Lithology Evaluation of Bazhenov Formation Reservoir using Seismic and Well Log Analysis

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***Abstract*— Bazhenov formation is an analogue of Bakken formation; these formations are source rocks and contain tight reservoirs of tectonic-hydrothermal model. The interpretation of well logs begins with identification of Bazhenov marker and with tracing of carbonate layer within Bazhenov by the GR, neutron and acoustic logs. Thickness of this layer has range from 1 to 2 m. Next step is seismic interpretation. Creation of 2D seismic forward models is presented in this works. In these models behavior of amplitude with and without carbonate layer was studied. These models allow tracing of sign of carbonate layer (negative amplitude peak). Analysis of slices of 3D seismic cube was done. Amplitude map was created. Distribution of carbonate rock was detected according to this map. So, using this approach thin layer was determined within Bazhenov suite.**

Keywords—Bazhenov, carbonate, tectonic-hydrothermal model; rock; well corellation, acoustic properties, wavelet, 2D seismic forward models, 3D seismic cube, generation productivity, attribute analysis

I. Introduction

In the last few years attention to the problem of unconventional hydrocarbon resources development is constantly growing. Bazhenov formation development problems become essential. The main aim of this project is the evaluation of Bazhenov formation reservoir and investigation of very thin reservoir rocks using wireline logs and seismic interpretation.

This aim may be subdivided into following tasks:

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

II. Comparison of Bazhenov and Bakken Formations

Deposits of Bazhenov and Bakken formations are oil shale which has properties of source rocks and characterized by very high content of organic matter.

The main similarity is tight rock reservoir within source rock. The main difference is the thickness of pay zone. The Bakken reservoir has the reservoir thickness of 40 m, Bazhenov reservoir has thickness of 0, 5 – 3 m. Reservoir of Bazhenov formation is confined to thin bed, and restricted in lateral direction.

However, Bazhenov is characterized by higher values of porosity, which can reach 10% or more (average 8%) and permeability up to 10 mD, but average is 1 mD. Also Bazhenov occupies area more than 1 million sq. km, while the Bakken takes 520 thousand. km^2.

The main feature of Bazhenov formation is very different content of rocks (kerogen and mudstone, carbonate and silica components) depending on the location [1, 2].

III. Evaluation of the Organic Matter of the Bazhenov Formation within the Field S

Dependency of organic matter versus average value of gamma ray was obtained by V.A. Kontorovich in his work [3]. He obtained two dependencies:

$$TOC=0.18GK–4.81\ (R2=0.9) \quad (1)$$

$$TOC=0.17GK+0.12\ (R2=0.94) \quad (2)$$

The second relationship works for transition zone between the Bazhenov and Maryanovsky suites (GR has average values 20-55). This area includes a significant part of the Tomsk region. S field is located in the transition region, in Ust-Tym depression. Thus, using the second relationship, TOC was determined in Fig. 1.

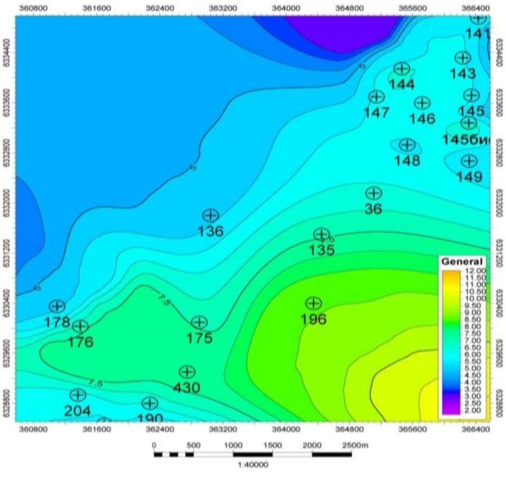

Fig. 1. Content of TOC of Bazhenov fm for S field

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

Foliated model explains that reservoir was formed by fluid auto-fracturing of formation, this process explained as a result of the processes of transformation from organic matter to liquid state by Gurari, F.G. Nesterov, I.I. in 1977-1985.

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

IV. Well Correlation

Correlation was performed on the basis of log data from eleven wells. Correlation (Fig. 2) was started with identification of markers in the investigated part of cross section. Bazhenov suite is the regional seismic marker, which lies on Georgiev formationm.

