Comparative Analysis of Oil-Saturated Fractured Reservoirs - Bazhenites Clays of Western Siberia and Khadumites of Eastern Caucasus

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***Abstract* – The rocks of clay natural reservoirs present particular interest. On the one hand, they attract the attention of scientists from the point of view of oil content (they are enriched to a large extent with organic material), on the other hand - from the point of view of accumulation of radioactive elements, as it is indicated by high radioactivity. In this regard, the article touches upon the issue of the relation of these factors. On the territory of the Russian Federation, such rocks are represented by the Jurassic bazhenites of Western Siberia and the Oligocene khadumites of the Eastern Caucasus. The article presents the peculiarities of the clay reservoirs of Western Siberia and Eastern Caucasus, a detailed description of the fractures of various generations, and the issues of reservoir capacity. A comparative analysis of the oil-saturated bazhenites of Western Siberia and the khadumites of Eastern Caucasus was carried out. The dependence of reservoir formation on the distribution of radioactive elements in the section was revealed.**

Keywords* – *reservoir; bazhenites; khadumites; clay reservoirs; cracks; radioactive elements; abnormally high reservoir pressure.

I. INTRODUCTION

During the course of the search for oil and gas, geologists and geophysicists have to deal with various types of traps and reservoirs. As it is known, a natural reservoir in classical understanding is a reservoir with certain reservoir parameters, limited by impermeable layer that do not have an effective capacity and permeability. From the point of view of identifying reservoirs — potential hydrocarbon accumulation traps — fractured clay reservoirs (mudstones) are the most difficult to use for geophysical well survey methods. The clay natural reservoir is characterized by the following specific features:

- It is located within the main zone of oil and gas formation;
- Reservoir rocks are represented by thinly-laminated argillites, enriched with organic substance;
- The system of reservoir properties consists of a permeable conductive fractured part and a low-permeable porous matrix;
- There are horizontal, vertical and inclined cracks.

II. RESEARCH PURPOSE

In clay natural reservoirs, rocks are oil source, since they are largely enriched in organic substance and, at the same time, oil-containing, i.e. they present interest as hydrocarbon reservoirs. They are of no less interest, under certain geological conditions, as reservoirs of radioactive elements, since they are characterized by high radioactivity [6].

In this regard, the interrelation of these factors presents particular interest. The typical representatives of such reservoirs on the territory of Russia are the bazhenites of the Jurassic period of Western Siberia and the khadumites (Batalpashinskaia and Khadumskaia Formations) of the Oligocene period of the Eastern Caucasus. Moreover, the radioactivity of bazhenites reaches 40–70 mcR/h with an organic content of up to 8–18% [5], and the khadumites of Eastern Caucasus are less enriched in organic substance, the content of which reaches 0.4–9.3%, and accordingly their radioactivity is lower than 20 26 mcR/h [7, 8]. Many researchers studied the features of the type of reservoirs, deposits, the nature of the origin of reservoirs, and the possibility of their isolation in such clay strata both in the bazhenites of Western Siberia [2, 5, 6, 9] and in the khadumites of the Eastern Caucasus [1, 3, 4, 7, 8, 10], but there are still some issues that need to be thoroughly investigated.

III. RESEARCH METHODS

In accordance with the research work [5], in Western Siberia, the bituminous fractured rocks of the Bazhenovskii Formation occur at depths of 1000–3500 m and spread over a vast territory (more than 1 million km^2). Their thickness is controlled by the basement structure and varies on average in the range of 20-40 m. In the bituminous sediments, the reservoirs of the Bazhenovskii Formation have a siliceous-carbonate-clay composition. Secondary pores, voids, slotted micro-cracks, void of desalinization are present in all rock components and cross-cutting cracks made with quartz, calcite, gypsum, jarosite, melanterite. The fractured and interstitial – fractured reservoirs has typical two-phase filtration. Organic substance is of the sapropel type. A part of it is scattered in the rock, the other forms lenses with a thickness of 0.01–2 mm, their content decreases down the section from clay lithotypes to micro-shelly silicites.

Many researchers studied physical, including reservoir, properties of rocks. The open porosity of bituminous rocks, determined by the Preobrazhenskii method, varies from 2 to 16%. The Bazhenovskii rocks are characterized by high values of the specific surface area of pores, which indicates their tortuosity and small size. The pore size varies in a narrow range from 0.02 to 0.06 mm, rarely to 0.1 mm. The pores well intercommunicate and arrange in layers. In such areas, the porosity can reach up to 25-28%, and where the connectivity of the pores decreases just to 5%.

