Lithological and mineralogical signs of the formation and destruction of the Bashkirian stage oil deposits within the Sokskaya saddle

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Abstract. Oil deposits in sections of the Bashkirian stage of the Sokskaya saddle are considered. It has been established those oil-bearing limestones are represented by leached peloidal-clumpy grainstones. The rocks were formed within the shallow shelf of sedimentation basin of normal salinity. The active hydrodynamics of the aquatic environment predetermined the dense structural packing of organic residues. The migration of aggressive oil-water fluids contributed to leaching of calcite cement from grainstones. Subsequently, the pore-cavernous space was filled with oil. The introduction of edge formation waters into oil-bearing reservoirs contributed to the oxidation of oil and the manifestation of secondary diagenetic mineralization. The initial stage of waterflooding was indicated by dolomitization of reservoir rocks. Due to an increase in the partial pressure of carbon dioxide in the pore space of rocks, calcite is metasomatically replaced by diagenetic dolomite. At this stage of reservoir rock alteration, a relatively small amount of oil is recovered from oil-bearing formations. The introduction of formation waters enriched with sulfate ions into reservoir layers leads to the precipitation of gypsum-anhydrite aggregates in the pore space of oil-bearing limestones. Calcium sulfate minerals clog the pore-capacitive space of reservoir rocks, reducing their productivity. At the stage of precipitation of gypsum-anhydrite aggregates, mainly mineralized brines with an admixture of oil are extracted from reservoir rocks.

1 Introduction

The deposits of the Bashkirian stage on the territory of the Volga-Ural oil and gas province are classified as regionally oil-bearing [1-2]. Therefore, in all oil and gas bearing areas that are part of the province, they are associated with forecasts for the replenishment of oil reserves in the depleting deposits of the Devonian and Lower Carboniferous. Despite the high oil production potential, the Bashkirian stage deposits are a difficult target for development. This is due to both the high lithologic-facial variability of rocks in sections along the strike, and the different intensity of manifestation of superimposed processes of fluid lithogenesis [3-9]. When developing oil deposits of the Bashkirian stage, the processes

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of superimposed lithogenesis significantly complicate the extraction of oil from reservoir rocks, reducing the productivity of the reservoirs. In many oil fields, a trend of decreasing production has been observed with an increasing proportion of authigenic mineral aggregates in reservoir layers. Taking this into account, work was carried out to study the relationship between the productivity of reservoir oil deposits of the Bashkirian stage and superimposed post-sedimentary mineralization. The object of the study was the core material of wells drilled within the Sokskaya saddle. We studied wells located on various domed uplifts, producing different influxes of waterflooded oil.

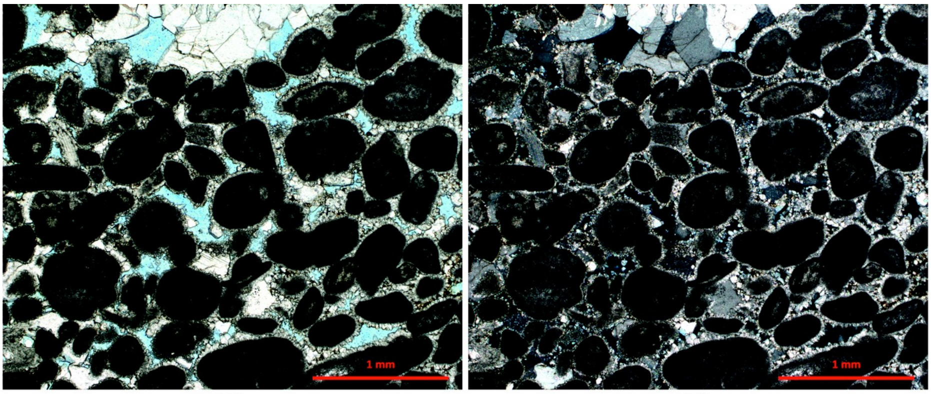
2 Methods

The main research method was optical-microscopic analysis, and the auxiliary method was X-ray analysis. Optical-microscopic analysis was carried out on a polarizing microscope Zeiss AXIO Imager A2. The purpose of the research was to determine the structural components of rocks, assess the pore space, identify secondary minerals and the characteristics of their distribution in oil reservoirs. Microscopic study was carried out on thin-sections about 0.03 mm thick. X-ray diffraction analysis was carried out using a Bruker D2 Phaser diffractometer. DIFFRAC.EVA and TOPAS software were used to decipher the mineral composition and semi-quantitative analysis.

