Development prospects for Bazhenov formation bituminous claystones in the southeast of the West Siberian Plate (Tomsk Region)

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Abstract. The article considers the use of time-tested bituminous shale development technologies in the southeast of the West Siberian Plate (Tomsk Region). A research target is the bituminous claystones of the Bazhenov formation. The Bazhenov formation was divided into stratigraphic units, and the sequence of forming these units within the territory under study was restored on the basis of the peculiarities of the Bazhenov formation section structure with gamma-ray logging data. The joint analysis of logs (gamma-ray logging, resistivity logging, SP logging, neutron gamma-ray logging, induction logging) and core data revealed the wide development of carbonatization processes in the lower stratigraphic units of the Bazhenov formation, whereas the upper, most bituminous units do not have the signs of carbonatization. It is a favorable factor for using the existing technologies of producing hydrocarbons from analogous sedimentary deposits. Considering the degree of lithological disconnection of an oil-bearing object from adjacent reservoir formations allows making a conclusion that the application of the existing technologies for developing bituminous claystones can be implemented only in the insignificant territory of the area under study where the Bazhenov formation overlies Georgiev formation claystones being over 8 meters thick. To develop the oil and gas potential of the Bazhenov formation in other territories, there will be a need for new technologies that allow forming a fracture-cavernous matrix in a carbonate rock.

1. Introduction

Much attention has recently been paid to the development of oil shales as a promising source of hydrocarbons. The “shale oil” prospects within the West Siberian Plate are connected with the bituminous claystones of the Bazhenov formation where a commercial oil content has been proven for a range of areas. Many scientific publications and production reports are devoted to the oil-and-gas content of the formation. Its development projects with the use of new technical oil production capabilities are being introduced.

Taking into account that there is a need for drilling a significant number of production wells during the development of oil shales, it is most expedient to perform these operations at fields where an oil production interval is stratigraphically lower than the “shale formation” and is characterized by the high recovery of commercial reserves. The territory of the southeastern part of the West Siberian Plate is an ideal object for such innovations. Practically all fields discovered in Tomsk Region are located under the bituminous clays of the Bazhenov formation. No commercial hydrocarbon fields have been located in the Bazhenov formation deposits within the region under consideration, but its study has...
revealed oil influxes for a range of areas. Besides, there is practically ubiquitous oil staining in the core taken from the wells drilled.

There are two important issues associated with the profitability of shale oil development connected with the territorial distribution of Bazhenov formation resources and geological prerequisites to its development based on the application of corresponding technologies providing for oil production efficiency [4, 6, 11, 12]. The material presented is devoted to the second route.

2. Assessments of prospects for developing Bazhenov formation bituminous claystones

The efficiency of developing hydrocarbons in the Bazhenov formation deposits depends on understanding the geologic conditions of its establishment. Both the paleoclimate of the sedimentation basin and the specificity of the geochemical depositional environment have had a significant influence on the lithological and geophysical characteristic of the Bazhenov formation. The significant area of the sea basin, low tectonic activity of the adjacent alimentation zones, recurrent changes in the climate and the reducing environment in the upper part of the sedimentary layer have contributed to the long-term development of a bituminous argillaceous-carbonate, argillaceous-siliceous deposit that is unambiguously interpreted with radioactive, sonic and electric logging methods.

The direct correlation relationship between the value of the natural radioactivity of claystones in the Bazhenov formation and organic carbon in the rocks reasoned by the presence of zoo- and phytoplankton [5, 7] allows segmenting the deposits under consideration with gamma-ray logging in more detail [1, 3, 10].

In compliance with the analysis of the thickness and the observed differentiation of the gamma-ray logs of the Bazhenov formation deposits connected with the presence of lower-radioactivity rock interlayers, it is possible to single out four units in its composition [1]. These units reflecting the evolution of organic life in the Volgian basin are characterized by the specific level of gamma-ray logging values and are divided by one or a group of carbonate or siliceous interlayers of an insignificant thickness (0.5-2.0 m). (figure 1B, C).