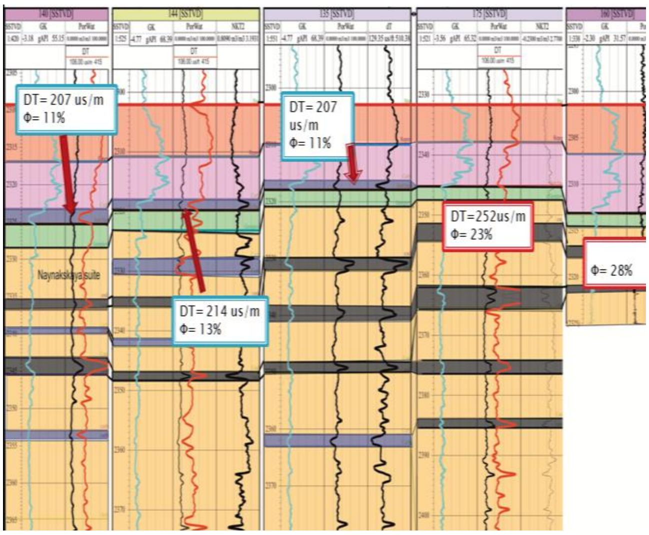

Fig. 2. Correlation panel for five wells

This marker was identified using gamma ray log and lateral device. Values of gamma-ray are very high and may achieve 30 mR per hour (anomaly high radioactive bituminous shale). The carbonate layer was indicated in the lower part of Bazhenov formation using acoustic log (travel time decreases), and also using neutron porosity log (porosity also decreases). This carbonate layer was indicated practically in all wells aside from two wells (175 and 160). The average thickness of layer ranges from 1.2 to 2 m. So this layer may be interested as potential reservoir within the Bazhenov fm.

Georgiev fm is also the marker of the first order, which is presented by black and grey thick mudstone. This marker was determined using induction log (minimum value of induction log). The Naunakskaya fm is subdivided into two sub fm: coal-overlaying sub fm and sub-coal sub fm. Coal layer divides these sub fm and has thickness of 1-1.5 m. This layer is laterally continuous in S field. Naunakskaya fm is characterized by clastic rocks.

V. Seismic Interpretation

The one of the basic methods of qualitative interpretation is the seismic amplitudes analysis, while amplitudes are main parameters of recorded seismic [6].

A. *Petrophysical analysis of velocity and density of rocks*

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

Firstly, velocity of Bazhenov formation was determined. As can be seen in Fig. 3, Bazhenov was divided into two parts in accordance with the velocity (low-speed part and high-speed part). Upper part has low velocity (2800 m/sec) while lower part has high velocity (3400 m/sec).

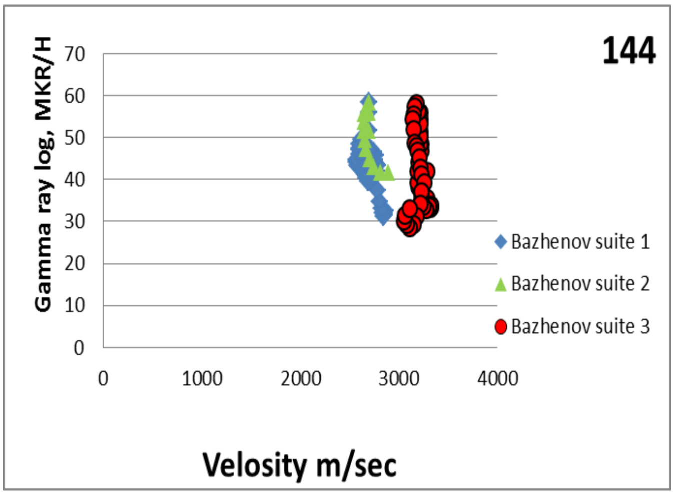

Fig. 3. Gamma ray response versus velocity for Bazhenov formation (well 144)

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

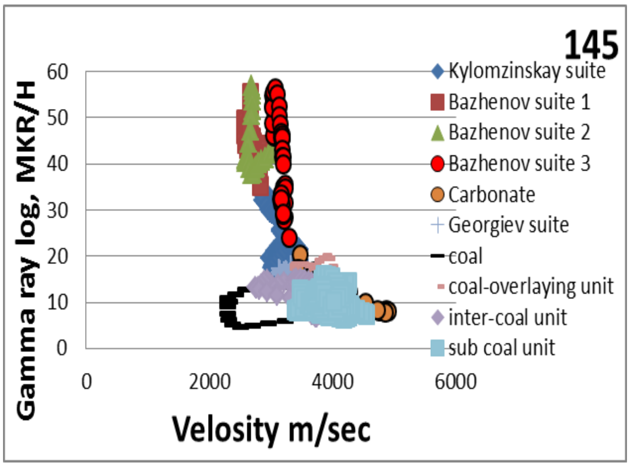

Fig. 4. Gamma ray response versus velocity for rocks with different lithology located under Bazhenov formation (well 145)

Determined velocities were used in creation 2D seismic forward models. Next figure (fig. 5) describes division of Bazhenov fm into packages, which can be characterized by fixed velocity value.

