

In-situ Stress Field of Fanzhuang Coaled Methane Block in Qinshui Basin

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Abstract. Geostress is a crucial factor that affects the in-situ permeability and reservoir stimulation, and thus the performance of coalbed methane (CBM) recovery from coal. Therefore, a systematically investigation of in-situ geostress was made based on pressure-time records of the hydraulic fracturing of 238 CBM wells collected from Fanzhuang block in Qinshui Basin of China. The results indicate the vertical stress, maximum and the minimum horizontal principal stress range from 5.92 to 20.08 MPa, 8.03 to 41.75 MPa and 5.38 to 21.24 MPa, respectively. The gradient of the maximum horizontal stress and least horizontal stress vary from 14.16 to 77.82 kPa/m and from 11.12 to 41.43 kPa/m in respective. The relatively high horizontal principal stress zone concentrates in the NE trending within the middle of the block, while the relatively low-stress zone distributes in west, east and south of the block. The analysis of the microseismic fracture monitoring from 72 CBM wells shows that the orientation of the maximum horizontal principal stress concentrates in the NEE~NE direction and locally distorted by the faults, which can be further used to optimize the CBM well drilling, completion and stimulation in the studied area.

1. Introduction

Extensive researches on coal seams in America, China, Australia and Canada have shown that the magnitude of principal stress and orientation has significantly influence on in-situ permeability as well as gas and water productions of CBM wells [1-5]. The higher the stress, the lower the permeability and CBM yield, and vice versa. In addition, the permeability of most coal seams in China is very low, usually lower than 0.5 mD, for which the CBM has no economic productivity unless hydraulic fracturing, horizontal well, or other further well completion technologies were adopted [6, 7]. The artificial fracture development degree and orientation of hydraulic treatment were also significantly affected by the geostress. For example, Lourdes B. Colmanares and Mark D. Zoback revealed that inferred vertical fractures based on the minimum stress direction growth result in excess water production of CBM wells in Powder River Basin, whereas the inferred horizontal hydraulic lead to the relatively low water production [8, 9]. Therefore, research on in-situ stress variation of coal seam is of



significance for CBM exploration and development due to its crucial influence on natural and artificially enhanced permeability of the coal seam.

Geostress, an internal stress in the earth, which was formed by the dynamic geology process during geological history, can be divided into gravity and tectonic stress, etc. The gravity can be easily calculated according to burial depth and rock density. The tectonic field is extremely heterogeneous and constantly changing with time due to complicated and different geological environment. Therefore, it is impossible to describe the tectonic stress with the precise analytical solutions [10]. Efficient methods to investigate the in-situ stress are including geophysical, mechanical and geological methods [11]. The hydraulic fracturing, stress relaxation, borehole breakout, acoustic emission and micromagnetic methods were commonly adopted in the in-situ geostress measurement [10, 12, 13].

The Qinshui Basin has abundant coalbed methane resource, representing the largest CBM development base in China due to relatively high exploration and development degree. The yearly CBM production from Qinshui Basin currently accounts more than 70% CBM production in China. However, water and gas productions of these CBM wells exhibit significantly difference, and a large number of CBM well are of low gas production. It is still obscure that the influence of key geostress factor on the CBM production level and difference due to lack of knowledge or information of in-situ geostress. Since there are thousands of CBM wells with detail well logging and hydraulic treatment data, and it has been extensively verified that the principal stress can be obtained from the pressure-time record of hydraulic treatment [10], there is no reason not to investigate the in-situ stress distribution. Therefore, taking the Fanzhuang coalbed methane block as an example, in which has high CBM development degree and large amounts of data, we will further extract the data of geostress based on the logs of hydraulic fracturing treatment of CBM wells. And the firstly systematic investigation of in-situ geostress will provide a reference for the followed analysis on in-situ permeable fracture aperture and orientation, wellbore stability, hydraulic fracturing design, and thus CBM production.

2. Geological background

The investigated area is located in the southeast of Shanxi Province, China (Figure 1). The area is an NW-NNW-dipping gentle dip monocline with dip angle of 2~7°. There are a few normal faults developed with SN, NW, NE and NNE trends, and also several reverse faults with SN trend in the south of Fanzhuang block. The biggest fault, Sitou fault, which is the western boundary of the block, trended in the NE-NEE direction with a dip angle of 60~70° and throw of 60~580 m. Although it is a normal fault, the fault fracture zone was tightly cemented, which is important for the coalbed methane preservation. As a result, the gas/water conductivity in this area is very poor.