The feasibility of dividing the Bazhenov formation into units on the basis of gamma-ray logging is confirmed by the studies of uranium content in core samples (figure 1B). The sampling points corresponding to the lower values of gamma-ray logging are characterized by the uranium concentration that does not exceed the values that are typical of the Vasyugan formation deposits, which testifies to significant changes in the ecosystem of this sedimentary basin.

The peculiarities of unit construction allow singling out two groups of sections (figure 1A, C). The first group (A) is characterized by the increased values of gamma-ray logging in the second and the fourth units, and the second group (B) demonstrates dropping values from upper unit 4 to lower units 1 and 3.

It is possible to determine 4 types of sections on the basis of the number of units within the groups under consideration. The first section type includes units 1-4. It is spread within the limits of the Pudinsky megalithic bank. The second type comprises units 2-4. This type covers the Nyurol depression, Parabelsky, Azharinsky megalithic banks, the eastern part of the Ust-Tym depression. The third section type comprises units 4 and 3. This type is spread in the wide territory of the Ust-Tym depression, Koltogor mega-downwarp, Kaymysov, Nizhevatovsk arches and Aleksandrovsky megalithic bank. The fourth section type comprises unit 4. It is localized within the second type development area and is confined to the most structurally elevated areas of first-order positive structures.

One of the main peculiarities of dividing the Bazhenov formation into units is the fact that the boundaries of the units are isochronous, as they reflect the intensity of zoo- and phytoplankton development at different stages of the Volgian basin development. It allows using them as reliable chronologic markers in paleographic reconstruction for the Bazhenov formation development time.

In compliance with the territorial zoning in the development of these section types at the initial stage of the Volgian transgression, the bituminous deposits of the Bazhenov formation were formed in the southwestern part of the territory under study (first type sections). The step-by-step extension of
the sea basin manifests itself in the formation of the second and third type sections. The fourth section type most likely characterizes paleo-elevations of the sea basin floor within the limits of major platform rises experiencing active consedimental growth during the Volgian transgression.

Figure 1. Segmenting (B, C) and zoning (A) the territory of the West Siberian Plate by types of Bazhenov formation section [1].

The microfaunal determinations of age for the lower Vasyugan formation deposits do not contradict the proposed Bazhenov formation development model either [2]. In compliance with figure 2, the western direction is characterized by the age slide of the Vasyugan formation top from Middle
Oxfordian (Somovskaya producing area) to Late Kimmeridgian (Vat-Yoganskaya producing area). Taking into account that there are no paleontological fragments in a good state of preservation in the Bazhenov formation territory under consideration, it allows determining the age of the first and the second units as Late Oxfordian, that of the third unit as Kimmeridgian, and the age of the fourth unit as Early, Middle Volgian.

The world experience shows that one of the main prerequisites to the efficient development of bituminous shales is the presence of carbonate layers in their composition [12]. Performing multistage hydraulic fracturing within the limits of these layers allows forming a conductive matrix able to drain hydrocarbons from the superincumbent and underlying beds of bituminous shales.

The presence of carbonate interlayers in the first, second and third units of all section types determined has been revealed in the territory under consideration with lithological studies and logging data [9]. These interlayers in most cases result from the replacement of radiolarites and silicites with calcite, dolomite and limestone.

As one can see from figure 3, carbonatization manifests itself as a complex of shallow-thickness interlayers. Carbonatization is absent or it is present as “traces” in the fourth unit that is characterized by the highest concentrations of organic carbon, which leads to higher gamma-ray logging values.

When considering the production-geophysical characteristic of the Bazhenov formation in terms of singling out section carbonatization zones, one should note the following:

- it is not always possible to register the presence of carbonatization in the formation section with gamma-ray logs and thermal neutron logs being the most popular types of logs for prospecting and exploration wells;
- the fourth unit having the highest content or organic carbon is represented with lower values of apparent formation resistivity (resistivity logging) vs. the third and the second units, which is connected with the absence of carbonized interlayers in it. This fact is also mentioned in work [4]. The “shift” of the apparent resistivity anomalies vs. the gamma-ray logging anomaly in the Bazhenov formation sections can be connected with carbonatization in the sections of the third, second and first units (figure 3).

