Bazhenov fm unconventional reservoir 3D geological modeling methodology

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Abstract. The Bazhenov Formation has been studied for more than 50 years, but its petroleum potential, optimal STOIIP or resource estimation approaches, the methodology used to select a reservoir, determine its properties are still unclear. The distinctive features of bituminous shale are specific geochemical properties chosen as basic parameters to perform the geological modeling of the Bazhenov deposits and determine the key areas. The main objective of this paper is to choose an optimal 3D geological modeling algorithm and test conventional (petrophysical) and specific (geochemical) properties.

1. Introduction

The Bazhenov Formation has been studied for more than 50 years, but its petroleum potential, optimal STOIIP or resource estimation approaches, the methodology used to select a reservoir, determine its properties are still unclear. The distinctive features of bituminous shale are specific geochemical properties chosen as basic parameters to perform the geological modeling of the Bazhenov deposits and determine the key areas. The main objective of this paper is to choose an optimal 3D geological modeling algorithm and test conventional (petrophysical) and specific (geochemical) properties. Moreover, some specialists characterize the reservoir as fractured and therefore the tectonic aspect plays an important role in the process of Bazhenov Formation reservoir development. The Bazhenov deposits of field A located in the south-western part of Tomsk Region are considered in this paper. Exploration operations are currently conducted in this area and one of the goals of this study is to estimate the petroleum potential and prospects of this field.

2. Materials and methods

Geochemical and petrophysical properties were chosen as the most important parameters used to determine oil-in-place and identify key zones for reservoir development. The author concludes that a set of core data, well logging and seismic data should be used for qualitative 3D geological modeling.

Lithotype differentiation was performed to ensure the accurate modeling of properties. One of the wells was selected as a reference well where core data and a complete necessary well logging complex are present. Eight lithotypes were detected and all of them were united into 2 groups: upper – more kerogenic silicite and low – more carbonated lithotypes, using a complex of core mineralogy, thin sections description and well logs (Figure 1).

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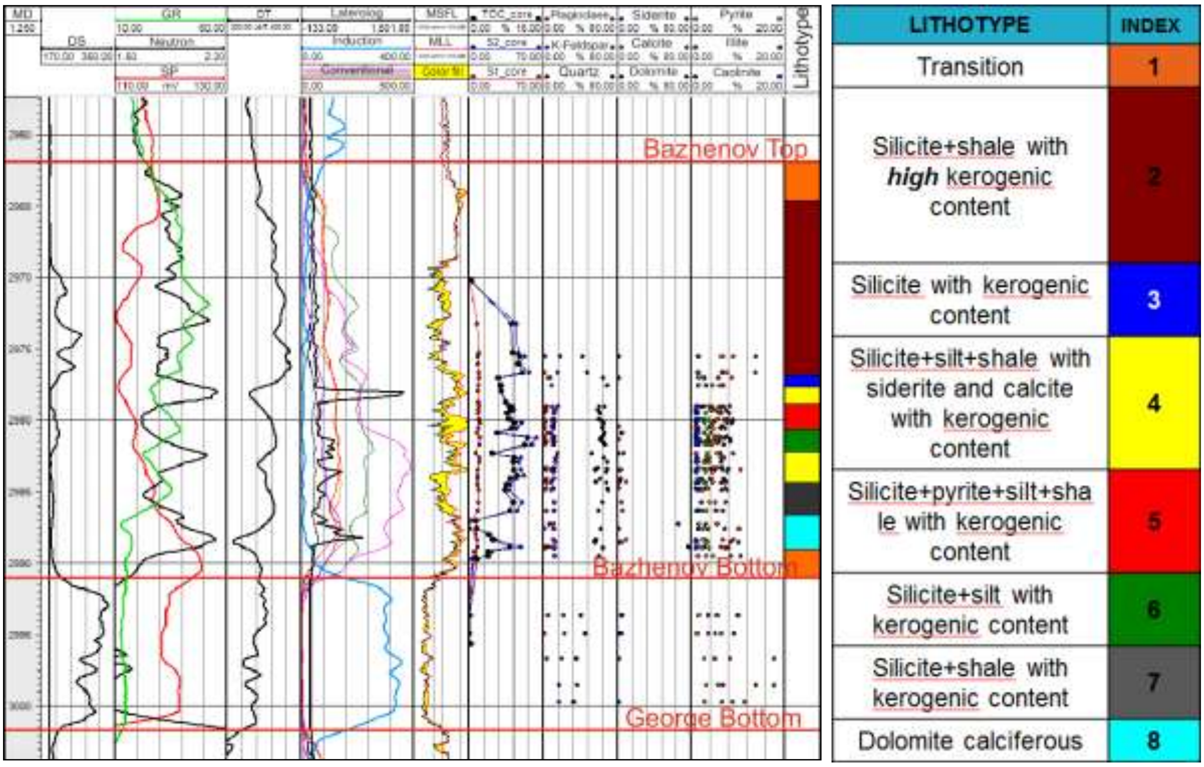

