Research on Fracture Prediction of Permian Volcanic Reservoirs of Jiamuhe Formation in Jinlong-2 Well Field

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Abstract: The practice of volcanic reservoirs exploration and exploitation for years shows that fractures are not only important factors in controlling hydrocarbon migration and enrichment, but also favorable conditions for efficient exploitation. This study used drilling data, seismic data and laboratory analysis data to clarify fracture characteristics and distribution of volcanic reservoirs. In study area. The fracture characteristics were predicted by using post-stack structure-oriented coherence and ant tracking methods with the result of various fracture developmental degree of different zones on the plane. Comparative analysis of drilling data, geostress and imaging logging interpretation results have obtained preferable prediction results, which is of great significance for effective exploration and exploitation of volcanic reservoirs.

Keywords: Jinlong-2 Well Field, volcanic rock, fracture characteristics, fracture prediction, imaging logging.

1. Introduction
At present, considerable volcanic reservoirs have been found worldwide, on behalf of Argentina, New Zealand, Chile, Italy[1-6]. In addition, China have many volcanic reservoirs in Songliao, Bohai Bay, Sichuan and Junggar Basin [7,8,9], which are characterized by deep burial, complex tectonic position, variable lithic facies, strong heterogeneity, and vast reservoir prediction difficulty[10],causing tremendous difficulty for effective exploit. The practice of volcanic reservoirs exploration and development for years shows that reservoir fractures are not only important factors in controlling hydrocarbon migration and enrichment in volcanic reservoirs, but also favorable conditions for efficient development. Therefore, the prediction of volcanic reservoir fractures will excellently promote its effective exploration and development.
2. Fracture Characteristics and Distribution Law

2.1. Fracture Types
Reservoir fractures in Jinlong-2 well field can be divided into three types according to the geneses: tectonic fracture, dissolution fracture and diagenetic fracture which can be further defined as contraction fracture, breccia intergranular fracture and interlayer fracture. If take fracture dip into account, the fracture can be categorized into horizontal fracture, low-angle fracture, high-angle fracture and vertical fracture. Based on core observation, slice identification and FMI imaging data, the investigative Jiamuhe Formation reservoirs mainly developed high-angle tectonic fracture.

2.2. Fracture Occurrence
The analysis results of core observation and FMI logging data indicate that fracture width distribution of third stage volcanic reservoir is mainly range from 0.01mm to 0.19mm, which are dominantly composed of small-micro-fracture, with fewer middle and large fracture. In addition, it can be observed that fracture density is range from 0.02 bar/m to 6.93 bar/m, with properties that fracture dips are universally greater than 45° and fracture types mainly affiliation to high-angle fracture, and fracture strike is nearly east-west.

2.3. Distribution Law
Longitudinally, the fracture densities of first, second and third stage of researched reservoir are (0.05~3.6), (0.04~3.7) and (0.02~6.9) Bar /m, respectively, in which fractures of third stage are relatively developed. Log interpretation results demonstrate that average fracture thickness of the first, second and third stage volcanic rock are 15.3m, 18.0m and 26.5m, respectively, and the third stage developed larger thickness of fractures. The third stage fractures in major oil layer of research area are well developed along fault, where fractures in north of Jin207-Jin219-JL2008 line are relatively developed, the most well-development of which is located in Jin208 and Jin214 fault. Conversely, fracture developmental degree in the south of that line is weakly, but locally developed near Jin220 and Jin201 wells.

3. Volcanic Rock Fracture Prediction

3.1. Forecasting Methods
There is no relevant shear wave seismic data in Jinlong-2 well field, so S-wave prediction cannot be carried out. Post-stack compressional wave seismic fracture prediction method can directly predict fractures by analyzing seismic response characteristics of P-wave which are represented by coherence, curvature, amplitude, impedance, and attenuation properties. In the places where faults or fractures well developed, tectonic occurrence, amplitude, wave number and other abrupt changes often occur, which can be better reflected by structure-oriented coherence and ant tracking methods. In order to identify fractures accurately, post-stack data was used to predict fractures by constructing structure-oriented coherence and ant tracking methods.