The main coal measures in the investigated area are Carboniferous Taiyuan and Permian Shanxi Formations. The most attractive target layer for CBM exploration and development is the No. 3 coal seam of Shanxi Formation in the Fanzhuang block. The thickness of coal seam ranges from 4.2 to 9.7 m averaged at 6.2 m. The burial depth of the coal seam varies between 239.7 m and 808.7 m, and most of them are shallower than 700 m. The maximum oil immersed reflectance of vitrinite ($R_{o,max}$) for the coal ranges from 3.32 to 4.25 % with mean value of 3.58 %. The gas content ranges from 11.6 to 22.8 m³/t (air-dried basis, ad) with an average value of 19.53 m³/t, and most of them are higher than 20 m³/t. The gas is mainly composed of methane with a concentration of 72.29 ~ 99.21% averaged at 96.43%, and the remainder is mostly carbon dioxide, nitrogen, and rarely heavy hydrocarbon. The Langmuir volume varies from 30.95 to 44.56 m³/t (ad) with an average value of 38.95 m³/t, and the Langmuir pressure ranges from 1.85 to 3.22 MPa with a mean value of 2.48 MPa. The permeability of well-testing changes from 0.0011 to 0.91 mD with an average value of 0.292 mD. The gradient of reservoir pressure ranges from 4.61 to 8.31 kPa/m with a mean value of 6.03 kPa/m, belong to the under pressure reservoir. To sum up, the CBM reservoir can be characterized as a stable coal seam with high coal rank, high gas content, low-pressure gradient, gas saturation and permeability. Due to low and strongly heterogeneous permeability, the research on in-situ geostress in this CBM block is particularly important.

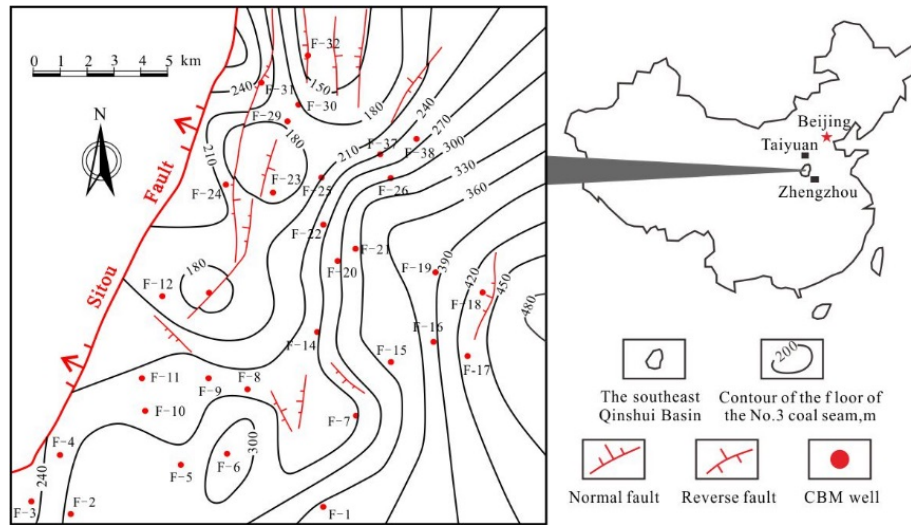


Figure 1. Location and contour of coal seam floor of the study area

3. Methodology

Due to low permeability of the coal seam, hydraulic fracturing is always adopted to stimulate coal seam to enhance CBM production in the Qinshui Basin. During hydraulic fracturing treatment, large volumes of water are pumped at a certain rate into the target coal seam isolated with inflatable packers to increase the fluid pressure until a fracture is initiated at the target coal section. Thus formation breakdown pressure will be obtained. After abruptly stopping the flow into the well, the fracture will stop to expand and tend to close. The pressure by that the fracture just keeps opening is defined as the fracture closure pressure. The least principal stress is equivalent to the fracture closure pressure. Therefore, the least and maximum principal stress can be obtained from the pressure-time records, which are expressed as follows [14, 15]:

$$\sigma_{hmin} = P_c \quad (1)$$

$$\sigma_{Hmax} = 3\sigma_{hmin} - P_f + T - P_p \quad (2)$$

where σ_{hmin} is the least principal stress, MPa; σ_{Hmax} is the maximum principal stress, MPa; P_c is fracture closure pressure, MPa; P_f is the formation breakdown pressure, MPa; T is the tensile strength, MPa; and P_p is the pore pressure of rock, MPa.

