Heterogeneity of the Tutleim formation (West Siberia)

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Abstract. Nowadays due to depletion of the west Siberian resource base, the research of unconventional reservoirs has become relevant. One of such objects is the Bazhenov formation and its analogues. In this paper, according to the results of the complex petrographic and geochemical studies, the nature of heterogeneity of the Tutleim formation was clarified. It was specified that investigated fragment of the section has two main lithotypes with clear mineralogical features. The alternation of the lithotypes in the section indicates cyclical deposition of sediments. This information and the results of XRF analysis have made it possible to divide section in details and distinguish four stages of development of the Tutleim formation. Each of these stages has certain physical and chemical parameters.

1. Introduction
The Tutleim formation is a stratigraphic analogue of the Bazhenov formation [1, 2] which is currently considered as a reservoir with potentially high hydrocarbons. The formation is widespread in the west of the West-Siberian Plain, in the Kazim-Konda structure-facies zone. The study area is located on the territory of Khanty-Mansi Autonomous Okrug. In structural plan, this area is within the Krasnoleninskiy arch (figure 1). Despite the high reserves of primary products, the getting of hydrocarbons is slow. The difficulties are connected with the problem of the accuracy of forecasts for the development of oil. The source rocks behavior is very difficult to estimate because of their composition complexity and the specifics of sedimentation and lithogenesis. There by the deposits of the Tutleim formation and its analogues are examined by the specialists from different fields [3-12].

In this paper, an attempt is made to establish the nature of heterogeneity of the Tutleim formation and establish sedimentation conditions on the basis of complex petrographic, mineralogical and geochemical studies.

2. Object and methods of the research
The object of the study was chosen to be a complete section of the Tutleim formation within the Krasnoleninskiy arch. Petrographic, mineralogical and geochemical features were determined on the basis of 45 samples. A petrographic analysis was carried out on a Leica DM750 microscope. It was accompanied by photography with 2.5x, 5x zoom lenses. X-ray diffraction analysis was carried out on a diffractometer XPERT PRO (PANalytical), X-ray fluorescence analysis – OXFORD ED2000 - energy dispersive X-ray fluorescence spectrometer. The research was conducted at the collective center «Analytical center of the geochemistry of natural systems». 
3. Results of the research

3.1. Petrography and mineralogy

Two alternating lithotypes were established by the results of the petrographic analysis: clay-siliceous rocks and calcite-clay-siliceous rocks. The clay-siliceous rocks are composed mainly of a mixture of clay material and siliceous matter, which are in a dense mixture and are not visually distinguishable, have a lenticular microbedding, sometimes bioturbated (figure 2, 3). The calcite-clay-siliceous rocks have also microcrystalline calcite, which often forms lenses (figure 4, 5). Throughout the section the rocks are saturated with organic matter, pyritized, contain up to 5% of an admixture of a terrigenous material with a size of 0,01-0,06 mm. Over the section, authigenic dolomite is unevenly developed (up to 25 single to 50%). It has diamond-shaped crystals with a size of 0,01-0,06 mm. At the bottom of the formation, glauconite is noted. Pyritized remains of cone-shaped radiolarians are often traced in the section, and in calcite lenses, they are often carbonated or silicified. Radiolaria is considered as the main source of silica in the pool [4]. In addition, ichthyodetritus, unicellular algae of calcite composition, bivalve shells, pelecypods, ammonites are often found in the rocks.