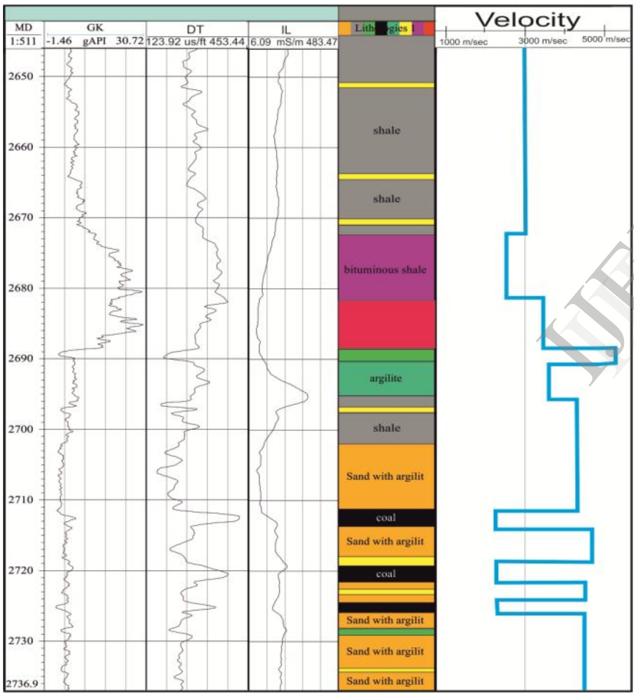

Fig. 5. Example of lithology division based on velocity values

2D seismic forward models were created in following succession:

- Models of the acoustic properties of rocks and thickness of layers were created in Excel.
- Geological suspecting were made in the models in Excel, such as: presence and absence carbonate layer, increasing of thickness of carbonate layer, as well as the presence of gas in coal overlaying formation were considered in Fig. 6;

	HL	VL	HR	VL	
		W1 =	40.0		
	10.0	3.0	10.0	3.0	
1	6.3	3.0	7.2	3.0	Kulomzin
2	5.5	2.5	7.7	2.5	Bazhenov
3	2.4	2.5	2.4	2.5	Bazhenov
4	1.0	2.5	0.5	2.5	Bazhenov
5	3.1	3.4	3.5	3.4	Bazhenov
6	1.5	5.0	1.2	5.0	carbonate
7	2.6	3.6	3.8	3.6	Georgiev
8	3.0	4.2	3.0	4.2	coal-overl
9	0.0	5.0	0.0	5.0	carbonate
10	4.3	4.2	8.6	4.2	coal-overl
11	0.5	2.5	2.3	2.5	coal
12	3.4	4.5	3.0	4.5	intercoal
13	0.7	5.0	0.0	5.0	carbonate
14	3.1	4.5	6.6	4.5	intercoal
15	2.1	2.5	1.1	2.5	coal
16	7.3	4.2	8.1	4.2	subcoal
17	0.0	2.5	0.0	2.5	coal
18	0.0	4.2	0.0	4.2	subcoal
19	1.1	5.0	2.3	5.0	carbonat
20	9.5	4.2	13.4	4.2	subcoal

	Intercoal member
	Kulomzinskaya Formation
	Bazhenov formation
	Carbonate
	Georgievsk Suite
	Overlaying coal member with gas
	Coal
	Overlaying coalmember
	Sub coal member
HL	Thickness, m
VL	Velocity, km / sec
W	Distance between the wells

Fig. 6. Part of the model, Legend for all models

Elementary wavelet was matched with similar characteristics of the real wavelet, knowing that real seismic section was recorded with frequency 19.2 Hz of wavelet. Shape of wavelet and its characteristics are depicted in Fig. 7 (at 19 Hz and 47 Hz were considered);

