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Relationship between joint development in rock and coal seams in the southeastern margin of the Ordos basin

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ABSTRACT

To predict joint development characteristics of coal seams, joint characteristics of rock seams from 88 field stations were observed and comparisons were made between joint characteristics of coal and rock seams at 10 coal outcrops. Additionally, detailed joint measurements of underground coal seams were taken at two coal mines. This study investigated the effects of seam thickness, lithology, and structure on joint development and established the relationship between joint development of coal and rock seams, which allowed predictions of predominant joint densities for the No.5 coal seam in the southeastern margin of the Ordos basin. The results show that outcrop and underground coal seams exhibit the same joint systems as rock seams. The joints are mainly upright. Predominant joints strike 55° on average, followed by joints striking 320°. The joint density of the coal seam is 18.7–22.5 times that of the sandstone seam at the same thickness. The predominant joint density of the No.5 coal seam, controlled by the structure, is ~4–20 joints per meter. Joint densities exhibit high values at intersecting areas of faults and folds and decrease values in structurally stable areas. The permeability increases exponentially with increasing density of the predominant joints.

1. Introduction

Fractures in coal seams, which are composed of cleats and tectonic joints, are important channels for fluid migration [1–3]. Cleats are formed during the coalification process, whereas the formation of joints is mainly due to tectonic stress [4–7]. Tectonic stress controls the joint development of coal seams and thereby causes heterogeneity in the coal reservoir permeability [8,9]. Specifically, the paleo-tectonic stress field controls the orientation and distribution of joints and the modern tectonic stress field determines the openness of joints [10,11]. Therefore, tectonism directly controls fracture development of coal seams and affects the distribution of the high permeability zone. There are current technological challenges involved with the acquisition of data to better understand the development characteristics of coal seam joints [12]. Therefore, it is particularly important to be able to predict the development characteristics of coal seam joints using limited data.

Wheeler and Dixon found that if the surface rock seams in some regions present denser joint development, the corresponding underground rock seams also show denser joint development than those of the rock seams in other regions at the same depth [13,14]. The coal in these regions, which is similar to brittle rocks with low mechanical strength, usually has more intensely developed joints [15]. Fractures in the coal seam tend to have the same attitudes as those of the joints in the upper and lower surrounding rocks [16]. Therefore, joint developments between coal seams and their upper and lower surrounding rock may yield important relationships that can be used to predict the development characteristics of underground coal seam joints.

The southeastern portion of the Ordos basin in China was chosen as the study area for our research. Joint development characteristics of coal and rock seams were studied. Combined with analyses of the effects of lithology, seam thickness, and geological structures on the joints, correlations between joint developments of coal and rock seams were revealed. Furthermore, correlations between the joints and the coal reservoir permeability were explored to provide a basis for evaluating the high permeability region in the study area.

2. Geological background

The Ordos basin is a large intracontinental, superimposed, and residual basin in north China craton [17]. The study area is located in the south of the Jinxi fold belt in the eastern margin of the basin (Fig. 1). The study area appears to be an overall NW-dipping

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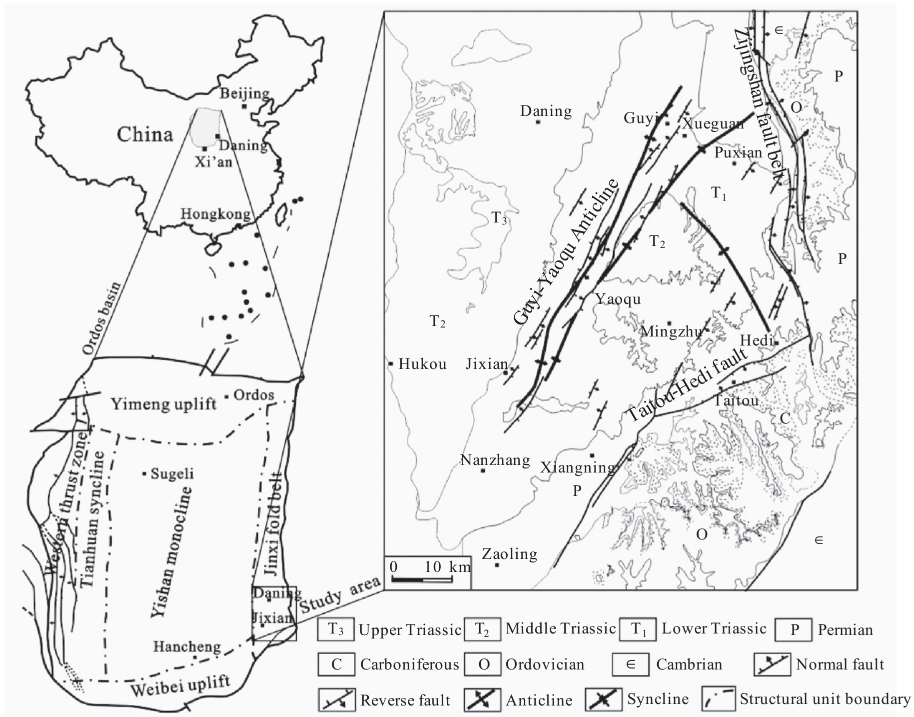

