[PS]In-Situ Stress State of the Upper Paleozoic Coal-Bearing Strata in the Southern Qinshui Basin, China: Implications for Unconventional Natural Gas Exploration and Production*

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Abstract

In-situ stress state has significant influence in the exploration and development of unconventional natural gas. The upper Paleozoic coal-bearing strata in southern Qinshui Basin, China, contain abundant unconventional natural gas resources, including coalbed methane (CBM), shale gas and tight sandstone gas. In this paper, the in-situ stress orientation and magnitudes of the Shanxi Formation in the Zhengzhuang block were investigated based on imaging logs, hydraulic fracturing, and finite element simulation method (FES). The FES results indicate that the horizontal maximum principal stress (σHmax), horizontal minimum principal stress (σHmin) and vertical stress (σv) range from 7.25-42.65 MPa, 4.62-25.68 MPa, and 5.18-22.53 MPa, respectively, which are consistent with hydraulic fracturing measurements. The magnitude of the vertical in situ stress is mainly affected by burial depth of strata and these of the horizontal affected by faults. The in-situ stress magnitude increases from the NW to SE with the increase burial depth. However, it is significantly reduced in the zone of large-scale faults and increases as the angle between the main fault strike and the loading direction increases. Three types of stress fields were found: normal faulting stress regime (σv > σHmax > σHmin), reverse faulting stress regime (σHmax > σHmin > σv) and strike-slip faulting stress regime (σHmax > σv > σHmin). The Zhengzhuang Block is dominated by reverse and strike-slip faulting stress regimes. The relation between the coefficient of lateral stress and burial depth shows that shallow strata are characterized by horizontal stresses, whereas deep strata are generally hydrostatic pressures that approximately equal to the principal stresses. High gas and low water production are associated with horizontal hydraulic fractures, wherein the vertical stress is the minimum stress. Based on borehole breakouts and drilling-induced fractures interpreted from imaging logs, the σHmax orientation trends NE-NEE, and locally distorted by the strike of faults, which can be used to optimize the drilling, completion, and stimulation of wells in the study area.

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In-situ Stress State of the Upper Paleozoic Coal-Bearing Strata in the Southern Qinshui Basin, China: Implications for Unconventional Natural Gas Exploration and Production

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Introduction

In-situ stress is important to coal permeability, hydraulically induced fractures, and coalbed methane recoverability. Therefore, understanding in-situ stress variation is extremely important for coalbed methane (CBM) exploration and development in the Zhengzhuang block in the southern Qinshui Basin, China.

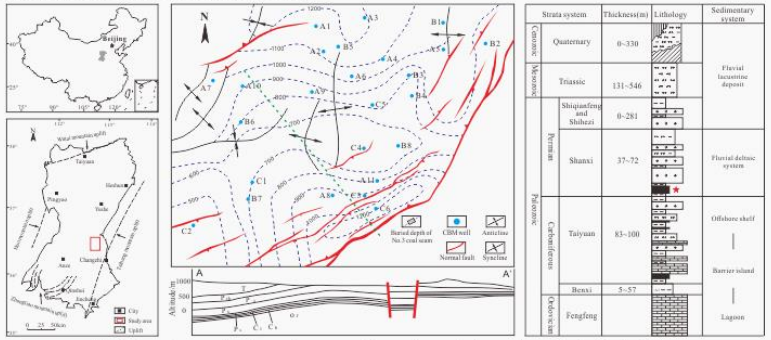

Fig. 1. Location, stratigraphy, and contours of the coal seams in the southern Qinshui Basin, China.

Method

In this paper, the ANSYS17.0 software was used for modeling and in situ stress field simulation. The work flow of the 3D FEM calculations involving three parts: 1) the variational principle is used to transform the variability problem to be solved into the corresponding variational problem; 2) the target layer is divided into a series of units, and the discrete cells are linked together by nodes; 3) through boundary stress loading, the tectonic stress field of the target can be obtained.

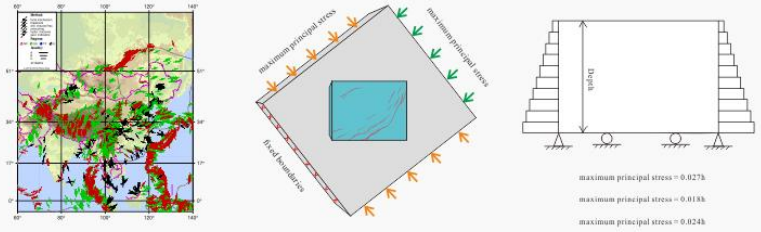

Fig. 2. In situ stress orientation and the boundary conditions of geo-stress in the No.3 coal seam in the study area .

