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Features of the Structure of Zones of Water-Oil Contacts in Carbonate Rocks of the Bashkirian Stage (using Akanskoye Oilfield in the Volga-Ural Petroleum and Gas Province as an Example)

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The problem of secondary transformation of rocks in the zones of water-oil contacts has been a concern of geologists studying terrigenous and carbonate reservoir rocks. A rather important aspect in studying the zones of water-oil contacts is searching the causes of natural destruction of petroleum reservoirs as formation of zones of ancient and modern water-oil contacts, in particular, in carbonate reservoirs, in fact, is field destruction with the features typical to destruction. These features include specific structural and mineral transformations of rocks as well as changes in properties of fluids contained in the rocks and, first of all, those of oil. The essential structure of the zone of the water-oil contact in deposits of the Bashkirian stage is shown using one of the wells of the Volga-Ural region as an example. Specific structural and mineral characteristics of the zones of water-oil contacts have been established, content of fluids contained in the rocks has been characterized. Common factors of alteration in hydrocarbon content through the section depending on the degree of secondary transformation of rocks have been shown.

Key words: Carbonate rocks, Secondary changes, Water-oil contact, Petroleum composition.

The main purpose of the research was to identify the features of mineral paragenesis in the zone of water-oil contacts using the Akanskoye oilfield of the Bashkirian stage in the Volga-Ural region as an example for study. This field is located in the eastern side of the Melekess depression of the Volga-Ural antecline, administratively in the Nurlatsky District, of the Tatarstan Republic (Fig. 1).

1. Boundaries of basic tectonic structures. Arches: I, South Tatar; II, North Tatar; III, Tokmovsky; IV, Zhigulevsky-Pugachevsky; V, Permsky; VI, Bashkirsky; VII, East Orenburgsky ledge. Saddle: VIII, Sokskaya; I%, Birskaya; %, Southeastern side of platform. Depressions, large deflections: %I, Buzulukskaya (northern part); %II, Stavropolskaya; %III, Melekesskaya; %IV, Kazansky-Kirovsky; %V, Verhne-Kamskaya; %VI, Abdullinsky; %VII, Belskaya;
2. Boundaries of the second-order structures;
3. Locations of Akanskoye oilfield.

The study of zones of water-oil contacts in carbonaceous rocks allows to obtain information about the mechanisms of oil reservoir destruction due to natural water encroachment of beds. A lot

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of oil companies do not drill out such intervals or drill out their upper parts only due to the lack of prospects for development of these zones and increased cost of drilling works. Therefore, such material, in a sense, can be rarely found which additionally encourages the researchers to study it. Understanding of the mechanisms of formation of zones of water-oil contacts, common factors for mineral and structural transformations of rocks, as well as change in hydrocarbon content in these zones allows to get closer to solving the problem of oil field destruction, especially in the central and eastern part of the Volga-Ural antecline. These old oil-producing regions and developed reserves are characterized by high water cut of the product recovered. Consequently, it is necessary to involve new objects in development, first of all, carbonate reservoirs with high-viscosity and slow-moving oil. Understanding of the structure, history of formation and transformation of such reservoirs is particularly relevant as it allows to choose reasonable process solutions to develop them.

The study of zones of water-oil contacts has been performed by a number of researchers[1-5]. However, in a consistent manner, transformations of rocks in the zones of water-oil contacts in carbonate reservoirs in connection with identification of the mechanisms of oil reservoirs destruction have not been studied until recently. The important aspect for studying the zones of water-oil contacts in carbonaceous rocks is lack of any clear or distinct line for changing the oil-bearing part of a section to the water-bearing one. The most reliable method to separate the oil-bearing part from the water bearing part of sections for petroleum geologists is a sharp resistance drop on geophysical data curves. However, the zone of the water-oil contact itself in structural and mineral characteristics and content of fluids contained in the rocks can reach several meters. As a part of the work an attempt has been made to unify structural and mineral characteristics of the rocks including the content of fluids that reliably characterize the zones of water-oil contacts using the oil field of the Bashkirian stage as an example.