The magnitude of overburden stress can be calculated by integration of rock densities from the surface to the target burial depth, giving:

$$\sigma_v = \int \rho(z)gz \approx \bar{\rho}gz \quad (3)$$

, where $\rho(z)$ is the rock density as a function of burial depth (z), g/m^3 ; g is the gravitational acceleration constant, N/kg ; $\bar{\rho}$ is the average overburden density, i.e. 2.3 g/cm^3 was adopted according to the statistics of density log.

4. Results and discussion

4.1 Magnitudes of principal stress

As per the methodology above, the magnitude of the modern in-situ principal stress was analysed based on pressure-time records of hydraulic treatment from 238 CBM wells. The result shows that at 257.13 ~ 873.05 m of burial depth of the No. 3 coal seam, the maximum horizontal stress ranges from 8.03 to 41.75 MPa with an average value of 19.38 MPa.

The gradient of the maximum horizontal stress varies from 14.16 ~ 77.82 kPa/m with a mean value of 37.71 kPa/m. The least horizontal stress ranges from 5.38 to 21.24 MPa with an average value of 11.93 MPa. The gradient of the least horizontal stress varies from 11.12 to 41.43 kPa/m with a mean value of 23.18 kPa/m. The vertical stress ranges from 5.92 to 20.08 MPa with an average value of 11.99 MPa.

Figures 2 and 3 show that the distribution of the maximum and the least horizontal principal stresses are similar. This implies that the relatively high horizontal principal stress zone concentrates in the NE trending within the middle of the block, e.g. around the wells F-27~F-20~F-14~F-6, while the relatively low-stress zone distributes in west, east and south of the block.

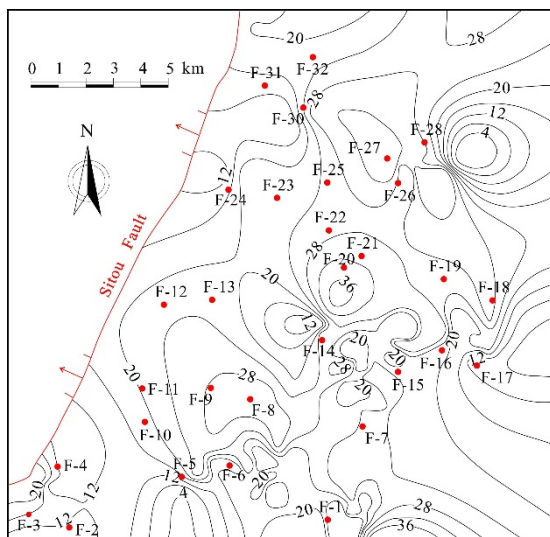


Figure 2. Distribution of maximum principal horizontal stress.

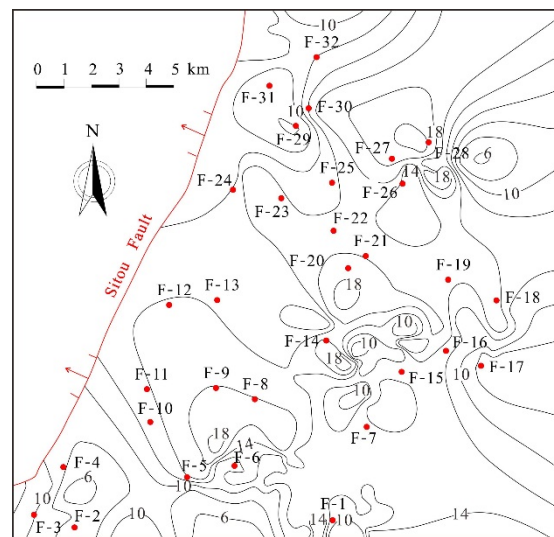


Figure 3. Distribution of the least principal horizontal stress.