In general, reservoirs are characterized by low values of open matrix porosity; they become effective due to fracturing. The basis of the capacity is the void of matrix, the development of which is associated, first of all, with the hydromicatization of montmorillonite. It is believed that the same process contributed to the formation of mainly horizontal fracturing, which caused the communication of voids in rock blocks and the emergence of filtration paths in reservoirs.

In the research work [5], it is noted that under the conditions of the sections of Western Siberia, there are both layers of undercompaction and layers of decompaction, and there are a number of factors in the formation of zones of decompaction. Here, the great importance is attached to compaction, catagenetic transformations of sediments and organic substance contained in them during oil and gas formation, the osmosis phenomenon, the introduction of high-energy fluids from underlying rocks or from deep subsoil, geodynamic and geothermal processes in subsoil.

It is believed that each of these factors may be predominant depending on the geological structure and development history. Most often there the complex effect of these factors is observed. Therefore, many zones of decomposition with AHRP are formed under the combined influence of dynamic factors: sedimentation, transformations during immersion, manifestations of tectonic fracturing and the concomitant change in the fluid-dynamic regime.

According to some scientists [5], the formation of many zones of decomposition begins in diagenesis and persists in catagenesis. The areas of increased intensity of post sedimentary changes in sediments are usually inherited from the zones of decompaction of the earlier formation. Wherein many decompressed zones with AHRP are short-lived. The appearance and disappearance of zones of different genesis reflects the auto-oscillating fluid-dynamic process of formation of reservoirs in the interior of the Earth. The cracks in rocks form a complex system consisting of parallel, echelon-like, winding and branching micro-cracks. They break rocks into blocks with dimensions (0.5-5) ÷ (0.5-15) mm in accordance with the distance between the cracks of 0.1-0.5 mm. The width (or opening) of cracks visible in thin sections – 0.01–0.05 mm, it reaches 0.5–5 mm in bulges, pockets, and cavities.

High porosity is reasoned by the horizontal fracturing, in a smaller amount of vertical and inclined one, as well as the existence of surface interstice of stratification of a lithological and catagenetic nature. The average linear density of cracks varies from 215^{m-1} to 259 $^{m-1}$. The cracks are filled with bitumoid (oil), authigenic clay, carbonate, siliceous substance and pyrite. Thus, in the Bazhenovskii Formation, according to the research work [5], secondary porous fractured and fractured reservoirs dominate. The permeability of Bazhenovskii rocks which are not reservoirs does not exceed 10-2 - 10-3 fm^2. In comparison with clays, the permeability of bituminous rocks is higher - up to 120 fm^2, 65 fm^2 in average, in massive siliceous clays - no more than 1-5 fm^2. The permeability of bituminous rocks on layering is two times higher in value than one perpendicular to it.

The high content of organic substance leads to a decrease in the density of bituminous rocks, which varies from 2.00 to 2.55 g / cm^3 (average is 2.32 g / cm^3), and in roof and bottom rocks is 2.40 g / cm^3 and 2.43 g / cm^3 respectively**.** With the increase in depth, the density of slightly bituminous rocks naturally increases, and the bituminous rocks, on the contrary, become decompacted. The density of organic substance in the Bazhenovskii formation varies from 0.92 g / cm^3 to 1.63 g / cm^3 (average is 1.30 g / cm^3). When studying the methods of accurate diagnostics in thin sections in rocks, in addition to cracks, meso- and microtextures were found. They formed during the geochemical interaction of rock-forming components. Organic substance plays the main role in the formation of mesothextures. Its presence in the rock in the form of fine interlayers and lenses creates the basis for the appearance of parallel-layered, looped, lenticular-layered textures and leads to anisotropy of the strength and filtration characteristics of reservoirs.

The heterogeneity of texture at the micro level presents particular importance. It occurs when clay minerals and silica are enveloped in organic matter, which hydrophobizes their surface, significantly reducing the sorption capacity.

The reservoirs of the Bazhenovskii Formation are characterized by sharply varying productivity, according to well test data, their flow rate varies from 0.06 to 300 m^3 / day. For example, in the crest of the Salymskii reservoir, the drilled wells are characterized by increased oil flow rates. As the distance from the crest of the well is reduced, the wells first decrease to 10-15 and then to 1-10 m^3 / day or less.

Due to the specificity of the composition, the rocks of the Bazhenovskii formation are clearly distinguished in the logs for abnormally high apparent resistances and natural radioactivity. Moreover they present a persistent marker in the section of the sedimentary cover of the region.

Khadumites of the Paleogene deposits of Eastern Caucasus are spread over an area of about 100 thousand km^2. They occur at depths of 2000-4000 m with an average thickness of 30-45 m and are also studied for a long time by many researchers. The use of models of natural reservoirs in the clay strata for the khadumites of Eastern Caucasus on the basis of global and national practice does not give satisfactory results, since does not explain many of the processes occurring in deposits during its development.