3.2. Prediction Results
This investigation was based on previous research of this field, mainly using post-stack structure-oriented coherence and ant tracking methods to predict fracture characteristics of Jiamuhe Formation, as shown in Figure 1 and Figure 2, in which the blue part in Figure 1 is interpreted as predicted fracture development area, and the black part in Figure 2 represents the fracture development area.
In this study, the above two methods were used to predict fractures, and it is recognized that Jiamuhe Formation in Jinlong-2 well field is relatively well developed. Fractures are mainly categorized in vertical fracture and oblique fracture and horizontal fracture is rather poorly developed, which is consistent with the previous research results, that is, there are various fracture developmental degree of different zones on the plane. The fractures are generally well developed below well Ke302-Jin218-Jin208-Jin201-Jin210, but underdeveloped in well Jin217-Jin207-Ke102. The major strike of fracture in Jin208-Jin204 well field is nearly SW-NW, while mainly embodies as two types direction, NW and NE in the north of Jin208 well field, resulting in network distribution of fracture throughout the plane.
4. Prediction Results Verification

4.1. Drilling Data Comparison Method
According to the drilling data, fracture in study area is mainly tectonic fracture. Core observation indicate that fractures are mostly high-angle vertical fracture with dips greater than 70°, as shown in Figure 3. Compared it with constructing structure-oriented coherence and ant tracking prediction results, a high of 77% compliance was obtained.

4.2. Geostress Method
Geostress field analysis of Jiamuhe Formation in Jinlong-2 well field (Table 1) shows that research area mainly developed two directions of geostress field : EW and nearly NS-NW. The two sets of stress fields act together on Jinlong-2 well field. The north of Jin208 well is mainly affected by near East geostress field while the south is mainly affected by nearly NS-NW geostress field. The geostress field structure is consistent with predicted fracture plane distribution law, indicating that prediction results are in line with the geological laws.

Table 1. Three-dimensional stress test results of volcanic reservoir

| well  | vertical stress (MPa) | maximum horizontal principal stresses (MPa) | minimum horizontal principal stresses (MPa) | maximum horizontal stress direction (°) | Stress difference (MPa) |
|-------|-----------------------|--------------------------------------------|--------------------------------------------|----------------------------------------|------------------------|
| Jin204 | 98.6                  | 104.9                                      | 90.9                                       | 124.5                                  | 14                     |
|       | 99.6                  | 104.7                                      | 95.8                                       | 119.5                                  | 8.9                    |
| Jin208 | 97.5                  | 69.2                                       | 67.3                                       | 120.4                                  | 1.9                    |
|       | 95.0                  | 72.3                                       | 55.2                                       | 113                                    | 17.1                   |
| JL2001 | 95.1                  | 68.4                                       | 48.4                                       | 117                                    | 20.0                   |
|       | 95.1                  | 72.9                                       | 54.8                                       | 114                                    | 18.1                   |
| Jin214 | 94.4                  | 67.5                                       | 51.8                                       | 84.4                                   | 15.7                   |
|       | 94.6                  | 61.6                                       | 49.9                                       | 83.7                                   | 11.7                   |
| average|                      | 109.6                                      |                                             |                                        | 13.4                   |

4.3. Imaging Logging Method
The volcanic core observation and FMI imaging data of Jiamuhe Formation in Jinlong-2 well field demonstrate that fractures with different occurrences, in particular to oblique fracture, vertical fracture, net fracture, micro-fracture and filling-half filling fracture in study area are relatively developed, as shown in Figure 3.

Figure 3. FMI imaging of Permian Jiamuhe Formation in Jinlong-2 well field
Through analysis of fracture development status by drilled well imaging logging data and combined with fracture prediction results, it shows that prediction results are in good agreement with drilled result, so the prediction results are fairly reliable.
5. Conclusion
(1) The main reservoirs of Jiamuhe Formation are volcanic rocks of third stage with high degree of fracture development. Fracture width distribution is mainly range from 0.01mm to 0.19mm. Fracture density is range from 0.02/m to 6.93/m. The fracture dips are generally greater than 45°, and the strike of fracture is mainly near East-West direction.

(2) Fracture characteristics of Jiamuhe Formation was predicted by using post-stack structure-oriented coherence method and ant tracking methods. It is considered that there are various fracture developmental degree of different zones on the plane. Fractures are generally well developed below well Ke302-Jin218-Jin208-Jin201-Jin210, but underdeveloped in well Jin217-Jin207-Ke102. The major strike of fractures in Jin 208-Jin 204 well field is nearly NS -NW, while mainly embodies as two types directions of NW and NE in the north of Jin208 well field, resulting in network distribution of fractures throughout the plane.

(3) Comparative analysis of drilling data, geostress and imaging logging interpretation results have obtained good prediction results.

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