Figure 1. Lithotype differentiation in a reference well.

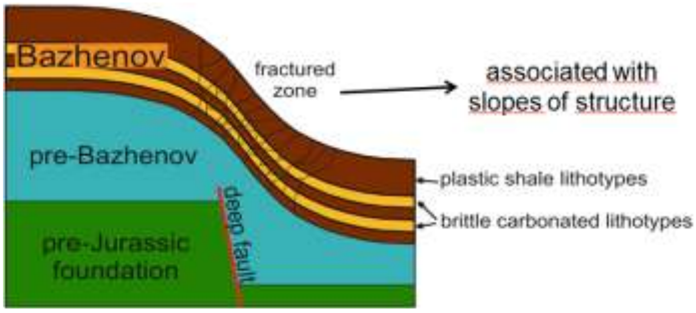

Figure 2. Diagram of fractured zones and deep faults.

It should be mentioned that one can see a difference in the rates of the synthetic model and CM during the initial period of time. It confirms a transient flow mode that cannot be evaluated with the CM method.

An empirical dependence between core properties and well log readings was found separately for each lithotype. In particular: Total Organic Content versus Gamma-Ray and Porosity versus Microlaterolog. The Direct TOC vs. GR dependence is explained by the high content of uranium in organic matter. The standard porosity well log methods (Acoustic and Neutron) are not suitable due to the small values of porosities and the impact of the mineral rock composition and TOC on well log readings. Porosity is determined with the thermogravimetric method that takes into account the matrix and fracture pore volume. The empirical dependence “Hydrogen index and S1 parameter versus TOC” was obtained. Thus, petrophysical and geochemical properties were determined for other wells without core.

Seismic data were used to analyze the distribution of properties in interwell space. This paper presents only 2D profiles of low frequency. This frequency is not sufficient to recognize any inner features of the Bazhenov Formation. The derivative analysis of the seismograms was made. The result of this analysis is an additional boundary between 2 zones of the Bazhenov Formation: upper – more organic rich and shale content (low AI) and low – less organic rich and more carbonate content (high AI). This information allows distributing lithotypes in interwell space more correctly.

A tectonic analysis was made and faults were interpreted in the Bazhenov Formation and deeper in the pre-Bazhenov rocks. According to pre-Jurassic foundation tectonic map, the main faults have an orthogonal direction – north-eastern and north-western. The interpretation of the faults in all 2D profiles shows that the faults have the same directions and the majority of the faults do not cross the Bazhenov Formation, but they create fractured zones and can be a reason for fractured reservoir development. The fractured zones in the Bazhenov Formation are associated with deep faults and with the high dip angle of the Bazhenov structure. In other words, the fractured zones are connected with the slopes of structure folds. This idea is shown in Figure 2. Moreover, brittle carbonated lithotypes are more likely to form fractures. Furthermore, an oil inflow was obtained from the wells located in the areas of high dips. Consequently, the productivity index can be connected with the dip angle.

According to most specialists [2, 3], the Bazhenov Formation has two basic types of fractures: auto fluid fractures and tectonic fractures (Figure 3).

