Research on Volcanic Reservoir Prediction in Jinlong-2 Well Area

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Abstract. Volcanic reservoirs have complex distribution that reservoir prediction is often required to provide a basis for development target optimization and horizontal well trajectory optimization. By analyzing the development model and petrographic distribution of volcanic reservoirs in Jinlong-2 well area of Junggar Basin, the lithology, porosity and oil saturation of volcanic rocks are predicted further. Defining favorable reservoir areas provides a basis for development target optimization and horizontal well trajectory optimization.

Keyword: Junggar Basin; Jinlong-2 Well Area; Volcanic rock reservoir; Reservoir prediction.

1. Introduction
Benefiting from the advancement of current exploration and development technology, volcanic reservoirs have gradually entered important areas of oil-gas industry. At present, a large number of volcanic rock reservoirs represented by Trieste reservoir in United States, Reciru reservoir in Brazil and Tupingato reservoir in Argentina have been found worldwide. China also has extensive volcanic reservoirs in Songliao Basin, Bohai Bay Basin, Sichuan Basin, and Junggar Basin [1, 2, 3, 4]. Unfortunately, the development of volcanic reservoir is extremely limited due to the characteristics of deep burial, complex structure, variable lithofacies, strong heterogeneity and significant difficulty of reservoir prediction.

Preliminary investigations have basically grasped favorable petrographic distribution and fracture development trends, but for local lithofacies and fracture distribution, it needs to be re-implemented in conjunction with newly drilled well, and reservoir prediction is required to provide a reference for development target optimization and horizontal well trajectory optimization, so as to guide efficient development of volcanic reservoir.

2. Development model and petrographic distribution of volcanic rock
Volcanic eruption patterns can generally be divided into two types: central eruption and fracture eruption. The P1 volcanic rock in Jinlong-2 well area mainly embodies as the composite eruption form of central eruption and fracture eruption. It is difficult to find a complete "volcanic cone" structure in research area
because the later tectonic movements destroyed the early structural planes. Based on previous research, combining lithology and electrical characteristics, the $P_{ij}$ volcanic rock was divided into three periods of bottom-up method. The three periods volcanic rock facies is manifested as characteristics of explosive-extrusive–transition-explosive-extrusive interaction, and there is no obvious interlayer between each period.

According to oil testing data, the reservoir is mainly developed in volcanic clastic rocks such as welded breccia, andesitic welded breccia and volcanic breccia, and manifested as explosive facies. In addition, there also develops lava reservoirs with extrusive facies such as amygdaloidal andesite and amygdaloidal basalt near well-Jin209. Consequently, the favorable reservoir lithology is welded breccia and volcanic breccia, and explosive facies is the advantageous volcanic facies of $P_{ij}$ volcanic reservoir in study area.

3. Volcanic reservoir prediction

3.1. Lithology prediction of volcanic rocks

There are two lithology types of volcanic breccia and lava in Jinlong-2 well area. It is recognized that seismic reflection features between explosive facies, extrusive facies, and sedimentary facies exist certain difference by statistical analysis of log facies and seismic facies in research area. In this research, the reflection features between each facies were used to identify overall characteristics of lithofacies, and to establish rock masses of different lithofacies. On this basis, targeted logging constrained seismic similarity inversion was applied to single rock mass to predict distribution of volcanic lithology. For South and North rock masses, the well control seismic similarity stochastic simulation inversion and well control seismic similarity layered model inversion were used respectively.

The lithology types explained by logging was used to predict the lithology distribution of Jinlong-2 well area by applying well control seismic similarity inversion. In well-drilled areas, well control seismic similarity inversion method can predict relatively accurate geological body information, but in areas with low well control, the prediction results are less reliable. In this study, well control seismic similarity inversion method was mainly used to predict the lithology distribution of $P_{ij}$ volcanic rocks in Jinlong-2 well area, where has relatively high well control degree, making it is highly feasible by using this method.

3.2. Seismic prediction of porosity

The reservoir lithology of Jinlong-2 well area is mainly breccia and rhyolite. The calculation method of logging porosity in this area was obtained by empirical formulas:

**Breccia:**
\[ \Delta T = 1.5264\Phi + 50.33 \quad r=0.96 \]

**Rhyolite:**
\[ \Delta T = 1.3671\Phi + 49.50 \quad r=0.96 \]

Where: $\Phi$ represents porosity, %, $\Delta T$ represents acoustic logging value, $\mu$s/ft.