4.2 Stress orientation

Hydraulic fracture will always propagate parallel to the orientation of the maximum principal horizontal stress [16]. Therefore, stress orientation can be analyzed from the azimuth investigation of the hydraulic fracture. Microseismic fracture monitoring was made in 72 CBM wells. By identifying and locating microseismic events of rock failure, the azimuth of hydraulic fractures was obtained. The azimuth of hydraulic fractures ranges from N41.7~123.8° with an average value of N75.9° and a median of N67.75°. The count of hydraulic fracture azimuth is well fitted by the distribution curve of the Kernel Smooth, which implies that most of the orientation of the maximum horizontal principal stress concentrates N60~70°, namely, NE-NEE direction (Figure 4). The result agrees well with those from geological structure analysis and focal mechanism in the studied area [17]. Figure 5 shows that the maximum horizontal principal stress is mainly in the NEE~NE direction in the non-fault area while changes of stress orientation occur around the faults.

Understanding the in-situ stress orientation and magnitude is critical to well drilling, completion, and stimulation [18]. As per analysis of stress magnitude and orientation above, CBM well pattern and spacing, horizontal well trajectory, perforated location and direction, and fracturing scale or fracturing fluid displacement can be optimized in the studied area to improve the depressurization efficiency and enhance CBM recovery. For example, to improve recovery efficiency cost-effectively, longer well spacing should be adopted in the NE~NEE direction (the maximum horizontal principal stress), while shorter well spacing should be utilized along the least horizontal principal stress. The small scale fracturing treatment should be adopted when the least horizontal stress is the least stress in order to lower the height of hydraulic fracture and avoid communicating with the overlying or underlying aquifer.

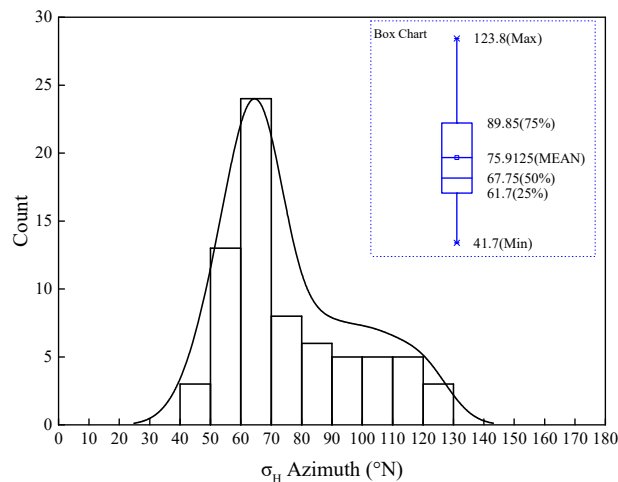


Figure 4. The distribution of hydraulic fracture azimuth

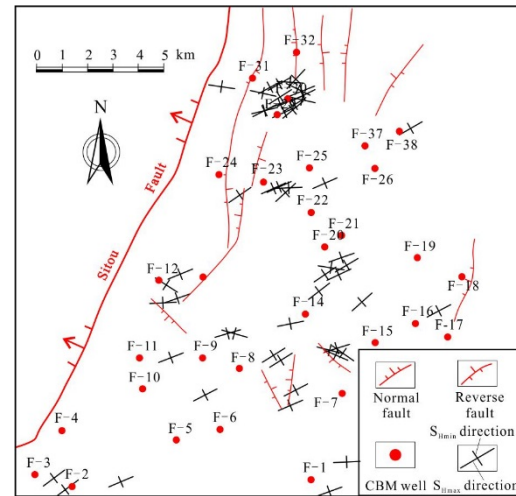


Figure 5. The distribution of the horizontal principal stress azimuth

5. Conclusions

This study presents an investigation on the in-situ stress of high rank coal seams in Fanzhuang block from south Qinshui Basin of China. The maximum and least horizontal stresses, vertical stress range from 8.03 to 41.75 MPa, 5.38 to 21.24 MPa, and 5.92 to 20.08 MPa, respectively. The gradient of the maximum and least horizontal stresses vary from 14.16 ~ 77.82 kPa/m and 11.12 to 41.43 kPa/m, respectively. The high horizontal principal stress zone distributes in the middle of the Fanzhuang block with trending in NE direction. The orientation of the maximum horizontal principal stress concentrates at N60~70°. Improved understanding of geostress in terms of magnitude and orientation suggested the optimization of the CBM development in the Fanzhuang block.

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