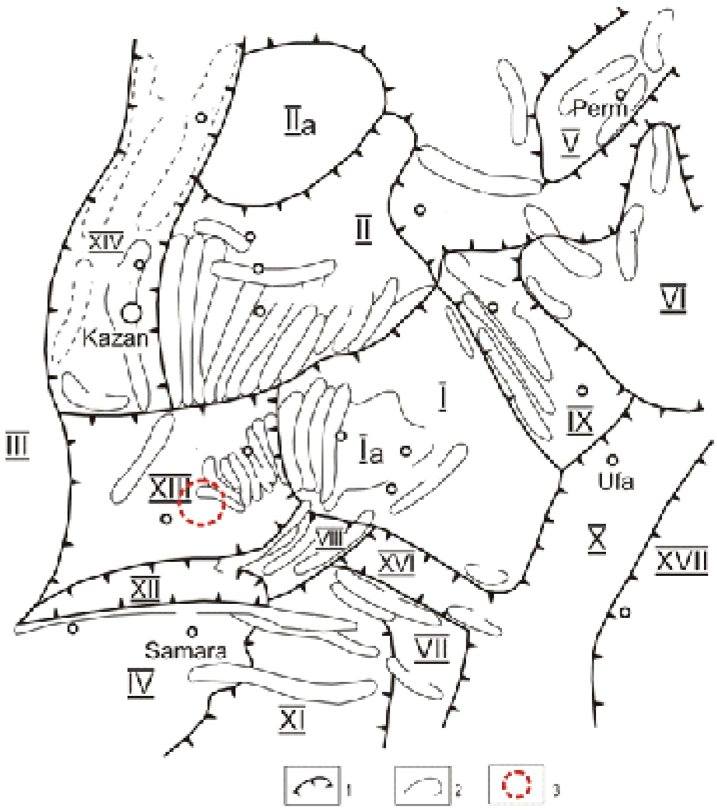

Fig. 1. Tectonic scheme of the Volga-Ural antecline (Voitovich, Gatiyatullin, 2003)

MATERIALS AND METHODS

The study of the core material began with collection of samples taken for detailed characterization of rocks in the zone of the water-oil contact. The thickness of the visual zone of the water-oil contact is 4 m (Fig. 2). The samples were collected with a high degree of detail, on the average every 10 cm. In addition to the zone of the water-oil contact, the core was studied which characterized the oil reservoir itself throughout the Bashkirian stage with the thickness of deposits of about 40 meters.

In the course of macroscopic description of samples close attention was paid to structural and textural characteristics of samples, peculiarities of relations of various structural types of limestone, fluid saturation and the nature of distribution of voids in the rock.

In addition to macroscopic description thin sections have been studied using a petrographic microscope. At that, thin sections were to different extends characterized by rock sections transformed by secondary alterations. Investigation of thin sections allowed to identify common factors of relations of secondary minerals in rocks as well as the degree of mineral and structural transformations. In addition to optical microscopic investigations and the X-ray analysis was used to identify peculiarities of the mineral composition of rocks. Thus, some minerals that were not identified by optical microscopic investigation data were rather reliably identified on the X-ray data. As a part of researches the method of a thermal analysis of rocks including fluids contained in rocks was also used. This method works well in assessment of qualitative hydrocarbon content. Thus, in particular, scrapes of hydrocarbons from fractures, large cavities and the material taken from samples with a matrix cavitation were analyzed. A small sample quantity weighed, relative rapidity and high accuracy of measurements allowed to establish differences in content of hydrocarbons from various types of voids. The research method is known and described in a number of works [6 and 7]. In addition to traditional methods of core material investigation the method of X-ray tomography was used to investigate the core which allowed to characterize the size, shape and length of void spaces of the rock, from small thin isolated pores to extended cavity channels using the non-destructive method.

RESULTS

Investigation of the cross section of oil reservoir allowed to identify three main zones in its structure:

1) Oil reservoir;
2) Partially destroyed oil reservoir;
3) Zone of the water-oil contact.

It is necessary to note that all the above

Fig. 2. Core sample from the zone of the water-oil contact

zones have been identified based on both differences in oil composition and specific structural and mineral characteristics. Various types of secondary transformations of rocks as well as secondary textures formed by them and structural variations of rocks can serve as such characteristics. Structural and mineral characteristics include the following:

1) Selective dissolution;
2) Nonselective dissolution;
3) Recrystallization;
4) Calcite cementation;
5) Silicification.