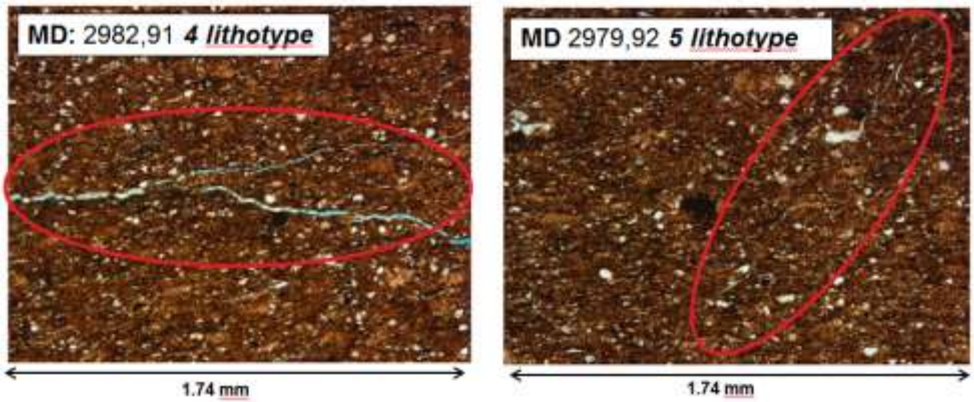

Figure 3. Photos of thin sections in a reference well: Left – Auto fluid fracturing (along horizontal lamination); Right – Tectonic fracturing (vertical fractures due to deep faults).

Organic matter converts into mobile hydrocarbons as it buries and enters an oil window. The growing volume of fluid leads to auto fluid fracturing, and microfractures are mainly formed in less consolidated zones with lateral orientation in conformity with sedimentation lamination. This process is the main reason for the abnormally high formation pressure. Tectonic fractures are mainly formed in fractured zones associated with deep faults.

The models of petrophysical and geochemical properties were based on the lithotype model that was constructed using Indicator Ordinary Kriging, as the Bazhenov Formation sediments are laterally extended at large distances and lithotypes are correlated in different wells.

Dip surface characterizing the fractured zones and, consequently, more voided zones or more porous zones was used as a 2D trend to model porosity with Sequential Gaussian Simulation. Permeability was modeled using an empirical equation with porosity.

Before describing the geochemical modeling process, we should briefly characterize the catagenic maturity of the Bazhenov Formation. According to the tectonic map of the sedimentary cover, Field A is located in the Nyurol Basin underlying surrounding positive structures. According to the tectonic map of the Pre-Jurassic foundation, Field A is above basic intrusive rocks. These 2 conceptual facts lead to high heating of the Bazhenov rocks and, consequently, to their high maturity. The Bazhenov deposits of Field A are in the oil window phase. Moreover, according to the catagenic maturity map developed by Goncharov, field A is located in the zone of a high Tmax value and, according to core data from the reference well, Tmax equals 440 degrees. This information explains the importance of determining geochemical properties.

Geochemical properties such as Total Organic Content, S1 parameter (Figure 4) and Hydrogen Index were modeled with the use of Sequential Gaussian Simulation based on the lithotype model. The highest TOC is concentrated in the second kerogenic silicite lithotype while carbonated lithotypes are characterized by low TOC values. Hydrogen Index characterizes the oil-generation potential of source rocks. According to the HI values, the source rocks of the Bazhenov Formation at Field A are in the oil window phase. HI is connected with TOC and therefore carbonated lithotypes are characterized by low HI thanks to which they are less organic-rich. The S1 parameter characterizes already generated mobile oil. The S1 parameter is only low for dolomites. Almost all lithotypes are characterized by high S1.