Oil accumulations in the Lower Maikop clay sediments (khadumites) are associated with a natural reservoir with a peculiar structure. This, in particular, is proved by the results of well testing. Within the established oil-bearing fields, often at a fairly close distance, the wells with industrial inflows of oil (25-100 m^3 / day), marginal (5-7 m^3 / day), low inflowing (0.01-1.5 m^3 / day) are without inflows were found.

In addition, in a number of wells, the inflows of water with varying amounts of oil, as well as inflows of water and inflows of oil with further rapid watering were obtained.

The main petrophysical parameters of the matrix of rocks of productive deposits of khadumites according to the statistical processing of laboratory definitions are as follows: porosity - 12.2%; density of 2.36 g / cm^3; permeability is $4.5 \cdot 10^{-3}$ mkm^2. The water content in the rock matrix, determined in the research work [10] on the basis of the waxed core, was 64% of the total pore volume, i.e. almost the entire pore space of the rock matrix was occupied by water. The results of the experiment to determine the presence of mobile water in the pores of the rock matrix show that the pores of the matrix contain mobile water, and the creation of a pressure drop in the clay matrix leads to the release of free water.

The calculation of the parameters of micro-cracking using the method of grinded osteometry was carried out on large thin sections made of rocks in the well №47 and №49 Vorobevskii field, well №3 Filippovskii Site and well №3 of Elizavetinskii Site (P.V. Bigun, 1990). The qualitative analysis of rock sections showed that horizontal, inclined and vertical cracks are present in the mudstones enriched with organic matter.

The most widespread are: horizontal (58.5%), than inclined (31.3%) and vertical (10.2%) cracks. The epigenetic and tectonic cracks are determined among the horizontal ones. The first ones are confined to the boundaries of lithological differences and partially filled with black oxidized bitumen. Sometimes well-formed dolomite crystals are grouped to them (up to 0.05 mm). These cracks are slightly sinuous, fairly mature in length and opening. The crack opening varies from 10 to 300 mkm, the crack density is 60-900 m^{-1} [4].

Matrix of rock is porous. The pores are formed by loose, sometimes disordered lying of fibrous-curved micro-blocks (laminary) of clay minerals and their units. Pores are characterized by a variety of forms: rounded, isometric, slit-shaped, crater-shaped. Nearly 90-95% is associated with pores with sizes from 30 to 5 mkm and only 5-10% with pores with a size of 5-10 mkm of the total volume of the pore space. The pores have good connectivity and are connected by means of thin constrictions with a diameter of 0.1-3 mkm. The strength of the matrix is provided by a partial cementation of its carbonate material, represented by calcite crystals scattered over the rock with dimensions of about 1 mkm. Calcite crystals bind contacting units of clay minerals and can dissolve during hydrochloric acid treatments of the formation, which will lead to destruction of the reservoir in the bottom-hole zone.

Interunit lenticular interstices are interconnected by tubular and other channels with dimensions of 3-10 mkm, creating a single hydrodynamic system of the first level. The second level of the filtration-capacitive system is formed by microblocks of rock with a thickness of hundreds of mkm, which consist of 10-20 units of clay particles and arched interstices. Microblocks are separated by lithological cracks of opening up to 150 mkm and are broken by sub-vertical cleavage cracks, which provide a hydraulic connection of lithogenetic cracks between them [11, 12]. Thus, the first-level filtration-capacitive system (rock matrix) is feeding, and the second-level filtration-capacitive system, formed by lithogenetic and tectonic cracks, having a much higher permeability than the rock matrix, is conductive.

According to electron microscopy data (V.I. Taranenko, M.Yu.Khakimov, V.N. Divakov, 1989), oil in clays is deposited in the form of films and lenses along lithogenetic cracks, which develop along the bedding planes of clays of different composition. Oil mobility is provided by cracks with increased opening. The thin pores of the matrix and thin inter-slab and inter- laminary interstices contain film, capillary and free water. Free water occupies separate interstices. The mobility of free water is ensured by inter- laminary interstices and through unit tubular channels. The lithological uniformity of laminary argillite-like clays, to which the oil deposits are confined, creates considerable difficulties in the allocation of reservoirs in the section of wells.

The main complex of development survey (KL, PL, BL, IL and NGL) practically does not allow establishing the presence or absence of reservoirs in the section. Gas logging results also provide uncertain information, and only materials from acoustic logging (AL), density (GGL-D) logging, caliper and thermometry logging make it possible to isolate decompaction zones and associated oil saturation in the section of the Lower Maikop. The reservoir layer is characterized by an abnormally increased acoustic wave (ΔT) run time up to 500-700 microsec/min with a background value in the enclosing clays of 350-400 microsec / min and low density of rocks (GGL-D) to 2.0 g/cm^3 with a background value of 2.5 g / cm^3.

