

Petrophysical rock properties of the Bazhenov Formation of the South-Eastern part of Kaymysovsky Vault (Tomsk Region)

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Abstract. The article presents the results of studying petrophysical rock properties of the Bazhenov Formation of the South-Eastern part of Kaymysovsky Vault with the Gas Research Institute (GRI) method. The authors have constructed dependence charts for bulk and grain density, open porosity and matrix permeability vs. depth. The results of studying petrophysical properties with the GRI method and core description have allowed dividing the entire section into three intervals each of which characterized by different conditions of Bazhenov Formation rock formation. The authors have determined a correlation between the compensated neutron log and the rock density vs. depth chart on the basis of complex well logging and petrophysical section analysis. They have determined a promising interval for producing hydrocarbons from the Bazhenov Formation in the well under study. Besides, they have determined the typical behavior of compensated neutron logs and SP logs on well logs for this interval. These studies will allow re-interpreting available well logs in order to determine the most promising interval to be involved in Bazhenov Formation development in Tomsk Region.

1. Introduction

Oil companies have recently started paying greater attention to unconventional reserves due to the depletion of conventional hydrocarbon resources. The biggest unconventional oil reservoir in Russia is the Bazhenov Formation located in the West Siberian Basin. The oil pools of this formation are considered one of the most important targets to replenish hydrocarbon resources in Russia [1, 2]. The uniqueness of the Bazhenov Formation consists in the fact that it, on the one hand, is the main source rock of the West Siberian Basin and, on the other hand, it is reservoir. Thus, Bazhenov Formation rocks are a source of both existing and potential oil, which indubitably should be taken into account during the selection of oil production technologies for such complicated reservoirs [3].

The main technology used to produce movable oil from the Bazhenov Formation is horizontal drilling with a subsequent multistage hydraulic fracturing [3]. The thermal gas treatment technology is now being tested for producing potential oil from kerogen-containing rocks in Russia [4, 5].

One of the most promising areas for J_0 development in Tomsk Region is the eastern part of Kaymysovsky Vault. This structure was submerged for a long time under sea basin transgression during the Late Jurassic – Early Cretaceous time, which allowed forming thick Bazhenov Formation rocks (about several dozen meters). Several major oil fields have been discovered in the eastern part of



Kaymysovsky Vault and they have been commercially developed for a long time. There are hundreds of wells drilled in this territory that penetrate Bazhenov Formation deposits. Besides, they have obtained an oil flow on the South-Eastern slope of Kaymysovsky Vault from J_0 at the Fedyushkinskoe field. All these facts together with the developed oilfield infrastructure will allow significantly reducing expenses on bringing the Bazhenov Formation into development in this territory.

However, despite the proven oil-bearing capacity of the Bazhenov Formation, there is a range of problems connected with production of hydrocarbons from it. First, these hydrocarbon reserves are hard-to-recover and require an individual approach to development. Second, the deposits of this formation are not well-studied enough now. Thus, the main problem of the geological-geophysical studies of Bazhenov Formation deposits at most fields in Tomsk Region is connected with the absence of a complete range of well logging methods and poor core recovery. Besides, there is the absence of a sufficient number of laboratory core studies for the unambiguous localization of areas with improved reservoir properties of the Bazhenov Formation. Due to the ultra-low reservoir properties of the siliceous-argillaceous-carbonate deposits of the Bazhenov Formation, it is impossible to determine the petrophysical properties of these rocks with laboratory equipment using standard methods [6].

Gas Research Institute (GRI) in Chicago has made significant progress in developing methods used to determine the petrophysical properties of shale formations. The Institute has developed a comprehensive method of determining shale reservoirs: "Development of laboratory and petrophysical techniques for evaluating shale reservoirs." [7].

The aim of this work was to study the petrophysical properties of Bazhenov Formation deposits in the South-Eastern part of Kaymysovsky Vault with the GRI method.

2. Method of studying petrophysical properties of Bazhenov Formation rocks

The GRI method [7] was developed to determine the main petrophysical properties (porosity, permeability, saturation) of shale formations. The method consists in crushing core into fractions of an equal size and determining parameters on crushed core. The GRI method allows significantly reducing the time of permeability experiments (2,000 seconds) and excluding the impact of natural fracturing on the values of the parameter under consideration. However, despite all the benefits of this method, its main drawback is making experiments in atmospheric conditions (without pore and ground pressure).

The paper [8] shows that the determined permeability values of the core plugs are $10\text{--}10^6$ times higher vs. rock matrix permeability due to the developed natural fracturing of Bazhenov Formation rocks. Thus, in order to determine the true values of shale reservoir permeability, experiments should be made on crushed core.

