Lithology evaluation of a Bazhenov formation reservoir using seismic and well log analysis

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Abstract. The Bazhenov formation is the analog of the Bakken formation; these formations are source rocks and contain tight reservoirs of a tectonic-hydrothermal model. The interpretation of well logs begins with the identification of the Bazhenov marker and tracing a carbonate layer within the Bazhenov formation by GR, neutron and DT logs. The thickness of this layer varies from 1 to 2 m. The next step is seismic interpretation. The creation of 2D seismic forward models is presented in this paper. In these models, the behavior of the amplitude with and without a carbonate layer was studied. These models allow tracing the sign of a carbonate layer (negative amplitude peak). The analysis of 3D seismic cube slices was performed. An amplitude map was created. The distribution of carbonate rock was detected according to this map. Thus, using this approach a thin layer was determined within the Bazhenov formation.

1. Introduction
Attention to the problem of unconventional hydrocarbon resources development has been constantly growing in the past few years. Bazhenov formation development problems are becoming essential. The main goal of this project is the evaluation of the Bazhenov formation reservoir and study of very thin reservoir rocks using wireline logs and seismic interpretation.

This goal may be subdivided into the following objectives:
- Comparison of the Bazhenov formation and other well-known formations;
- Evaluation of organic matter in the Bazhenov formation within Field S;
- Interpretation of logging data and correlation of layers in the wells;
- Analysis of the amplitude and creation of 2D seismic forward models that allows detecting the sign of carbonate distribution;
- Analysis of horizontal and vertical sections of the 3D seismic cube;
- Creation of an amplitude map and analysis of the distribution of reservoir rocks.

2. Comparison of the Bazhenov and Bakken formations
The deposits of the Bazhenov and Bakken formations are oil shale that has the properties of source rocks and characterized by a very high content of organic matter. The main similarity is a tight rock reservoir within source rock. The main difference is the thickness of the pay zone. The Bakken reservoir is 40 m thick, the Bazhenov – 0.5-3 m thick. The reservoir of the Bazhenov formation is confined to a thin bed and restricted in the lateral direction. However, the Bazhenov formation is characterized by higher values of porosity that can reach 10\% or more (on average, 8\%) and permeability up to 10 mD, but being 1 mD on average. Also, the Bazhenov formation occupies the area of more than 1 million sq. km, while the Bakken formation covers 520 thousand km\textsuperscript{2}. The main
feature of the Bazhenov formation is a very different content of rocks (kerogen and mudstone, carbonate and silica components) depending on the location [1, 2].

3. Evaluation of organic matter in the Bazhenov formation within Field S
The dependence of organic matter versus the average gamma ray value was obtained by V.A. Kontorovich in his work [3]. He obtained two dependencies:

- TOC=0.18GK−4.81 (R²=0.9)
- TOC=0.17GK+0.12 (R²=0.94)

The second relationship is applicable for the transition zone between the Bazhenov and Maryanovsky formations (GR has the average values of 20-55). This area covers a significant part of Tomsk Oblast. Field S is located in the transition region, in the Ust-Tym depression. Thus, TOC was determined on the basis of the second relationship (figure 1).

![Figure 1. TOC content in the Bazhenov formation at Field S](image)

Three reservoir models are considered below. The model of a fractured reservoir assumes that reservoir-rock was represented by bituminous mudstones ("bazhenite") in which horizontal microcracks (65%), vertical (65.7%) and stylolite cracks comprise up to 11%. This model was described by E M Halimov and V S Melik-Pashayev [4].

The foliated model explains that the reservoir was formed by the fluid auto-fracturing of the formation. This process was explained to be the result of the transformation from organic matter to liquid state by F G Gurari, I I Nesterov in 1977-1985.

The tectonic - hydrothermal model is associated with tectonic and hydrothermal effects on the rocks. This reservoir was characterized by a fracture-cavern-pore texture (M U Zubkov) [5]. Only the third reservoir model was considered with a wireline log analysis and seismic modeling.
4. Well correlation

Correlation was performed on the basis of log data from eleven wells. Correlation (figure 2) started with the identification of markers in the part of the cross section under study. The Bazhenov formation is a regional seismic marker lying on the Georgiev formation.