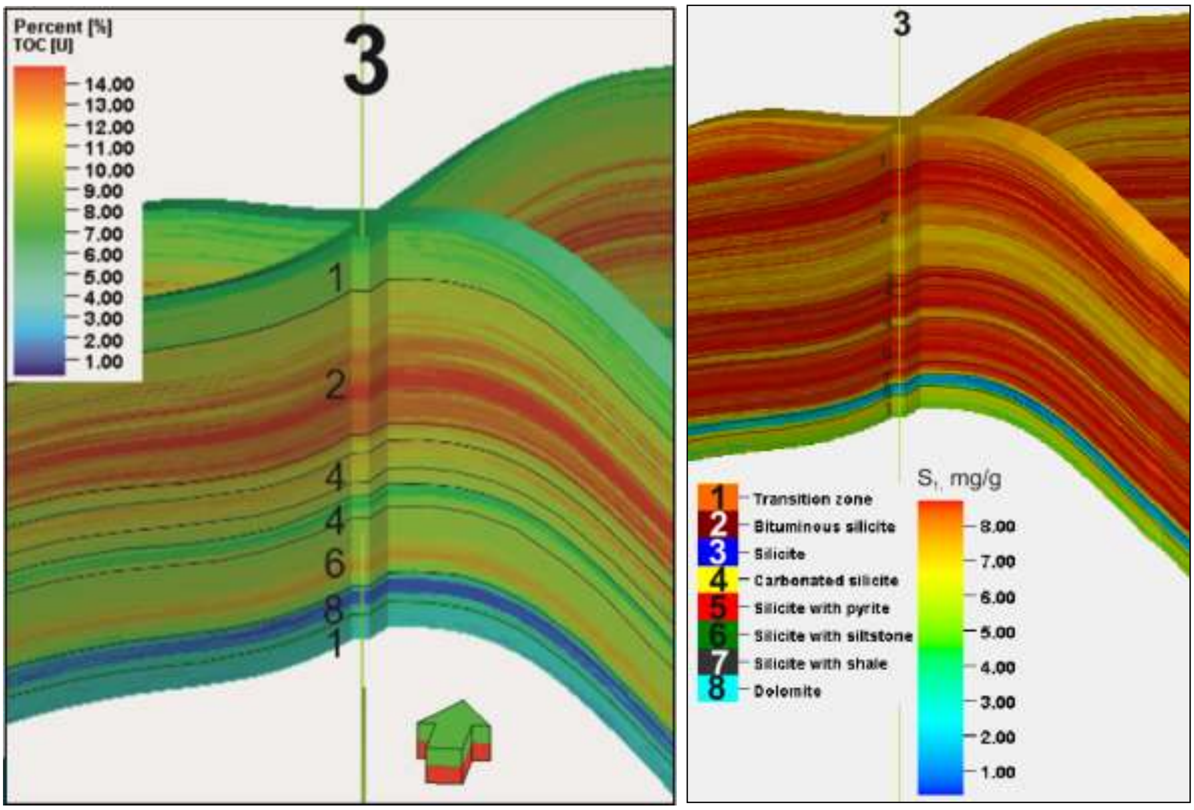

Figure 4. Total Organic Content and S1 parameter 3D model with lithotype differentiation.

Resources were estimated with a conventional method on the basis of the pore volume and also the S1 parameter as the mass fraction of rock [4] and the volume and average density of rocks. The oil-generation potential was estimated with the hydrogen index as a mass of the total organic content. The total organic content was calculated as the mass fraction of rock on the basis of the volume and density of rock. HI was defined as the mass fraction of this TOC. All these parameters were calculated with the help of lithotype differentiation. The following equations were used to estimate resources:

Mobile oil:

Conventional method:

$$\text{Oil-in-place} = \boldsymbol{\Sigma}\,(V_i{*}\text{Poro}){*}S_o/B_o$$

where V_i – lithotype volume, S_o – oil saturation =1, B_o = Volume Factor.

Method using S_1 parameter:

$$\text{Oil-in-place} = \boldsymbol{\Sigma}\,(V_i{*}S_1){*}S_o{*}\,\rho_{rock}$$

where S_1 – mass fraction of already generated mobile oil [mg of HC/g of rock]

Oil-generation potential:

$$\text{Oil mass} = \boldsymbol{\Sigma}\,(V_i{*}\text{HI}){*}\,S_o{*}\,\rho_{rock}$$

where HI – mass fraction of the total organic content [mg of hydrocarbons/g of TOC].

3. Conclusion

Geochemical modeling with lithotype differentiation is an instrument to estimate the oil-potential of a shale formation. Tectonic analysis is necessary to determine promising zones in fractured unconventional reservoirs and to set trends for petrophysical modeling. Modeling geochemical properties is an additional method used to calculate mobile oil resources and oil-generation potential. Also, lithotype identification can be used to choose well intervention. For example, carbonated lithotypes are more prone to hydraulic fracturing while kerogenic silicites can possibly develop with combustion or thermal gas treatment. An additional study is necessary for this analysis.

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