3 Research results

The study of core material showed that within the Sokskaya saddle in the sections of the Bashkirian stage there are 2-3 oil reservoir deposits. The thickness of oil-bearing intervals ranges from 1.2 to 3.5 m. The nature of oil saturation of rocks varies from uniform to spotty-banded depending on the intensity of leaching processes. Oil-bearing layers are separated from each other by dense bridges of carbonate rocks. The cap-rocks are represented by mudstones and wackestones, according to the classification of R.J. Dunham [10]. The limestones are composed of microgranular calcite with rare inclusions of organic remains. The rocks contain thin layers of greenish-gray clayey material, and in some wells, they show traces of supergene influence. The latter are expressed by the presence in limestones of thin films of iron oxides-hydroxides and vertical karst cavities filled with greenish-gray carbonate-clayey material with inclusions of ferruginous brownish calcareous fragments.

Oil-bearing limestone reservoirs are represented by peloidal-lumpy grainstones that have undergone leaching processes. The rocks are characterized by a biomorphic structure, massive or spotted-banded texture. Limestones are 80-85% composed of organic residues, 15-20% - cementing mineral matter (Figure 1). Organic remains with an average size of 0.1-0.25 mm are represented mainly by microgranular spheroidal lumpy aggregates (75%), to a lesser extent oolites and calcispheres (10%), granulated whole foraminiferal shells (10%), brachiopod valves (5%), rare fragments of crinoids. Bioclasts touch their edges to each other, forming a dense structural packing, which indicates the active hydrodynamics of the aquatic environment. Organic remains are cemented with calcite cement. Based on the time of formation, cement is divided into syngenetic and epigenetic. Syngenetic cement is mostly leached from the interparticle space of the rock, fixed in the form of small-thick rims around organic residues, microgranular in structure. Epigenetic cement is predominantly of the pore type, represented by large monograins up to 0.25 mm, filling the previously formed void-cavernous space. In reservoir layers, the porosity of limestones ranges from 10 to 15%. interparticle pores, communicating, form winding channels with a diameter of 0.05-0.15 mm. These are the structural features of reservoirs in oil deposits of the Bashkirian stage within the Sokskaya saddle.



NL PL

Fig. 1. Photo of thin section of peloidal-lumpy limestone with uniform oil saturation in normal and polarized light (NL/PL).

The study of the same reservoir layers of the dome uplifts, which produce highly watered oils, showed the presence of various diagenetic minerals in them. The most common are epigenetic dolomites. Analysis of the spatial occurrence of minerals in oil-saturated limestones and their relationship with the components of the original limestones allows us to establish the stages of formation of dolomite aggregates. The earliest generation of minerals is confined to stylolite sutures (Figure 2). Here the dolomites form dense, light gray vein bodies elongated along the stylolite cavity. The dolomitization process covers part of the original carbonate rocks located directly below the stylolite sutures. Above the stylolites, dolomitization is not observed. Newly formed dolomite aggregates metasomatically completely replace all structural elements of limestones, including cement and organic remains. A later generation of dolomites is recorded in oil-saturated limestone reservoirs. Here, authigenic dolomites form either isolated crystals of rhombohedral habit or nest-like aggregates. Dolomitization develops mainly along micrograined calcite cement of limestones, practically without affecting organic remains. Dolomite grains contain relict inclusions of fragments of the original limestone and clots of oil captured during their growth. This indicates the formation of dolomite mineralization at the stage of oxidation of oil hydrocarbons in reservoir layers.