Thus, the main and most manifesting feature within the oil reservoir is selective dissolution only which forms uniformly developed porosity in the rock. The mechanism of such leaching is described in detail in a number of previous author's works [8 and 9]. Other types of secondary transformations are rather sporadic in their (locating) manifesting and often do not directly relate to rock alteration processes involving fluids migrating through the rock mass and are just the result of classical diagenetic rock changes in conditions of background lithogenesis. Partially destroyed part of the reservoir is a combination of reservoir rocks and dense rocks where in reservoir rocks to a lesser extent in dense rocks structural and mineral alterations and weighting of content of hydrocarbons can be found including their movability reduction as compared to the reservoir zone. It is clearly seen in the curves of the thermal analysis. In the zone of the partially destroyed reservoir such secondary transformations as secondary silicification, calcite cementation and recrystallization have been found. Secondary cavities with nonselective dissolution can be also often found. Silicification as a secondary process can be found not only in filling the pore space with secondary quartz and chalcedony aggregates rather than replacement of organic remains. !alcite cementation and recrystallization that often accompanies it manifest themselves rather intensively. Thus, in the zone of the partially destroyed reservoir when using an optical microscope the newly formed calcite aggregates quite reliably manifest themselves in the form of round, isometric and sometimes veinlet forms of release. Nonselective cavern porosity relatively reliably manifests itself when investigating thin sections and using an optical microscope. Large cavities and cavity channels

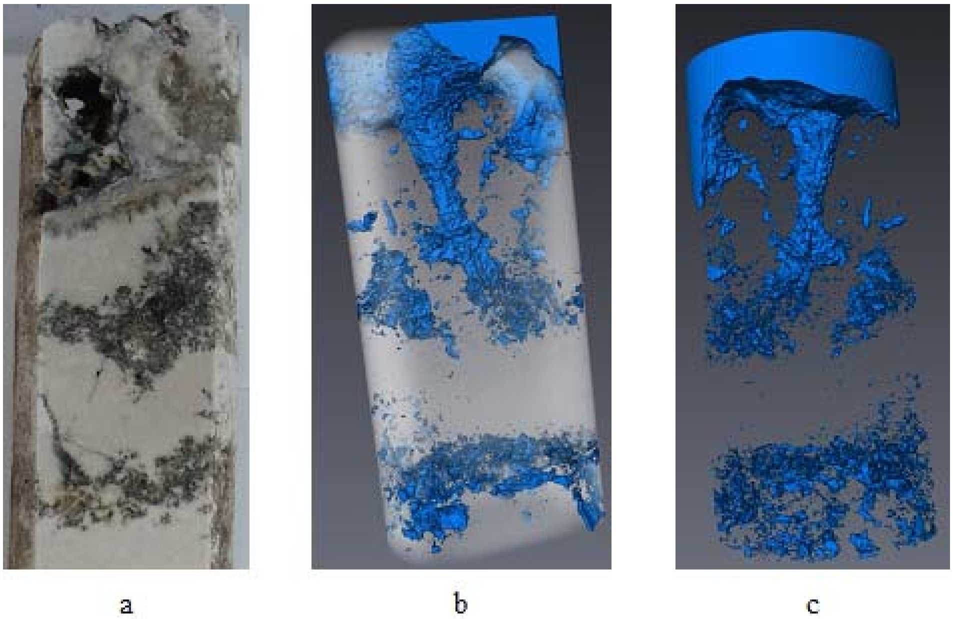

Fig. 3. X-ray tomography data: a) initial sample; b) leaching channel; c) distribution of pores and pore channels in the sample

have not been found in the macroscopic core analysis except for solution cracks.

The secondary macroscopic description of rocks from the zone of the water-oil contact has shown that the samples significantly in their structural and textural characteristics, fluid saturation and mineral composition from the oil reservoir rocks and to a lesser extent from the rocks of the partially destroyed reservoir part. It is also necessary to note that secondary processes have manifested themselves most intensively in the section areas with obviously higher porosity and permeability properties while relatively dense areas of rocks have been slightly changed by secondary processes or have even remained unchanged. Large cavities and leaching channels often extending up to 10-15 cm, with the diameter of up to 2-3 cm manifest themselves in a macroscopically reliable way (Fig. 3).

