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Development characteristics and formation stages of tectonic fractures of Cretaceous Bashijiqike tight sandstone reservoir in Keshen gas field, Tarim Basin, China

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Abstract. The Cretaceous Bashijiqike formation in the Kuqa Depression of the Tarim Basin is ultra-low porosity and ultra-low permeability reservoir, where fractures have important influences on single well productivity and natural gas accumulation. According to the core CT scanning, casting thin section, laser copolymerization, imaging logging and other data, the basic development characteristics of fracture in this area are analyzed. Based on the analysis results of the core fracture cutting relationship, the carbon and oxygen isotope of the fractures filling, and the temperature measurement of the inclusions, the main stages of the regional fractures are determined. The results show that the fractures in the study area are mainly high angles, mostly filled with calcite and gypsum, and the fracture width is generally less than 0.2mm. There are three groups of structural fractures, which are EW/NE-SW and NW-SE, with the dominant orientations being NE-SW and NW-SE. The structural fracture were formed in three stages, which were the late Yanshan movement period-early Himalayan tectonic movement, the middle period of Himalayan, and the late period of Himalayan tectonic movement. The tectonic activity of the late Himalayan tectonic movement is the strongest, and the formation of fractures formed in this period were low degree of filling and effective.

1. Introduction

The Cretaceous Bashijiqike formation is the main gas-producing layer of the KeShen gas field, the properties of which is tight. The core and imaging logging data show that the fractures are relatively developed in this area. The well test explains that the formation permeability is higher than the matrix permeability 1-3 order of magnitude [1]. This result indicates that the existence of fractures has greatly improved the permeability of the formation. Fractures are the result of superposition caused by multiple periods of tectonic movement [2-4]. Taking the structural fractures of the tight sandstone reservoirs of the Bashijigike formation in the KeShen Gas Field as the research object, the author use the data of core CT quantitative scanning, imaging logging, casting thin sections and laser confocal observations to comprehensive analyse the characteristics of fracture development in the study area. According to the fracture cutting relationship, the use of carbon and oxygen isotope and fluid inclusion experimental data,

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we carry out fracture formation phase research to provide a foundation for the research of fracture distribution prediction.

2. Geological background

The Keshen gas field is located in Kelasu structural belt in the Kuqa Depression [5], Tarim Basin. Since the Mesozoic, the KeShen zone has experienced two major tectonic movements, Yanshan and Himalayas, with the strongest orogenic movement in the late Himalayas [6]. In the late Yanshan movement-early Himalayan movement, the tectonic movement was relatively weak, which was affected by the north-south tensile stress. In the middle and late stages of the Himalayan tectonic movement, the Indian Ocean plate and the Eurasian plate collided violently and quickly wedged, the Qinghai-Tibet Plateau uplifted rapidly, and the Tianshan Mountains uplifted strongly. Under the action of the north-south tectonic compression stress, several long-axis anticline structure were developed with near-east-west directions. The Cretaceous Bashijiqike formation is the main reservoir in the study area, which burial depth is mainly $6000m \approx 8500m$ [7]. The average matrix porosity of the Cretaceous Bashijiqike formation reservoir is 5.4%, and the average matrix permeability is 0.049×10^{-3} um³. The Core, imaging logging data and well test interpretation all show that the fractures are developed, and the test permeability is much higher than the matrix permeability.

3. Basic characteristics of cracks

Based on the computer tomography scans of 8 core wells with a total length of 20.21 m, the core observations of 8 wells and the imaging logging interpretation results of 51 wells, it is believed that the fractures are mainly semi-filled and unfilled vertical and high-angle structural fractures in the study area (Figure 1), with a small number of low-angle and horizontal fractures; The main substances are calcite and paste, and the filling degree is related to the opening. Generally, the fractures with a small opening have a low filling degree, and the fractures with a large opening have a high filling degree. The fractures opening is generally less than 0.2mm, mainly distributed between 0.05mm and 0.5mm, and the maximum can reach 3.0mm. The apparent porosity FVPA of fractures is mainly $0.01\% \sim 0.2\%$, with an average of 0.04%. The fractures directions are mainly northeast-southwest and northwest-southeast.

Observation of 944 cast thin slices and 66 laser confocal micro-cracks in the study area show that micro-fractures are mainly associated with micro-fractures of cut particles produced by tectonic extrusion, micro-scale grain edge fractures that are not consolidated at the edge of the grain, and the inside of the grain. Nano-scale fractures are the main ones, and the fracture filling is mainly calcite and dolomite, and a small amount of anhydrite. The width of the grain edge is generally between 1 and 10 μ m, and the width of the nano-scale fractures inside the grain is generally less than 1 μ m (Figure 2).



Figure 1. Core fracture characteristics of Bashijiqike Formation in KeShen block

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Figure 2. Microscopic characteristics of fractures in the Cretaceous Bashijiqike formation reservoir in KeShen gas field.

4. Period of crack formation

4.1. Fracture cutting relationship

The conjugate fracture represents the maximum principal stress direction of the regional tectonic stress field. According to the results of the CT scan core fractures, early fully-filled conjugate fractures were found in some cores, with larger opening. Semi-filled high-angle fractures were found in Wells Ks2-2-8, Ks2-2-3, and Ks2-2-4. The direction of the conjugate angle is about 5-10 degrees to the right from the early conjugate angle. It is almost north-south, and undergoes strong later transformation. Unfilled or a few filled conjugate fractures were found in wells Ks2-2-8. The deviation angles between the direction of the sharp bisector and the first two fractures are all within 20 degrees.