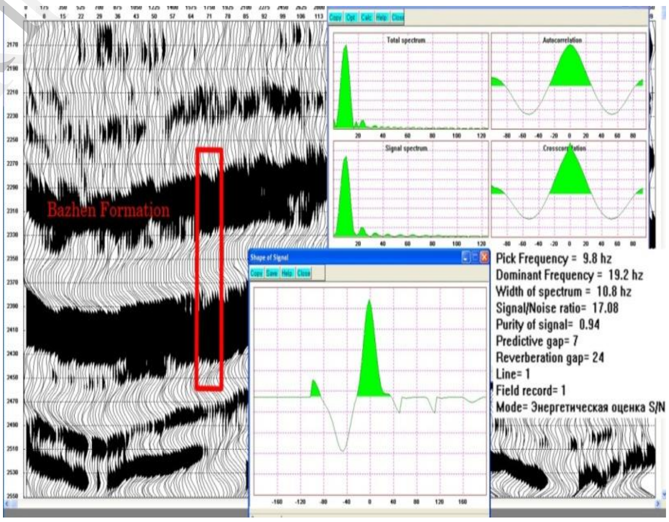

Fig. 7. Shape and characteristics of wavelet

B. 2D seismic forward models with and without carbonate layer for seismic impulse at 19Hz

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

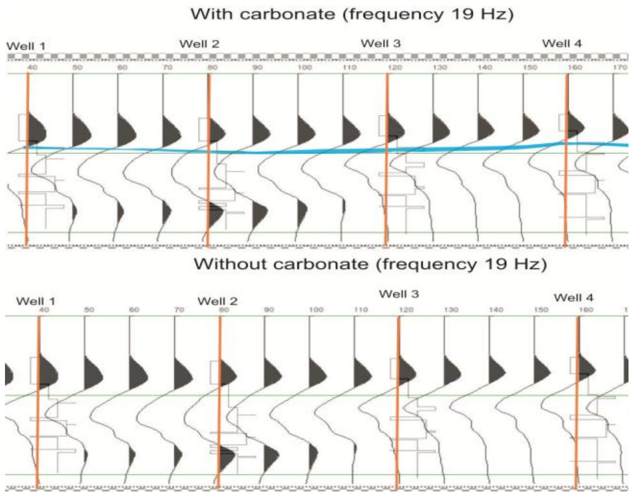

Fig. 8. 2D seismic forward models (with and without carbonate) at 19Hz

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

Obtained by the one-dimensional simulation (fig. 9) synthetic seismic trace was analyzed for the presence and absence of carbonate reservoir, which was detected using wire line log interpretation. According to this figure it can be seen that the presence of carbonates affect the image, since the negative amplitude increases (is more pronounced) where carbonates occur.

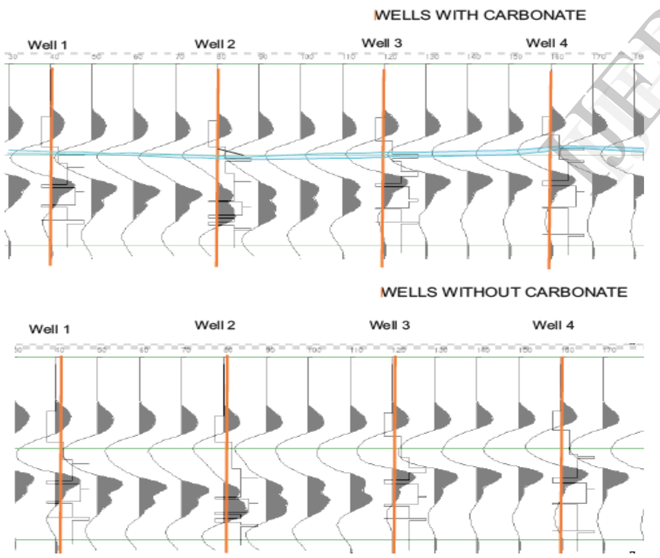

Fig. 9. 2D seismic forward models (with and without carbonate)

VI. ATTRIBUTE ANALYSIS

Visual analysis of slices in each well for a certain period of time (where carbonate is located) was conducted. Information from slices and information from 2D seismic forward models was taken as basis. It is known that the carbonate layer is located immediately in the bottom of Bazhenov and seismic surface of bottom Bazhenov was given as the initial data (but this surface is slightly lower than the carbonate layer) then carbonate surface was created. This surface has the same configuration as the bottom of Bazhenov, however surface is located higher where first largest peak occurs («carbonate peak») in Fig.10.

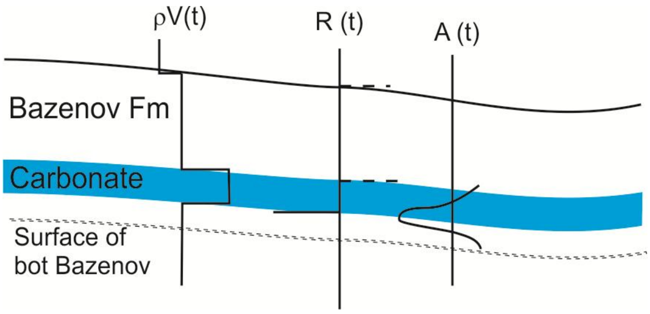

Fig. 10. Location of carbonate layer within Bazhenov formation

The next step is to create amplitude map in Fig. 11. This attribute retrieves the value of the amplitudes of the existing 3D seismic cube with respect to the carbonated bed.