These cavities are often implemented by coarse crystalline calcite aggregates which form brushes and druses (Fig. 4). Calcite grains often contain bitumen inclusions sealed during crystal growth. Thus, another type of secondary rock transformation – calcite cementation – manifests itself rather intensively. This process like nonselective dissolution is intensively developed. At that, it manifests itself not only in partial or complete sintering-out of cavities and cavity channels but it is also often associated with the recrystallization process where it is often impossible to reliably distinguish the

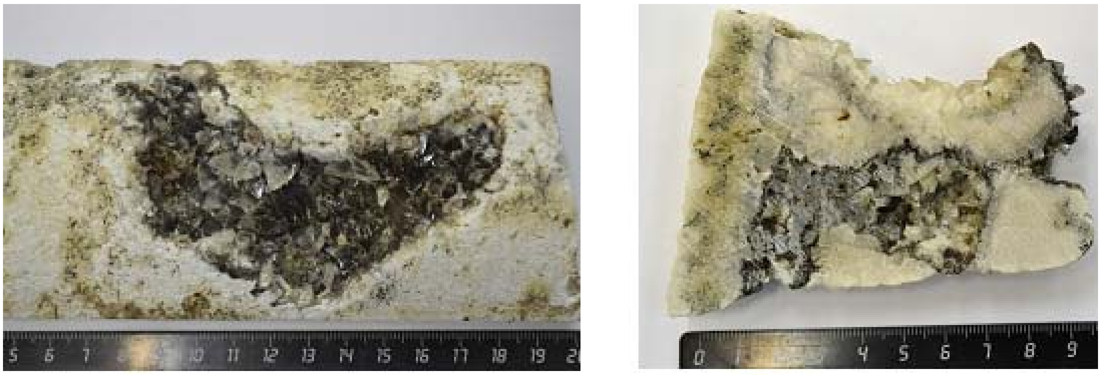

Fig. 4. Secondary calcite aggregates

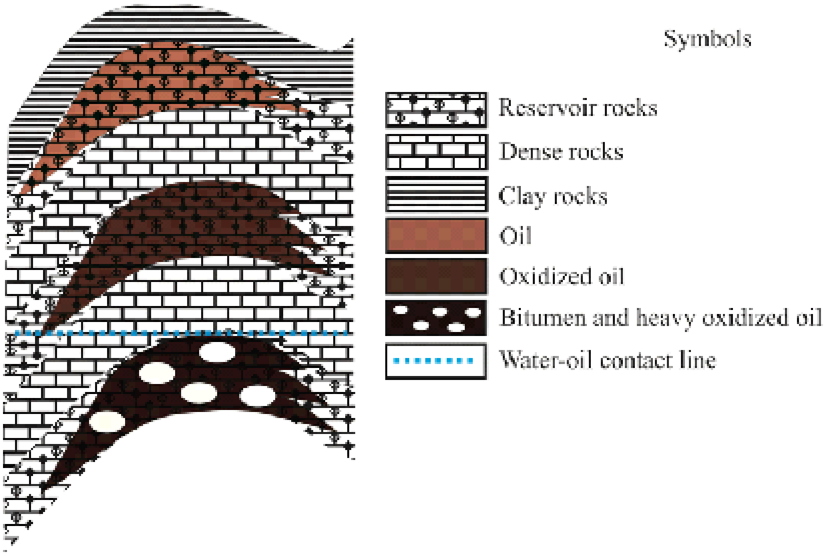

Fig. 5. Schematic section of the reservoir structure of the Akanskoye oilfield

recrystallization features of the primary rock from calcite cementation. Due to this, it is necessary to mention the diversity of secondary structures formed in intensive rock transformations. These structures are usually spotted, as well as spotted and banded and are mainly associated with the uneven nature of manifestation of the above secondary alterations, as well as uneven nature of the fluid saturation (nonuniform distribution of bitumen saturated areas in the rock).