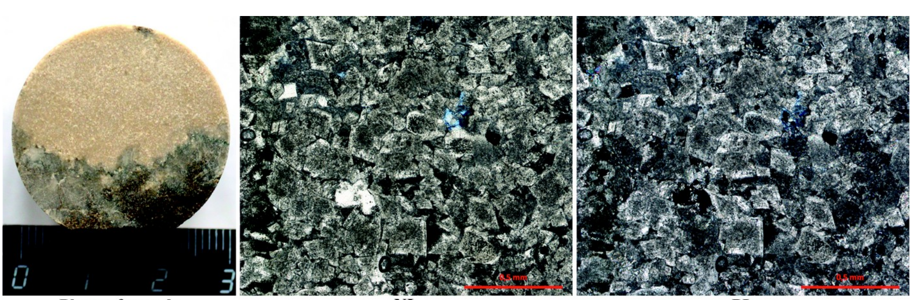


Photo of sample **NL** **PL**

Fig. 2. Photo and thin section (NL/PL) of peloidal-lumpy limestone with veined dolomite aggregates under a stylolite suture.

The next most common manifestation in oil-saturated limestones is sulfate mineralization. It is represented by bluish-gray veined and nest-like anhydrite aggregates with an admixture of gypsum up to 5.0 cm in size. Aggregates of sulfate aggregates in some reservoir layers fill previously formed cavities, in others they metasomatically replace all the structural elements of primary carbonate rocks (Figure 3). Gypsum-anhydrite segregations are composed of columnar and short-prismatic grains forming dense intergrowths. Inside the grains of sulfate minerals, fragments of relicts of the original limestones captured during the growth process are noted. According to the Bashkirian stage sections, there is a tendency for the proportion of gypsum-anhydrite aggregates to increase as the oil oxidizes up to the formation of bitumen. It should be said that from reservoir layers with a high content of sulfate mineralization, there are mainly influxes of aqueous brines with a small amount of oil.

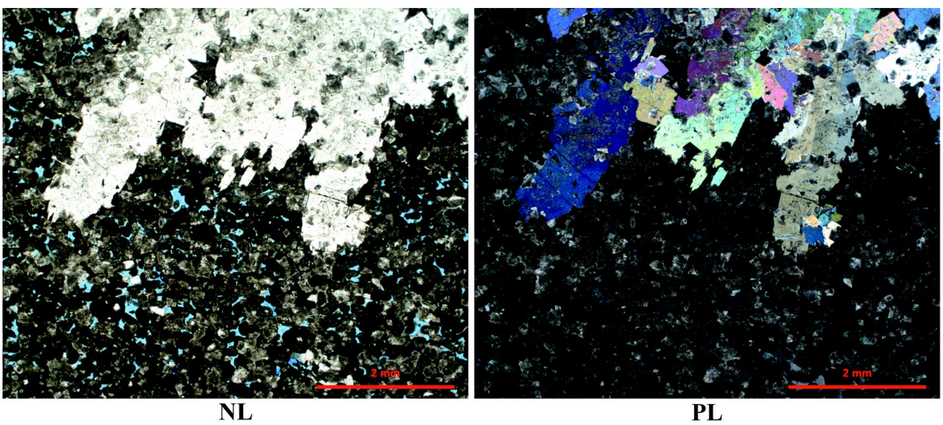


Fig. 3. Photo of thin section (NL/PL) of peloidal-lumpy limestone with allocations of gypsum-anhydrite aggregates.

4 Discussion

Optical-microscopic studies of carbonate rocks make it possible to reconstruct the stages of their formation at the stages of sedimentogenesis and fluidogenesis. Thus, the association of organic remains indicates that the limestones were formed within the shallow shelf of a sea basin of normal salinity. Good sorting of bioclasts by size and their dense structural packing in the rock volume indicates that accumulation took place under hydrodynamically active conditions of the aquatic environment, i.e. at the level of wave action. Periodically, the level of the Bashkir paleo-sea decreased. At this time, micrograined mudstone-wackestone limestones were accumulating. At certain time intervals, mudstones and wackestones emerged from below the level of the paleosea, undergoing karstification. During the burial of muddy carbonate sediments, during the process of their lithification, the structural components became closer, compacted and cemented with each other. All carbonate rocks acquired a relatively dense composition with a predominance of fine subcapillary porosity. During the period of migration of oil-water fluids, micrograined

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mudstones and wackestones were not subjected to leaching processes, maintaining a dense structure. In the grainstones, pelitomorphic and microgranular calcite cement was partially leached, and the rocks acquired good capacitance-filtration properties.