Figure 2. Lithologic-paleontologic correlation of Upper Jurassic deposits in the central and southeastern parts of the West Siberian Plate [2].

A prerequisite to the efficient development of bituminous claystones with the use of hydraulic fracturing is the presence of impermeable beds underlying and overlying carbonate deposits in the composition of the shale formation. The reason is that the need for drilling horizontal wells with subsequent multistage hydraulic fracturing through carbonate deposits requires the lithological
separation of the object to be developed from the above and below lying reservoirs. Such conditions are consistently observed for the central part of the West Siberian Plate where the Bazhenov formation lies on the Abalak clay formation and is overlaid with claystones of the Kulomzn, Megion, Sortym, Akhsk and Frolovskaya formations.

**Figure 3.** Main types of the Bazhenov formation section for the Kaymysov acrh and Koltogor megadownwarp [9].

Within the limits of the territory under study, bituminous shales are deposited on the sand-clay J1 horizon of the Vasyugan formation and on the continental deposits of the Naunaksk formation and are overlaid by Kulomzn formation claystones. The lithological separation of the Bazhenov formation from the lower deposits is possible in case of the presence of Georgiev formation claystones (figure 1 and 4).

Figure 4 presents an isopach map for the Georgiev formation based on the results of drilling prospecting and exploration wells. The map shows that the thickness of this formation varies from 0 to 6 meters in a significant territory, which is insufficient for the high-quality development of the shale formation with the existing method.

Assuming that such a method of Bazhenov formation operation is possible provided the Geogiev formation thickness is 8 meters, its area of application is limited to the central and southeastern parts of the Nyurol depression, southeastern part of the Pudinsky megalithic bank, northern and southern parts of the Ust-Tym depression.

Other territories need the development of their own methods of bituminous claystone development, excluding hydraulic fracturing for forming a fracture-cavernous matrix of a carbonate formation or restricting its penetration into underlying rocks. These methods will allow producing shale oil not only
in areas with an enhanced generation potential of the Bazhenov formation, but also in the fields of Tomsk Region under development (figure 4). It will significantly enhance oil production efficiency in this region.

**Figure 4.** Thickness map for the Georgiev formation of the southeastern part of the West Siberian Plate.

### 3. Conclusion

This work devoted to the use of the existing bituminous shale development methods in relation to the Bazhenov formation deposits in the southeast of Western Siberia (Tomsk Region) is based on the analysis of its structure peculiarities obtained with logging techniques (gamma-ray logging, thermal neutron logging, resistivity logging, SP logging, induction logging) and analyzing core samples from prospecting and exploration wells.

The division of the formation into stratigraphic units with gamma-ray logging data and the analysis of the uranium content in the core have allowed determining the spatial sequence of their formation, whereas the existing connection between the organic carbon content and the values of gamma-ray logging has contributed to the high-quality assessment of the hydrocarbon generation potential for each of these units. The lithological studies of the Bazhenov formation rocks [9] and the analysis of the correspondence between gamma-ray logging anomalies and apparent rock resistivity testify to the
active manifestation of layer-by-layer secondary carbonatization in the lower, less productive units of the Bazhenov formation. It allows using the carbonate part of the Bazhenov formation section to form a filtration fracture-cavernous matrix in it by performing multistage hydraulic fracturing with a subsequent mud-acid treatment. The purpose of this operation is draining oil from the upper bituminous unit. As there are no reliable impermeable beds in the bottom of the Bazhenov formation, using this technique is limited to insignificant territories where the underlying claystones of the Georgiev formation are over 8 meters thick, which guarantees the reliability of hydrodynamic isolation for the subjacent reservoirs of the Vasyugan (Naunaks) formation and hydraulic fracture cracks. For a significant part of the territory under study, there is a need to develop a unique bituminous claystone development technology based on forming a filtration carbonate formation matrix without hydraulic fracturing or restricting its penetration into the underlying reservoirs of the Vasyugan and Naunaks formations. Such technologies will allow producing shale oil not only in the areas with an enhanced generation potential of the Bazhenov formation, but also in the fields of Tomsk Region under development. It will significantly enhance oil production efficiency in this region.

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