The above formulas were used to calculate the porosity of drilled wells in Jinlong-2 well block and porosity and wave impedance intersection analysis was performed further (Figure.1.). The conclusion shows that wave impedances of different lithologies overlap with each other, but porosity and wave impedance is displayed a certain correlation, which has better correlation of same lithology, as follows:

- $\Phi_1(x) = 5 \times 10^{-15}x^2 - 3.35 \times 10^{-8}x + 0.408$, $R^2=0.85$;
- $\Phi_2(x) = 7.5 \times 10^{-16}x^2 - 3.6 \times 10^{-8}x + 0.391$, $R^2=0.93$;
- $\Phi_3(x) = 2.52 \times 10^{-15}x^2 - 2.75 \times 10^{-8}x + 0.936$, $R^2=0.90$;
- $\Phi_4(x) = 3 \times 10^{-15}x^2 - 1.03 \times 10^{-7}x + 0.884$, $R^2=0.88$;
- $\Phi_5(x) = 2.88 \times 10^{-15}x^2 - 1.87 \times 10^{-8}x + 0.039$, $R^2=0.92$;
- $\Phi_6(x) = 3 \times 10^{-15}x^2 - 1.21 \times 10^{-7}x + 1.046$, $R^2=0.92$;
In the above formulas: $\Phi_1$ represents basalt porosity, $\Phi_2$ represents andesite porosity, $\Phi_3$ represents dacite porosity, $\Phi_4$ represents basaltic breccia porosity, $\Phi_5$ represents andesitic breccia porosity, $\Phi_6$ represents rhyolite porosity, $X$ represents wave impedance, $R^2$ represents correlation coefficient.

According to the relationship between porosity and wave impedance, the porosity of various lithology could be calculated by wave impedance. (Figure.2).

Figure 1. Porosity-wave impedance-lithology intersection diagram of P1j volcanic reservoir in Jinlong-2 well area

Figure 2. Porosity inversion profile of Jiamuhe Formation in Jin 218-Jin 214-Jin 202-Jin 201-Jin 204 well-tie
The correlation function between porosity and wave impedance of P1j volcanic rocks of different lithology is different. The lithology distribution model predicted by inversion prediction of well control earthquake similarity was used to convert the wave impedance data objects into porosity data objects to complete porosity prediction of P1j volcanic rock.

3.3. Seismic prediction of oil saturation
The oil saturation calculation of P1j volcanic reservoir was based on Archie's formula: 
\[ S_o = 1 - \frac{a \cdot b \cdot R_w}{(R_t \cdot \Phi^m)^{1/n}} \]
referring to the proven reserves report of Jinlong-2 well area, the specific parameters of study area were as follows: lithology coefficient (a) by 0.967, porosity index (m) by 2.019, lithology coefficient (b) by 1.097 and saturation index (n) by 1.989.

The formation water resistivity (Rw) of P1j reservoir was determined by actual water analysis data. The temperature in reservoir center is 100°C, and the resistivity of formation water at 100°C is 0.110Ω.m according to equivalent NaCl chart method.

The value of \( S_o \) in Archie's formula depends on \( R_T \) and \( \Phi \). The porosity prediction method has been explained earlier, Therefore, \( S_o \) could be calculate only by determining \( R_T \). In this investigation, the well control resistivity model was used to restrict. According to Archie's formula and calculated porosity value, the oil saturation was calculated (Figure. 3).

![Figure 3. Oil saturation inversion profile of Jiamuhe Formation in Jin 218-Jin 214-Jin 202-Jin 201-Jin 204 well-tie](image)

4. Conclusion
The favorable reservoir lithology is welded breccia and volcanic breccia, and explosive facies is the advantageous volcanic facies of P1j volcanic reservoir in study area.

In well-drilled areas, well control seismic similarity inversion method could predict accurate geological body information, but the reliability of prediction results was poor in areas with low well control.

According to the relationship between porosity and wave impedance, the porosity of various lithology could be calculated by wave impedance. In order to convert wave impedance into porosity, it was necessary to use well control resistivity model to limit lithology type. The oil saturation was calculated based on Archie formula and the calculated porosity value. From the results, it can be seen that the predicted porosity and oil saturation are relatively reliable.
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