The petrophysical properties (bulk and grain density, open porosity, matrix permeability) of Bazhenov Formation deposits were determined on cores with natural saturation the SMP-200 shale permeameter. Before the start of the experiment, whole core was crushed and sieved through two- and one-millimeter cells to obtain a fraction of a homogeneous size. The mass of one weighed portion amounted to 30 ± 0.01 g.

The bulk and grain density of the samples was determined on crushed core via the gas saturation method. The experiment on determining bulk and grain density consisted in calculating a sample volume at the baseline (before helium penetration into pores) and at the end of the experiment (after sample saturation with helium) correspondingly for the pressure drawdown curve. Pressure drops as gas (helium) penetrates into the micropores of separate rock particles [9]. Since SMP-200 works on the basis of the Boyle's law, we can calculate a corresponding value of a core volume for every pressure value in case of the isothermal process during the whole experiment.

The open porosity coefficient was calculated on the basis of bulk and grain density values [9].

The permeability of the Bazhenov Formation samples was determined via the Pressure Pulse Permeability method. The method consists in the approximation of the theoretical curve of experimental data on a pressure drop that occurs due to helium penetration into the micropores of

separate particles in crushed core, as well as the subsequent calculation of matrix permeability values on the basis of the obtained curve parameters [7, 10].

The insignificant pressure change during the experiments (0.1-0.5% of the absolute value) imposes heightened requirements to device calibration, the absence of leaks and thermal stabilization during the process of determining petrophysical properties [9].

3. Petrophysical and geological-geophysical study of Bazhenov Formation deposits in the South-Eastern part of Kaymysovsky Vault

The authors used rock samples from Bazhenov Formation deposits (J_0) at one of the fields in the South-Eastern part of Kaymysovsky Vault. The Bazhenov Formation is exposed at this field and drilled with core sampling in an exploration well. In the well section, the Bazhenov Formation with its top located at the depth of 2,663.0 m is characterized by conformable bedding on deep-sea dark-grey Georgiev Formation clays and is interbedded by a unit of marine, predominantly argillaceous Kulomzin Formation deposits. The thickness of this formation is 13 m.

Figure 1 shows the results of the petrophysical studies of the Bazhenov Formation rock samples from the exploration well under consideration.

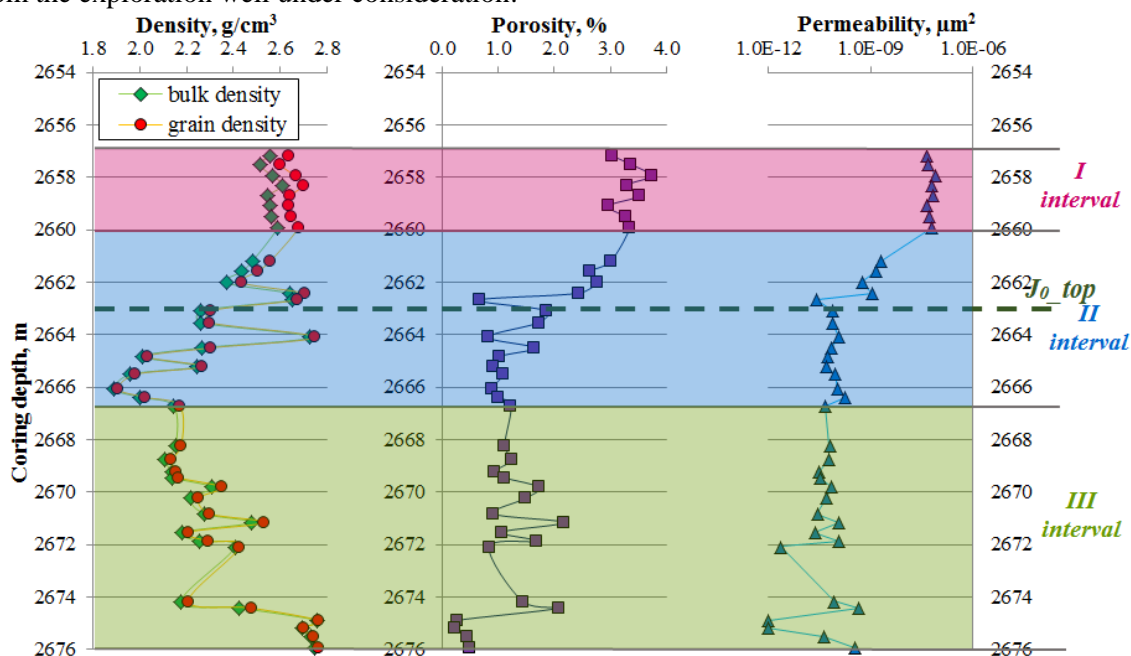


Figure 1. Results of the petrophysical studies of Bazhenov Formation rocks in the South-Eastern part of Kaymysovsky Vault.