Results

The FES results indicate that the horizontal maximum principal stress (σ_H), horizontal minimum principal stress (σ_h) and vertical stress (σ_v) range from 7.25-42.65 MPa, 4.62-25.68 MPa, and 5.18–22.53 MPa, respectively, which are consistent with hydraulic fracturing measurements.

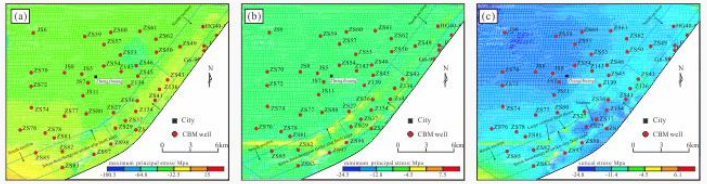

Fig. 3. The distributions of σ_H, σ_h and σ_v in the No. 3 coal seam in the Zhengzhuang block.

Through constant loading, the in situ stress distribution can be determined. When the error between the simulated and measured in situ stresses is relatively small, the loading scheme is reasonable.

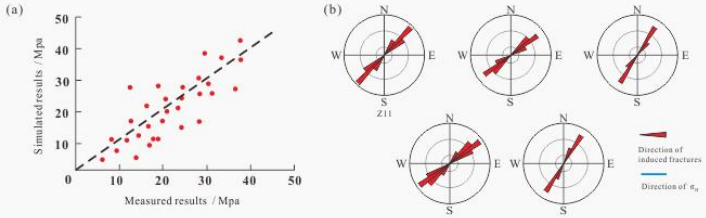

Fig. 4. Comparison of the measured and simulated results for the current in situ stress.

Three different classes of stress regimes that are derived from three different combinations of the three principal stresses, i.e., $\sigma_v > \sigma_H > \sigma_h$, in a normal faulting regime;$\sigma_H > \sigma_v > \sigma_h$, in a strike-slip regime; and $\sigma_H > \sigma_h > \sigma_v$, in a thrust faulting regime.

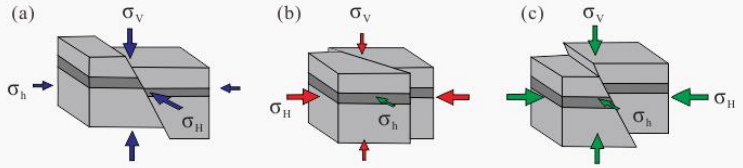

Fig. 5. Types of in situ stress fields determined in the study area.

Discussion

In the Zhengzhuang block, both the relationships between the σ_H magnitude and coal permeability, and the σ_h magnitude and coal permeability indicated the typical negative exponent pattern. In contrast, the relationship between the σ_v magnitude and coal permeability was relatively complicated, which in fact indicated coal permeability varied with burial depth.

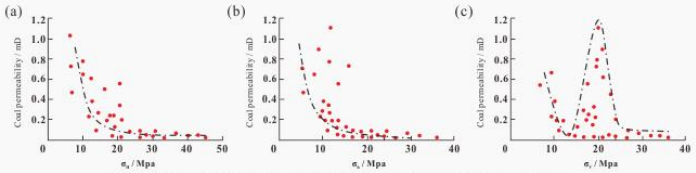

Fig. 6. Scatter diagrams of effective stress magnitudes and coal permeability.

The differential stress and presence of fractures on the geometry and pattern of hydraulic fractures in CBM reservoirs are exhibited in Figure 7 with a case of σ_H-σ_h planar view. Conditions in Figure 7A, C are similar except that Figure 7A has a high differential stress, and the results indicate that a relative low differential stress is in favor of forming complex hydraulic fracture networks parallel to the σ_H orientation.

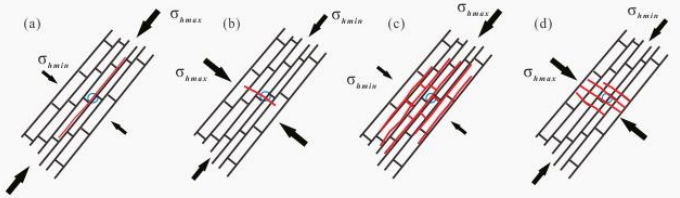

Fig. 7. Different patterns of hydraulic fractures are shown in coal reservoirs caused by stress anisotropy and the horizontal maximum principal stress (σ_{Hmax}) orientation with respect to fractures.

Conclusions

(1) The FES results indicate that the σ_H, σ_h σ_v range fron 7.25-42.65 MPa, 4.62-25.68 MPa, and 5.18–22.53 MPa, respectively.

(2)The permeability in coal seams of Zhengzhuang block decreased exponentially with the increased effective stress.

(3)Hydraulic fracture propagation are greatly controlled by the in-situ stress field.

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Coblentz, D.D., Richardson, R.M., 1995. Statistical trends in the intraplate stress field. J. Geophys. Res. 100 (B10), 20245–20255.

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