According to caliper logging data, the reservoir is marked by cavern porosity (an increase in the diameter of the well by 5-8 cm), which is reasoned the reduced strength of the decompompacted clay rocks and their ability to crack. According to thermometry logging data, temperature drops are observed against the productive zone, explained by the throttle effect, i.e. cooling the solution during the expansion of gas entering the wellbore from the permeable oil and gas saturated formation. The value of the temperature drop of an unstable thermal field is 0.5–4 °C. There is no decrease in temperature above the intervals from which, subsequently, during testing, oil inflows were not obtained. Useful information is provided by temperature measurements taken at regular intervals.

When comparing them with each other, it was noticed that the negative temperature anomalies, clearly recorded immediately after the opening of a reservoir, decrease with time. This fact makes it possible to suggest that there is a clogging of the productive zone with solid particles of the solution and the deterioration of the hydrodynamic connection of a reservoir with a well. However, reliable selection of clay reservoirs by geophysical methods is often difficult. They do not give even in intervals with industrial oil content characteristic high resistance on the electric logging curves, in contrast to the clay reservoirs of the Bazhenovskii Formation. They fix monotonous thickness with low (within 1 Ohm) resistance without differentiation in records. Increased electrical resistance values are associated only with carbonate interlayers.

The most differentiated, as mentioned above, are the curves of the interval time of the acoustic wave and gamma-ray logging. The increase in gamma activity values in oil-saturated intervals is explained by the presence in the rocks of an increased amount of dispersed organic substance that absorbs radioactive elements from the waters of the sea basin. N.N. Bogdanovich [3] found that lower values of the hydrophobicity coefficient (C_{hb}), less than 0.17 with background values of 0.25-0.3, are associated with oil-saturated reservoir layers. Researchers believe that increased C_{hb} indicate that hydrocarbons under the influence of polar forces are in a tightly bound state, and low C_{hb} values indicate that hydrocarbons are in a free state and able to move.

IV. Findings

Thus, on the basis of the comparison of the characteristics of the Bazhenovskii Formation of Western Siberia and the productive part of the Oligocene sediments of the Eastern Caucasus, it is possible to enumerate a number of aspects which indicate the similarity of these reservoirs. These aspects include abnormally high pressures, temperatures not lower than 100 °C, abnormally high values of natural gamma activity, abnormally low density and the speed of passage of elastic acoustic waves, the timing of the main volume of reservoirs to the interlayer-laminary space, closed natural mode of deposits, etc.

Nevertheless, there are a number of distinctive features, including significant differences in the values of specific electrical resistances. Thus, the zones with oil manifestations in bazhenites are characterized by values of up to 400-500 Ohm and more, while the electrical resistivity in Maikop reservoirs reaches 1-1.5 Ohm. The analysis of well test results in khadumites shows that inflows were obtained not only from intervals with increased bituminous, therefore it is difficult to assume the validity of the hypothesis about the mechanism of the formation of void space only due to the transformation of organic material, which explains the causes of the occurrence of a reservoir in bazhenites.

It is also impossible to explain the formation of void space due to the abnormally high reservoir pressure, under the action of which the clay porosity increases, and it acquires the properties of reservoirs. This interpretation of the mechanism of formation of void space in Maikop clays is contradicted by the fact that there were not any wells with abnormally high reservoir pressure which had significant inflows of formation fluid, despite significant pressure differences up to 20 MPa**.** In addition, the calculated and analyzed pressures along the section show that in all wells where the inflows were obtained, the oil deposits were confined to relatively low sections of abnormally high reservoir pressure. The results of well testing indicate that in the section of these strata there were separate parts represented by reservoirs, while others were not.

V. Conclusion

The use of spectrometric gamma logging is one of the promising areas in the determination of oil-saturated intervals in the clay-carbonate Oligocene sediments of the Eastern Caucasus [7, 8]. The analysis of gamma-spectrometry materials shows that the distribution of different radioactive elements in the section is correlated with zones of development of reservoirs or non-reservoirs.

The following regularity was revealed: in deposits that are not reservoirs, radioactivity is caused by thorium in the absence of uranium (up to 90% for deposits of the Polbinskii site). For the reservoirs of the Batalpashinskii and Khadumskii formations, the prevalence of radium is typical (80% and 84%, respectively). In this regard, it was important to analyze to what extent the presence of increased concentration of radium could affect the conditions of reservoir formation and the presence of increased concentration of thorium did not contribute to the manifestation of such conditions. Moreover it is important to understand why in separate strata of rocks an increased content of both organic materials and radioactive elements accumulated simultaneously.

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