The results of X-ray diffraction analysis, which are presented in the section on figure 6, provide more accurate information about the material composition and quantitative ratio of the components of the rocks. According to the analysis, the rocks are composed of 73 % of the clay-siliceous material, with a predominance of quartz (44,5 %) over the clays (28,5%). The clay part of the rock is presented by kaolinite (38%), hydromica (44%) and the small part of mixed-layer clay minerals (17%) and the
by the chlorite (1%). According to the results of X-ray diffraction analysis, distribution boundaries of calcite coincide at the top of the section. The calcite-clay-siliceous rocks contain 21 % of calcite (max up to 44 %). In the lower part of the section, according to the results of X-ray diffraction analysis, calcite is poorly developed. Dolomite is unevenly presented in the section. Its content in the rock is from 1-9% to 18-30%, which coincides with the thin section analysis. Sometimes admixture of siderite is noted (1-5 %). The rocks of the Tutleim are pyritized, but it is difficult to define the content of pyrite optically with proper accuracy. According to the results of X-ray diffraction analysis, average content of pyrite in the section is 7%. In the roofing part of the bed, in the range of 2330,0-2333,86 m, pyrite content rises up to 30-55%. In thin sections, plagioclase is observed in the form of rare terrigenous grains 0,02–0,06 mm in size. According to the results of X-ray diffraction analysis, an average content of plagioclase in the section is 4-10%. Its content increases at the top of the section. In the range from 2332,90 to 2338,11 m, the content of plagioclase is 11-17%.

3.2. Geochemistry

On the basis of the variability of the contents of the main rock-forming oxides, the section can be subdivided by 7 members (figure 6) [10,12].

1. Aluminum – silicon member lies down at the base of the Tutleim formation in the range from 2368,0 to 2371,6 m. This member is presented by clay-siliceous rocks. Deposits have a high content of SiO₂ (56,5-73,2 %) and Al₂O₃ (7,8-15,6 %), increased Fe₂O₃ (3,5-9,4 %) and low CaO (0,2-1,1%).
2. Calcium-aluminum-silicon member is situated in the range from 2361.4 to 2368.0 m. It is composed of calcite-clay-siliceous rocks. The boundary of the member is well traced by the increase in the content of calcium oxide and the appearance of carbonate lenses in the section. The rocks are
characterized by a slight decrease in the content of SiO$_2$ (45,9-73,1 %), Al$_2$O$_3$ (7,5–15,7 %), Fe$_2$O$_3$ (2,6–9,9 %) and an increase in CaO (0,4- 9 %), mainly in the roof of the member.

3. Silicon member is situated in the range from 2357,2-2361,4 m. This member is presented by clay-siliceous rocks. Deposits are characterized by a significant increase in the content of SiO$_2$ (58,4-80,1 %). The amount of Fe$_2$O$_3$ (1,4–9,3 %) practically does not change in comparison with the underlying members. A decrease of content Al$_2$O$_3$ (2,6-9,3 %) and CaO (0,27-1,7 %) is also registered.

4. Aluminum-silicon member is traced in the range from 2348,6 to 2357,2 m. It consists of clay-siliceous rocks. There is a stable chemical composition with minor variations for this member in the section. Deposits are characterized by a high content of SiO$_2$ (52,3 – 62,8 %) and Al$_2$O$_3$ (9,7-12,6 %). Comparatively to the lower members, there is a decrease of Fe$_2$O$_3$ (4,0-6,7 %) and a slight increase of CaO (0,5 – 3,5 %).

5. Calcium member lies down in the range from 2337,2 to 2348,6 m. It is presented by calcium-clay-siliceous rocks. The boundaries of the member are clearly traced by a sharp increase (at the bottom) and decrease (at the roof) of CaO (0,6-31,6 %). It shows a significant carbonatization of rocks. For the remaining oxides, a symbate decrease in the concentrations of SiO$_2$ (15,5–54,6 %), Al$_2$O$_3$ (6,9–17,7 %), and Fe$_2$O$_3$ (0,6–13,4 %) are observed.

6. Aluminum-silicon member is observed in the range from 2334,2 to 2337,2 m. It is composed of clay-siliceous rocks. Comparatively to the rocks from the members 1 and 4, there is an increase of Al$_2$O$_3$ (13,4-14,3 %) and a slight decrease of SiO$_2$ (46,3-50,7 %), Fe$_2$O$_3$ (3,7-5,4 %), CaO (0,6-1,7 %). An increase in alumina content is recorded by an increase in the number of clay minerals according to XRD data.