Fig. 1. Location and structural outline map of the study area.

monocline with gentle stratum dip angles of less than 15°. The typical structure is represented by the NE-striking Guyi-Yaoqu fault-fold belt, which consists of one wide anticline, one wide syncline, and some reverse faults. The NS-trending Zijingshan fault belt is developed in the eastern edge and the NE-striking Hedi-Taitou fault is developed in the southeastern edge of the basin.

The strata exposed in the study area are in the order of Cambrian, Ordovician, Carboniferous, Permian, Triassic, Neogene, and Quaternary strata from east to west. Coal-bearing strata are mainly the upper Carboniferous-Lower Permian Taiyuan Formation (C_2-P_1t) and the Lower Permian Shanxi Formation (P_1s). The No.5 coal seam of the Shanxi Formation presents good coalbed methane reservoir conditions with a coal thickness of 2–7 m buried at a depth of 700–1500 m; the vitrinite reflectance is 1.0–2.2%. The caprock, hydrogeological conditions, and relatively stable tectonic conditions in the study area are favorable for coalbed methane storage. The gas content ranges from 10 to 20 m^3/t. Therefore, the No.5 coal seam is a key formation for coalbed methane exploration and development in the eastern part of the Ordos basin [18–20].

3. Correlations between joint developments of rock and coal seams

The joint density is defined as the number of joints per unit length along the direction perpendicular to the joint strike. Because the scan line in the field always exhibits an acute angle, θ, with the direction of the joint strike, measured data needs to be transformed using the equation $D = D_1/\cos(90° - \theta)$, where D and D_1 are the true and measured joint density, respectively.

3.1. Joint attitudes

3.1.1. Joint attitudes of the rock seams

The study area has a weak tectonic deformation and a relatively developed brittle joint structure. A total of 88 observation stations with 7629 joint attitudes of the rock seams were observed in field. The results show that the rock seam joints are mainly upright or present at high dip angles. The joints striking 55° on average are the predominant joint set in the whole study area, followed by joints striking 320°, while the SN- and EW-striking joints are less developed as shown in Fig. 2. According to geological ages of strata formations, there are 11 strata formations of the Carboniferous-Triassic age, i.e., from the Benxi Formation (C_2b) to the Yanchang Formation (T_3y). Those strata present the same structural deformation history of the Indochina, Yanshan, and Himalayan tectonic movements. The results from rose diagrams of the joint strikes in the 11 strata formations have extremely similar morphologies. Specifically, rock seams of those 11 strata formations develop the same sets of joints.

Joints of the study area are mainly from shear genesis. Conjugate shear joints are commonly developed. Two conjugate joints cross and cut each other by an angle smaller than 90°. Fault antisteps indicate that micro-sized displacement can be found in the joint surface. The Indosinian tectonic stress field of the study area mainly resulted in SN-trending compression, and then NE- and NW-striking conjugate shear joints were weakly developed. The most intense Yanshanian tectonic activity occurred in multiple stages, and tectonic stress directions were variable. The Zijingshan fault presented an EW-trending compressive stress during the Yanshan period, and the conjugate shear joint striking 45° and 320° were well developed. Compressive stress directions were mainly NWW-trending in both the Hedi-Taitou fault and Guyi-Yaoqu fault-fold belt; here, the conjugate shear joints were mainly present at orientations of 60° and 320°. Compressive stresses in other regions are NW- or NNW-trending, and conjugate shear joints were developed in nearly SN- and EW-trending directions. Yanshanian tectonic joint strikes were mainly 45°–60°. The Himalayan compression direction was mainly the NE-trending in the whole study area and conjugate shear joints exhibited nearly SN- and EW-striking.

3.1.2. Comparisons of joint strikes in coal and rock seams

Tectonic joints in coal seams present a high dip angle and good directionality. At the observation station 5 shown in Fig. 3a, the