The X-ray analysis data from different areas of samples have shown that they are monomineral rocks and are represented by calcite only. Cavernous oil-saturated areas, secondary calcite aggregates, as well as, to a lesser extent, rock areas exposed to secondary transformation have been investigated. A very small quartz admixture has been detected only in the oil-saturated, cavernous rock area among calcite. Perhaps, it has appeared as a result of weak silicification at the acid geochemical barrier[10]. As to hydrocarbon content, in the zone of the water-oil contact, hydrocarbons are identified as heavy immobile oils, up to bitumens, with a large portion of resinous and asphaltene fractions.

DISCUSSION

As a result of core analysis of the Akanskoye oilfield by litho-mineralogical characteristics and hydrocarbon content data three zones have been identified: the zone of distribution of reservoir rocks with relatively movable oil, the zone of distribution of partially destroyed reservoir rocks with weakly movable and viscous oil, the zone of the water-oil contact with heavy, bitymen, immobile oil.

Absence of any significant secondary rock transformations within distribution of reservoir rocks with movable oil or in the oil zone can be associated with the preserving oil property where due to lack of water all the processes of mineral rock transformations run extremely slow. Therefore, rocks here most often have only the features of classic dia-catagenetic transformations such as recrystallization, filling bio-cavitations with clear granular calcite aggregates, stillolitization, etc. Only one type of rock transformations – uniform secondary porosity – which is the main porosity type in Bashkirian reservoir rocks cannot be referred to the features of classic background diagenetic changes. Formation of the secondary rock uniformly distributed in the volume, porosity and time should refer to the stage before oil accumulation and the stage of oil accumulation itself.

The important factor in favour of the secondary nature of uniform porosity formation, its local distribution and inclination to arch-like sections of oil-bearing structures should be mentioned, while in the direction of winged sections the distribution of such pores type significantly reduces. Such localization of porosity formation proves its superimposed nature relative to post-sedimentation processes associated with the lithogenesis of rock mass penetration.

The zone of the water-oil contact is characterized by greater degree of incidence of secondary transformations which is caused by biochemical and chemical reactions at the water and oil contact. Thus, the local acid geochemical barrier formed in this zone or acid reaction medium encouraged intensive development of nonselective dissolution processes with formation of large cavities and cavity channels, nonuniform recrystallization and crystallization of coarse-grained calcite on the walls of pore channels and cavities. At that, in constant presence of water, hydrocarbons are oxidized to the state of bitumens and heavy, immobile and highly viscous oils.

The zone of the partially destroyed oil reservoir in fact is a partially watered-out oil reservoir where together with reservoir attributes with the relatively movable oil the rock also has the features of the zone of the water-oil contact. First of all, it is manifested in increase of the proportion of secondary alterations such as calcite cementation and silicification, appearance of secondary spotted structures caused by nonuniform substance recrystallization as well as weighting of hydrocarbon content towards increasing of the proportion of resinous and asphaltene fractions and increasing their mobility (viscosity growth). Secondary transformations as well as oil weighting in the zones of partially destroyed reservoirs should be associated with penetration of water bearing fluids. In fact, they are intermediate zones between oil reservoirs and rocks of the zones of water-oil contacts. However, they mostly should refer to reservoirs development of which involves the use of modern techniques for reservoir stimulation.

The investigated oil reservoir with all the zones identified can be schematically presented in the form of a diagram shown in Figure 5.

CONCLUSIONS

Thus, the following can be mentioned as basic results of the core of the Akanskoye oilfield:

1. The zones of oil reservoirs (oil pool) partially watered out or partially destroyed reservoirs and the zones of water-oil contacts can be distinguished not only by content of hydrocarbons contained in them but also by the degree of mineral and structural transformations of rocks.
2. The degree of secondary alterations gradually increases from reservoir rocks with well-movable oils to the zones of water-oil contacts with heavy immobile oils including bitumens.
3. Increase of proportion of secondary transformations in the zones of reservoir watering out and in the zones of water-oil contacts should be associated with formation of local geochemical barriers as well as non-equilibrium state of the system as a result of chemical and biochemical reactions at the water and oil contact.
4. The zones of water-oil contacts at the Akanskoye oilfield should be considered as destroyed reservoir parts as they have the features of oil reservoirs with alterations of existence of rocks in the zones of water-oil contacts superimposed on them.

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