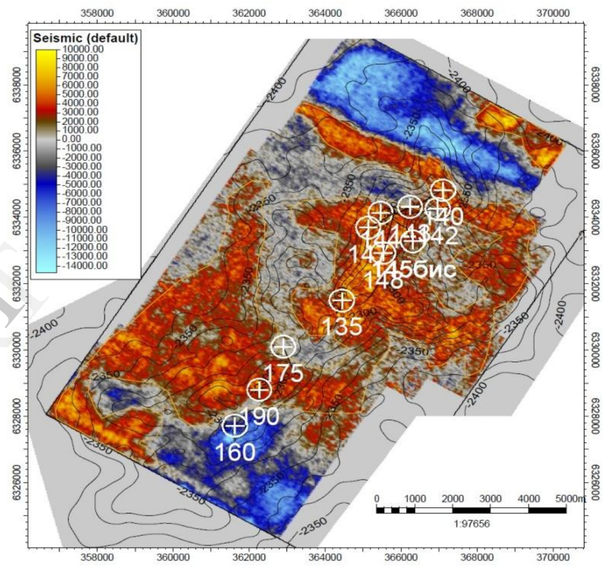

Fig. 11. Amplitude map for carbonated bed

As a result of this map interpretation, distribution of carbonate was contoured. So, it may be concluded that distribution of carbonate is laterally expressed. The most of all wells exactly lie on carbonate layer and only two wells (160 and 175) lie on grey color i.e. transition zone. Thus carbonate formation wedges out in wells 160 and 175.

VII. GENERATION PRODUCTIVITY OF BAZHENOV ROCKS

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

Following approach of Bazhenov formation generation productivity estimation was applied: the product of the mass of organic hydrocarbon by 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 using the generation coefficient because this coefficient may be used to identify specific generation productivity.

Generation productivity map of the Bazhenov in the Tomsk region, presented below in Fig. 12 was obtained by multiplying the map of organic matter (Corg) in the Tomsk region by generation coefficient (Kgn) and by the mass of organic hydrocarbon of the Bazhenov formation (Msp) [2].

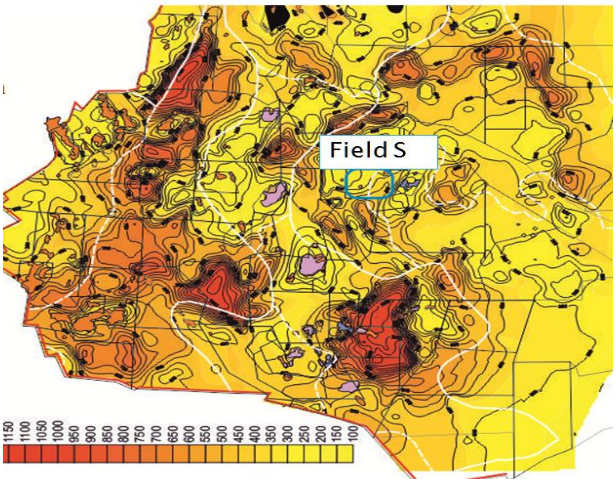

Fig. 12. Generation productivity of Bazhenov fm Tomsk region

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 Bazhenov formation have high generation potential and for field S it achieves 350-500 kg/m^2.

VIII. CONCLUSION

The increasing demand for oil and depletion of traditional oil reserves raise the interest of the involvement of the unconventional oil reserves. Thus, special attention should be paid for Bazhenov formation, which is a primarily source rock, and belongs to unconventional reservoir. Bazhenov suite is a continuous formation, which is represented by bituminous mudstones, interlaying-shale-carbonate-silica and high content of organic matter. In this project fracture-cavern-pore model of the reservoir was considered, which is mainly associated with the layers of secondary transformed radiolarites.

Carbonate nature of this layer was confirmed by acoustic, neutron and gamma ray logs (high velocity values (5000m/s), anomalously low neutron values, and also low gamma ray log values). On the mentioned logs silicate rocks do not differ from carbonate rocks, so for their more confident separation, photoelectric absorption log is recommended. The essential difference is that the carbonate rocks have a very high Pe and silicates are characterized by minimum value of Pe.

Sign of carbonate layer can be traced based on 2D seismic forward model;

Map of Amplitude may be used for analysis of carbonate distribution and future development strategy.

In addition, this approach, based on visual analysis of the wave pattern, may be suggested for determination of thin layers.

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