A chart featuring the dependence of petrophysical rock properties vs. depth is constructed on the basis of processing 13 Kulomzin Formation samples and 28 Bazhenov Formation samples (interval – 2,657.2-2,675.9 m).

The petrophysical data (Figure 1) and core description allow dividing the entire section into three intervals each of which characterized by different conditions of rock formation.

In compliance with the core description, the first interval (2,657.2-2,659.9 m) is formed by dark-grey, silty, sometimes slabby shalestone having homogeneous composition. Composition homogeneity is confirmed by the insignificant change in the grain density of rocks varying from 2.60 g/cm³ to 2.70 g/cm³ and close values of the open porosity coefficient (from 3.00% to 3.73%). The significant changes in the grain density values and open porosity coefficient are connected with the horizontal microlamination of the deposits. Besides, this interval is characterized by high matrix permeability

coefficient values – about $6 \cdot 10^{-8} \mu\text{m}^2$. It is possible to conclude for the first interval that these deposits were formed in a relatively quiet depositional environment (Kulomzin Formation).

The second interval (2,659.9-2,666.7 m) is formed by brownish shales. The samples are characterized by a big amount of pyrite in the form of microscopic inclusions, which testifies to deep-water depositional conditions. The interval demonstrates significant changes in the mineral composition of its rocks: varying density from 1.91 g/cm^3 (at the depth of 2,666.1 m) to 2.75 g/cm^3 (at the depth of 2,664.1 m). The low rock density values are connected with the high content of kerogen and bitumen in the shales. The content of total organic carbon in this interval reaches 25% in compliance with pyrolytic core studies. The high density values are connected with the presence of big broken thick-walled shells composed of white calcite. Besides, this interval has two dense beds: one in the top of the Bazhenov Formation and another in the bottom of the Kulomzin Formation. These beds can be mapped on the basis of the high rock density (2.71 g/cm^3 and 2.75 g/cm^3 , respectively) and low open porosity coefficient values (0.66% and 0.82%). All these factors testify to a heterogeneous and changeable deposition process in the South-Eastern part of Kaymysovsky Vault. The shape of the curve in the open porosity coefficient distribution chart for this interval repeats the shape of the curve of rock grain density vs. depth, but has a more flattened look. Sample porosity gradually drops from 3.35% (at the depth of 2,659.9 m) and reaches a mean value of about 0.88% by the end of the interval under study. Analogous behavior is also typical of matrix permeability. The matrix permeability of the rocks drops with depth to reach the value of about $6 \cdot 10^{-11} \mu\text{m}^2$ and is practically invariable up to the bottom of the Bazhenov Formation. The research findings show that the second interval corresponds to a transient depositional process from sea basin transgression to regression. The deep-water shales of the Bazhenov Formation are gradually interbedded with more shallow-water Kulomzin Formation deposits. The density and porosity chart does not allow clearly determining the boundary of the Bazhenov Formation top – both on well logs and on the basis of petrophysical studies.

The third interval (2,666.7-2,675.9 m) is formed by homogeneous dark-brown to black shales. The density of its rocks makes 2.17 g/cm^3 on average, which testifies to the relatively quiet depositional environment of Bazhenov Formation rocks. The beds of carbonized shales characterized by the density values of up to 2.53 g/cm^3 and open porosity coefficient values making up to 2.16% start appearing at the depth of 2,669.8 m. The bottom of the Bazhenov Formation has an argillaceous-carbonate bed at the depth of 2,674.2 m. It is characterized by almost equal high values of grain density amounting to up to 2.76 g/cm^3 and low open porosity coefficient values reaching less than 0.43%. The carbonate rocks found in this interval have zero matrix permeability (emphasized with white color in Figure 1), whereas, in compliance with the core description, this argillaceous-carbonate interval is characterized by a high degree of rock fracturing and the core is crushed into separate pieces.

Figure 2 shows the results of the petrophysical studies of the Bazhenov Formation samples vs. the results of the geological-geophysical studies for the exploration well under consideration.

The analysis of the range of well logging methods in the exploration well of the field under consideration makes it possible to conclude that the thickness of the Bazhenov Formation is determined on the sections on the basis of the abnormally high electric resistance and high gamma ray logging values, therefore the Bazhenov Formation shales are one the basic benchmarks in Western Siberia. Besides, the section shows several negative SP log anomalies that testify to the presence of a reservoir in the Bazhenov Formation. However, the negative anomaly of the SP log also testifies to carbonate beds. In this connection, there is a need for a priori information on the formation (geochemical core analysis, field tests, etc.) to map reservoir rocks in the Bazhenov Formation in a more detailed way.