![Figure 2. Correlation panel for five wells](image)

This marker was identified with gamma ray logs and a lateral device. The values of gamma ray logging are very high and may reach 30 mR per hour (abnormally high-radioactive bituminous shale). The carbonate layer was indicated in the lower part of the Bazhenov formation with acoustic logs (travel time decreases), and also with neutron porosity logs (porosity decreases too). This carbonate layer was indicated practically in all wells, except two wells (175 and 160). The average thickness of the layer ranges from 1.2 to 2 m. Thus, this layer may be interesting as a potential reservoir within the Bazhenov formation.

The Georgiev formation is also the first-order marker that is represented by black and grey thick mudstones. This marker was determined with induction logs (the minimum value of the induction log). The Naunakska formation is subdivided into two sub-formations: coal-overlaying sub-formation and sub-coal sub-formation. The coal layer divides these sub-formations and is 1-1.5 m thick. This layer is laterally continuous at Field S. The Naunakska formation is characterized by clastic rocks.

5. Seismic interpretation

One of the basic methods of qualitative interpretation is the seismic amplitudes analysis, while amplitudes are the main parameters of seismic data recorded [6].
5.1. **Petrophysical analysis of velocity and density of rocks**

The acoustic impedance of rocks is the main factor that affects the reflection coefficient and the amplitude of the wave. Acoustic impedance depends on density and velocity. If \((\rho \times V)\) increases, then acoustic impedance increases too. Amplitude increases, if the acoustic impedance of two layers is very different. Thus, if a reflectivity coefficient is high, then the amplitude is also high.

Firstly, the velocity of the Bazhenov formation was determined. As one can see (figure 3), the Bazhenov formation was divided into two parts in accordance with the velocity (low-speed part and high-speed part). The upper part has low velocity (2,800 m/sec), while the lower part has high velocity (3,400 m/sec).

![Figure 3. Chart of gamma ray response versus velocity for the Bazhenov formation (well 144)](image)

Secondly, the same plots were created to determine the velocities of each lithology type (figure 4).

![Figure 4. Chart of gamma ray response versus velocity for rocks with different lithology types located under the Bazhenov formation](image)

The velocities determined were used to create 2D seismic forward models. The next figure (figure 5) describes the division of the Bazhenov formation into packs that can be characterized by a fixed velocity value.
2D seismic forward models were created in the following sequence:

- models of acoustic rock properties and layer thicknesses were created in Excel.
- geological study was made for the models in Excel, such as: presence and absence of a carbonate layer, increasing thickness of the carbonate layer, as well as the presence of gas in the coal-overlaying formation (figure 6);

![Figure 5. Example of lithology division based on velocity values](image)

### Figure 6. Part of the model, Legend for all models

The elementary wavelet was matched with the similar characteristics of the real wavelet, knowing that a real seismic section was recorded with the frequency of 19.2 Hz of the wavelet. The wavelet shape and its characteristics are depicted in figure 7 (consideration was performed for 19 Hz and 47 Hz);
5.2. 2D seismic forward models with and without a carbonate layer for a seismic impulse at 19Hz

According to this 2D seismic forward model 1, the sign of carbonate layers was not unambiguously detected (figure 8). Thus, the real seismic cross section cannot be applied to detect a carbonate layer. The amplitude with a carbonate layer is almost the same as the amplitude without a carbonate layer. Thus, in the next 2D seismic forward models, a wavelet with the frequency of 47 Hz was used, because this frequency is applicable to detect exactly the Bazhenov formation and is the sign of a carbonate layer.

5.3. 2D seismic forward models at 47 Hz with and without a carbonate layer

Obtained by one-dimensional simulation (figure 9), the synthetic seismic trace was analyzed for the presence and absence of a carbonate reservoir that was detected with wireline log interpretation. One
can see from this figure that the presence of carbonates affects the image, since the negative amplitude increases (is more pronounced) where carbonates occur.