Blue represents the maximum principal stress in the Quaternary; brown-red represents the maximum principal stress at the end of the Miocene; red represents the maximum principal stress at the end of the Miocene; yellow represents the maximum principal stress at the top of the fold.

Figure 3. Results of the main CT scan conjugate slits in the KeShen area

According to the results of CT scan conjugate fractures, the fracture development periods in KeShen area can be divided into three periods. The first period fractures are mainly filled with post-diagenetic lime, dolomitic, and argillaceous materials, partially filled with half; the second period shearing fractures are semi-filled with gray matter and dolomitic, partially full filled, which mainly distribute in the two wings of the fold; the third period fractures are mainly unfilled, partial semi-filled by calcite and dolomitic. The fractures are vertical shearing joints and tensioning shearing joints (Figure 3).

4.2. Carbon and oxygen isotope analysis

In this study, 16 calcite fillings near the fracture walls of 9 wells in the Keshen block were selected for carbon and oxygen isotope tests. The test results show that the carbon and oxygen isotopes in the Keshen block can be divided into two zones, in which the average oxygen isotope averages are -8.9‰ and - 14.8‰. The result reflect that the main crack formation period is 2 stages (Figure 4). The oxygen isotope is mainly related to the water medium (the salinity of paleo-water bodies during the deposition period of the Bashijiqike Formation was low-medium salty) and temperature. In order to further determine the period of fracture formation, we calculate the ancient geothermal temperature during the fracture formation period according to the oxygen isotope temperature (average 15 °C), the ancient geothermal gradient (2.5°C/hm[8]) and the burial history of the target layer, we comprehensively determine that the fracture developed periods were the late Yanshan movement-Early Himalayan movement and mid Himalayan movement in study area.

$$\Gamma = 31.9 - 5.55(\delta^{18}0 - \delta^{18}0_w) + 0.7 (\delta^{18}0 - \delta^{18}0_w)^{-2}$$

T-the temperature when the fracture filling is formed, $^{\circ}C$;

 $\delta^{18}O_w$ - the oxygen isotope value of the water medium when the filling was formed (-8[12]), ∞ .

① Late Yanshan Movement-Early Himalayas

The average value of δ ¹⁸O during the development of the fracture filling was -8.9‰, the temperature was 37.5°C, and the corresponding burial depth was about 900m. It is the product of late Yanshan-early Himalayan tectonic movement.

2 Middle of the Himalayas

The average value of δ ¹⁸O during the development of the fracture filling was -14.8 ‰, the temperature was 102.5 °C, and the corresponding burial depth was about 3500m. It was the product of mid-Himalayan tectonic movement. During this period, the study area was slowly squeezed by the nearly north-south tectonic stress. A relatively large number of northwest-southeast and northeast-south-trending structural fractures dominated by shear fractures have been produced.

Considering the unfilled fracture and the above analysis, there are at least three periods of fracture development.



Figure 4. C/O isotope test results of fracture filling

4.3. Fluid inclusions

A total of 14 test points in 8 samples of the fracture fillings of different cutting periods in the Cretaceous Bashijiqike Formation in the Keshen block were selected for uniform temperature testing. According to the temperature distribution and morphology of the fracture fillings of different periods, there are two mainly development periods of structural fractures in this area, combined with tectonic evolution. The filling material of the first period is mainly muddy. The inclusions of the fracture filling material are liquid phase, and the uniform temperature is about 40 °C. The filling material of the second period is mainly calcite, the inclusions are also liquid phase. The homogenization temperature is mainly 80-130 °C (Figure 5). Taking the unfilled structural fractures into account, there are at least three periods structural fractures in the study area.



Figure 5. The temperature measurement results of the inclusions of the fracture filling.

According to the analysis of core CT scan, carbon and oxygen isotope analysis of fracture fillings, and the temperature measurement of inclusions, it is believed that the development periods of structural fractures of the Bashijiqike Formation in the Keshen block are three stages, combined with the structural evolution history of the study area. The first period of structural fractures was formed in the late Yanshan movement-early Himalayan movement, mainly developed near east-west extensional fractures, with small openings. The fractures of the first period were basically filled with mud and gypsum. The uniform temperature of the inclusions was 40°C, and the corresponding buried depth is 900m. The second period of structural fractures was formed in the middle of the Himalayan movement, mainly developed NW-SE, NEE-SW trending shear fractures. The fractures of the second period were semi-filled with carbonate. The uniform temperature of inclusions is 80-130°C, and the corresponding buried depth is mainly 3000-4000m. The third period of structural fractures was formed in the late Himalayas, mainly developed near north-south shear fractures, with good effectiveness and high opening degree. The structural fractures of the third period are mainly distribute in structural high parts, fault turning ends and nearly secondary faults.

5. Conclusions

The fracture of the Bashijiqike formation in Keshen gas field are dominated by high-angle oblique and vertical fractures filled with calcite, the openings of which are mainly distributed between 0.05mm and 0.5mm. The apparent porosity of the fractures averages 0.04%, and the fracture strikes are mainly northeast-southwest and northwest-south east.

There are three development periods of structural fractures in the Keshen block, which are the late Yanshan movement and the early Himalayan movement (small number, filling degree) High), the middle of the Himalayan movement (medium quantity, high filling level), and the late Himalayan movement. Among them, the late Himalayan movement is the main development period of fracture. The effectiveness of the fractures and the opening degree are highly, which is the key to stable production of gas fields.

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