7. Ferruginous member is traced in the range from 2330,0 to 2334,2 m. It is presented by clay siliceous rocks. Among geochemical features, there is a significant increase in the content of Fe$_2$O$_3$ (4,91-21 %). It is confirmed by intense pyritization of rocks and by a decrease of SiO$_2$ (30,1-44,3 %), Al$_2$O$_3$ (4,5-12,2 %), CaO (0,5-17,0 %).

4. Discussion of the results

According to Kontorovich [4] in the Late Jurassic territory of the West-Siberia was deflecting and during the development of the Tutleim formation, the depth of the sea basin increased from 25-100 to 100-200 m (figure 7). Lithological section, which is mainly presented by the clay-siliceous rocks with subhorizontal bedding, corresponds to the specified conditions. By the results of comprehensive studies, 4 main stages of development of sediment basin in the Bazhenov time were identified.

The first stage of sedimentation occurs during the formation of the three lower members (aluminum-silicon, calcium-aluminum-silicon, silicon), which confirms by instable behavior of the curves. For this stage, a gradual decrease in the concentration of aluminum oxide is observed, which may indicate a lack of input of terrigenous material in the sediment basin. At this stage there was a slow immersion of the territory and, as a result, an increase in the depth of the sedimentation basin. According to Kontorovich [4], this stage was characterized by a weak receipt of clay material and the flourishing of life of radiolarians, which formed siliceous sediments.

The second stage corresponds to the overlying aluminum-silicon member. This fragment of the section is characterized by a stable behavior of oxides. It fixes the constancy of the physical and chemical parameters of the waters of the basin. A significant increase in the alumina content at the boundaries of the stage corresponds to the flow of terrigenous material. After the immersion, the input of clay material increased and its content increased in relation to silica. Life of radiolarians became less active.

The third stage (calcite member) is characterized by the change in the chemistry of the waters of the basin. It is marked by a wide development of carbonate mineralization. This fact may indicate an increase in water content of carbon dioxide. The biogenic mechanism may be the reason for mass precipitation of carbonate minerals (with a sharp increase in the content of aragonite in seawater, spontaneous precipitation of calcite may occur).
The fourth stage combines upper aluminum-silicon and ferruginous members. The boundary is clearly traced by the content of Al$_2$O$_3$ (13-15 \%) and a sharp decrease of calcium oxide (figure 6). The rocks of this stage are characterized by the development of intensive pyritization (the content of pyrite progressively increases from the bottom to the roof of the members). The appearance of pyrite may be due to a change in the chemistry of the basin. The reason for it is the saturation of water with carbon dioxide and sulfur, which causes a sequence of chemical reactions. At the first phase, there is an appearance of sulfate salts of iron, which are then restored under the influence of organic carbon, occurs due to the interaction of surface waters with bottom waters. Another option is the presence of hydrogen sulfide contamination of the basin due to the decomposition of buried organic matter in anoxic conditions [13-15].

5. Conclusion
Based on the petrographic and mineralogical studies, it was found that the Tutleim formation was composed of an uneven alternation of two lithotypes — clay-siliceous and calcite-clay-siliceous, with a clear separation according to the mineral composition. The alternation of lithotypes emphasizes the change in the environments of sedimentation and changes in the physical and chemical characteristics of the waters of the sediment basin.

According to the results of the XRF analysis, the researched section was subdivided into 7 members [15]. Selected stratigraphic units are emphasized by the results of petrographic and mineralogical studies. For each of the seven members, the boundaries and limits of change in the content of oxides are described. The complex of the carried out studies allowed to distinguish four stages of the formation of the Tutleym formation within the Krasnoleninsky arch. At the first stage, there is gradual subsidence of the territory and, as a result, an increase in the depth of the basin with a decrease in the supply of terrigenous material (members 1-3). At the second stage, there is a
stabilization of physical and chemical parameters of the water (member 4). The third stage is characterized by carbon dioxide contamination of the water, which is reflected in massive precipitation of carbonates. This fact can be explained that the sediment basin begins to be semi-enclosed. At the fourth stage (members 6-7), there is a development of hydrogen sulfide contamination in anoxic conditions (15), which may indicate a closed lagoon-type body of water (15).

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