![Figure 9. 2D seismic forward models (with and without a carbonate layer)](image)

6. **Attribute analysis**

The visual analysis of slices in each well over a certain period of time (where a carbonate layer is located) was performed. The information from the slices and that from the 2D seismic forward models was taken as a basis. It is known that the carbonate layer is located immediately in the bottom of the Bazhenov formation, and the seismic surface of the bottom part of the Bazhenov formation was used as initial data (but this surface is slightly lower than the carbonate layer), then a carbonate surface was created. This surface has the same configuration as the bottom part of the Bazhenov formation, however, the surface is located higher where the first largest peak occurs (“carbonate peak”) (figure 10).

![Figure 10. Carbonate layer location within the Bazhenov formation](image)

The next step was to create an amplitude map (figure 11). This attribute retrieves the value of the amplitudes of the existing 3D seismic cube with respect to the carbonated bed.
As the result of this map interpretation, the distribution of the carbonate layer was contoured. Thus, it may be concluded that the distribution of the carbonate layer is lateral. Most wells lie exactly on the carbonate layer and only two wells (160 and 175) lie on the transition zone, i.e. grey color. Thus, the carbonate formation wedges out in wells 160 and 175.

7. Generation productivity of the Bazhenov rocks

The average content of organic matter is quite high (around 8%). TOC is one of the main parameters that characterizes the generation potential of rocks, the quality of organic matter, the state of katagenesis and the volume of rocks containing organic matter; all these parameters affect the generation productivity [7].

The following approach in estimating the generation productivity of the Bazhenov formation was applied: the product of the organic hydrocarbon mass with a generation productivity coefficient for the area where the maturity of katagenesis corresponds to the main phase of oil generation. Passive hydrocarbon resources can be assessed with a generation coefficient, as this coefficient can be used to identify specific generation productivity.

The generation productivity map of the Bazhenov formation in Tomsk Oblast presented below (figure 12) was obtained by multiplying the map of organic matter (Corg) in Tomsk Oblast by the generation coefficient (Kgn) and by the organic hydrocarbon mass of the Bazhenov formation (Msp) [2].
This map shows the amount of hydrocarbons generated from one square area. According to the obtained map, it may be concluded that the rocks of the Bazhenov formation have a high generation potential and it reaches 350-500 kg/m$^2$ for Field S.

8. Results

The fracture-cavern-pore model of the rocks possibly represents a carbonate layer that was determined through logging interpretation and seismic data. Constructing 2D seismic forward models allowed identifying and tracing the sign of carbonate rocks.

The amplitude map was plotted on the basis of these 2D seismic forward models and the slices were analyzed. This map may be applied to evaluate the spread of the reservoir rocks that are possibly represented by carbonates.

9. Conclusion

1. Unconventional oil reserves are becoming more and more challenging due to the growing demand for oil and the depletion of traditional oil reserves. Thus, special attention should be paid to the Bazhenov formation, which is primarily a source rock and is an unconventional reservoir. The Bazhenov formation is continuous and is represented by bituminous mudstones, interlaying-shale-carbonate-silica and the high content of organic matter. In this project, the fracture-cavern-pore model of the reservoir was considered, which is mainly associated with the layers of secondary transformed radiolarites;

2. Carbonate nature of this layer was confirmed by acoustic, neutron and gamma ray logs (high velocity values (5,000m/s), abnormally low neutron values, and also low gamma ray log values). Silicate rocks do not differ from carbonate rocks as depicted on the mentioned logs, so a photoelectric absorption log is recommended for their more confident separation. The essential difference is that the carbonate rocks have a very high Pe value and the silicates are characterized by the minimum value of Pe;

3. Sign of a carbonate layer can be traced with a 2D seismic forward model;

4. Amplitude Map can be used to analyze the carbonate distribution and create a future development strategy;

5. In addition, this approach based on the visual analysis of the wave pattern can be suggested to determine these thin layers.
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