calcite cement. The second generation of calcite developed in the cavities of large pore caverns. The opportunities for free growth contributed to the formation of large calcite grains with habit elements. The appearance of calcite grains with polysynthetic twinning in the samples may indicate non-stationary conditions in pore solutions due to variations in acidity-alkalinity. The relationship between diagenetic calcitization and oil oxidation processes is emphasized by the presence of dark brown inclusions of heavy hydrocarbons in fine-medium-grained calcite grains. Oil oxidation was accompanied by the development of sulfate-reducing microbial colonies, the result of which was the development of pyrite aggregates [15-17]. Considering the relatively high content of sulfate aggregates in flooded oil deposits, it can be assumed that the source of sulfur for sulfate reduction was the edge waters enriched with sulfate ions. Penetrating into reservoir rock layers, sulfate ions interacted with active calcium ions and formed nest-like aggregates of anhydrite with an admixture of gypsum [18]. Newly formed minerals significantly worsened the petrophysical properties of reservoir rocks. There is a tendency that the more diagenetic minerals in oil deposits, the less oil recovery from reservoir. The lower potentially productive oil reservoir in the upper part of the Bashkirian stage section is exposed to natural flooding. Thus, despite the relatively large thickness of the second oil-bearing interval from the top, its productivity will depend on the degree of oil oxidation and the intensity of secondary authigenic mineralization.

5 Conclusion

Considering the above, the following conclusions can be drawn:

- Within the sections of low-amplitude uplifts of the Bashkirian stage on the southwestern slope of the South Tatar arch, two reservoir oil deposits in the upper parts of the sections are potentially oil-producing. Reservoir oil deposits in the middle and lower parts of the sections are destroyed due to the penetration of stratal water.
- The productivity of the upper oil-bearing interval is determined by the proportion of packstone-grainstone layers that have undergone leaching. With an increase in the number of uniformly oil-saturated layers and a decrease in the proportion of layers with spotty-banded oil saturation, the productivity of the oil-saturated interval in the top of the Bashkirian stage increases.
- The productivity of the lower oil-bearing interval is determined by the degree of natural flooding due to the penetration of stratal waters into decompacted reservoir rocks. On the one hand, flooding leads to an increase in the proportion of heavy hydrocarbons, on the other hand, to the clogging of the previously formed void pore-cavernous space with diagenetic mineral aggregates.
- The low oil productivity of Bashkirian stage deposits is determined by the following factors: the intensity of leaching of packstones-grainstones, especially in the upper oil-

bearing interval; natural flooding of oil deposits with stratal waters; sediment of diagenetic aggregates of calcite, dolomite and gypsum-anhydrite in the void-cavernous space of reservoir rocks.

Acknowledgement

This work was funded by the subsidy allocated to Kazan Federal University for the state assignment in the sphere of scientific activities, project No. FZSM-2023-0014.

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