The subsequent changes were associated with the introduction of edge formation waters into the reservoir layers. Groundwater, gradually penetrating into reservoir oil deposits, oxidized hydrocarbons. This process was accompanied by periodic fluctuations of carbon dioxide in the system, causing changes in the acidity of pore solutions. As a result, the processes of dissolution of the original calcite cement and organic residues, accompanied by the deposition of diagenetic minerals, intensified in the pore space of the limestones. Of the latter, the earliest formations were dolomites. Obviously, their formation was associated with periods of increased carbon dioxide pressure in pore solutions. The penetration of edge formation waters into oil reservoirs occurred through the most weakened areas, which were stylolite sutures. Lateral filtration of mineralized groundwater along the extended stylolite cavities contributed, on the one hand, to the enrichment of pore brines with free magnesium ions, and on the other hand, to the saturation of waters oxidizing hydrocarbons with carbon dioxide. As a result, vein aggregates of newly formed dolomites gradually formed near the stylolite sutures according to the reaction:

$$2CaCO_3 + Mg^{2+} = CaMg(CO_3)_2 + Ca^{2+} \quad (1)$$

Over time, edge formation waters began to penetrate into reservoir rocks. The relatively low content of magnesium ions in the incoming aqueous brines contributed to the development of metasomatic processes. The original calcite of the structural elements of limestone, dissolving, saturated the pore solutions with calcium ions. When a high partial pressure of carbon dioxide was created, free calcium ions together with magnesium ions formed double salts of carbonic acid, which in the form of dolomites metasomatically replaced calcite in the cement of oil-saturated grainstones. Thus, dolomitization processes marked the initial and middle stages of flooding of reservoir oil deposits in the sediments of the Bashkirian stage. A feature of diagenetic dolomitization was the replacement of the mineral skeleton of the original limestones without changing the volume of the pore-cavernous space of the reservoir rocks. At the same time, oil oxidation occurred and the volume of hydrocarbon production decreased due to an increase in the proportion of reservoir water brines.

As the intensity of natural flooding of oil reservoir deposits increases, edge waters enriched with sulfate ions begin to penetrate into reservoir rocks. By saturating pore solutions enriched with calcium ions, sulfate ions contribute to the formation of gypsum-anhydrite aggregates. Due to the supersaturation of aqueous pore solutions with anhydrite and gypsum, the pore-cavernous space of oil-saturated limestones was gradually healed with calcium sulfate minerals. Over time, gypsum-anhydrite aggregates begin to metasomatically replace calcite cement and organic remains, forming large veined and nest-like aggregates. At the same time, the capacitance-filtration characteristics of reservoir rocks significantly deteriorate. At the same time, the proportion of oxidized oil increases. When developing formations enriched in gypsum-anhydrite aggregates, there is a high probability of producing aqueous mineralized formation fluids with a low hydrocarbon content.

5 Conclusion

Considering the above, the following conclusions can be drawn:

- Within the Sokskaya saddle, in sections of the Bashkirian stage, 2-3 potentially oil-producing layers of carbonate rocks with a porosity of 10-15% are distinguished. Reservoir rocks are represented by leached peloidal-lumpy grainstones separated by dense mudstones and wackestones.
- Carbonate reservoir rocks were formed within the shallow shelf of a sea sedimentation basin of normal salinity with active wave hydrodynamics of the aquatic environment.
- Reservoir oil deposits have undergone natural flooding as a result of the penetration of edge formation waters. During the rock flooding process, the reservoirs underwent superimposed mineralization. The primary diagenetic minerals were dolomites, metasomatically replacing the mineral calcite skeleton of limestones. Dolomitization of oil-saturated limestones is caused by two factors: the entry of free magnesium ions into pore solutions and an increase in the partial pressure of carbon dioxide in the system. Later diagenetic mineralization is represented by gypsum-anhydrite aggregates. Calcium sulfate minerals filling pore cavities and caverns are indicators of the most intense waterflooding of reservoir rocks. Their presence indicates low and very low productivity of reservoir oil deposits.

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