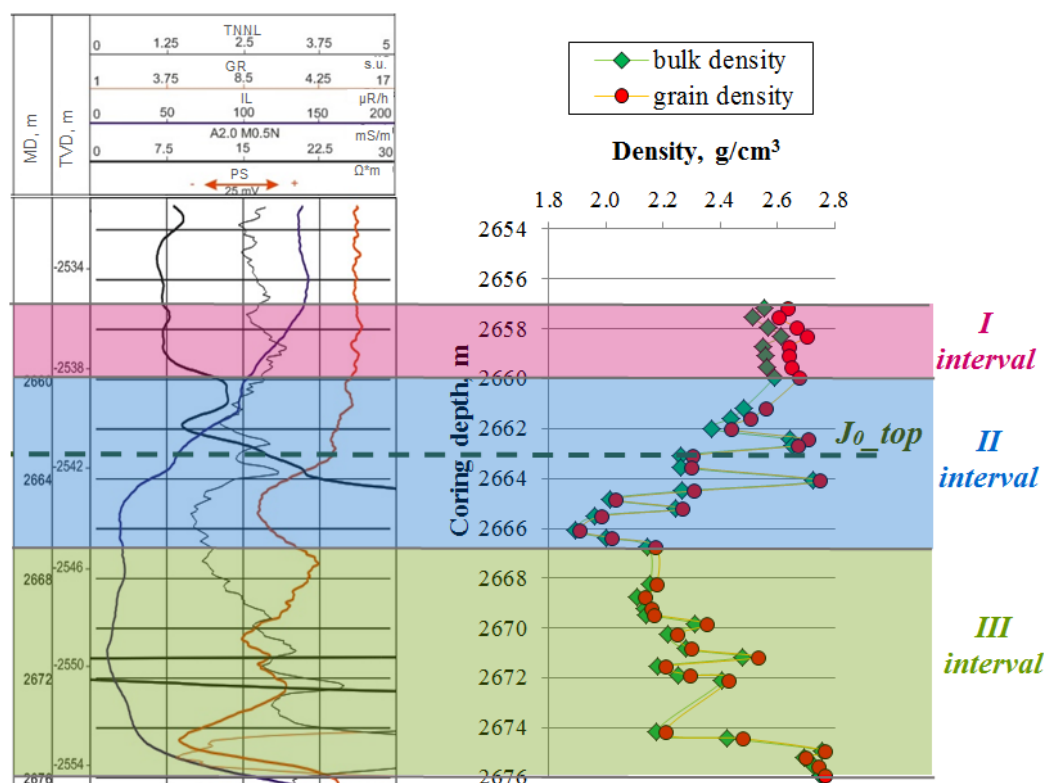


Figure 2. Results of geologic-geophysical and petrophysical studies of Bazhenov Formation rocks in the southeastern part of Kaymysovsky Vault.

It should be noted that the intervals determined with the help of petrophysical studies and core descriptions are invisible on well logs. However, the chart featuring the dependence of the bulk and grain density of the rocks vs. depth reliably correlates with the compensated neutron log on well logs. This relationship can be used in well logging interpretation to determine Bazhenov Formation lithotypes.

4. Conclusion

Thus, the GRI method was first applied in Russia at the laboratory of Tomsk Polytechnic University to study reservoir rocks with ultra-low reservoir properties. The petrophysical analysis of the Bazhenov Formation rocks in the South-Eastern part of Kaymysovsky Vault shows that the GRI method with the use of the SMP-200 shale permeameter allows dismembering deposits depending on rock density distribution in a more detailed way. This dismembering allows determining the inhomogeneity of depositional conditions.

The geological-geophysical and petrophysical study of the section has allowed determining a correlation between the compensated neutron log and the rock density vs. depth chart. This relationship can be used in the future in well logging interpretation at the fields of Tomsk Region to determine Bazhenov Formation lithotypes. Besides, compensated neutron log values can be used for the preliminary evaluation of mechanical rock properties forming the section in order to design a multistage hydraulic fracturing.

The complex study of the section and the geochemical analysis have allowed concluding that one of the intervals under consideration (the second interval) is the most promising bed of the Bazhenov Formation for development. This interval is formed by bituminous shales characterized by the high content of movable hydrocarbons and kerogen (TOC amounting to up to 25% in compliance with

the pyrolytic research data). The interval has the minimum values of compensated neutron logging on well logs and density in compliance with the petrophysical analysis and a negative anomaly on its SP log.

Finally, the present studies and the relationships obtained will allow re-interpreting the existing well logging data in order to determine the most promising intervals for further Bazhenov Formation development.

5. Thanks

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