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Mineral occurrence and its impact on fracture generation in selected Qinshui Basin coals: An experimental perspective

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ABSTRACT

The effect of mineral matter on the fracture evolution was investigated for Lower Permian and Upper Pennsylvanian coal samples from the Qinshui Basin of China. Optical microscopy, scanning electron microscopy with energy dispersive X-ray spectrometry (SEM–EDS), and X-ray computed tomography (X-ray CT) were used to investigate the composition and modes of occurrence of minerals within the coals and to characterize the natural and induced fractures present within the samples. The spatial distribution of mineral matter investigated by X-ray CT demonstrates that the variation of mineralization within the cleats/fractures occurred at fine scales, and most of minerals were scattered in coal core samples. The original fractures normally were present as two sets: one set was almost parallel to the bedding plane, and the other was almost perpendicular to the bedding plane. For created fractures, the difference in density between the matrix and mineral matter may weaken the cohesion of coals, and it could explain why the created fractures propagate along the junction of minerals and organic coal matrix. The internal fracture porosities varied from 0.06% to 20.69%, which indicates a strong internal heterogeneity of the coals after a stress is applied. The inclination of the main shear fractures ranges from 55° to 95°. Using energy analysis, the fracture energy appears to represent nearly half of the total dissipated energy, which can be correlated with the fracture density and orientation. The formation and distribution of shear fractures is related to the spatial distribution of mineral matter and the overall mineral content. These investigations serve to characterize hydro-fracturing and pulverized coal generation during coalbed methane development.

1. Introduction

Coal consists of two types of materials: organic components (macerals), and a variety of inorganic constituents (minerals and non-mineral inorganics) that are broadly referred to as “mineral matter” (Ward, 2002). The benefits derived from the organic components in coal include its energy output on combustion, its reducing capacity in metallurgical processing, and its capacity for in-situ coalbed methane (CBM) adsorption as an alternative hydrocarbon source. From the genetic perspective, the mineral matter in coal, similar to the organic matter, is a product from the processes associated with coal formation, as well as changes in subsurface fluids and other aspects of sediment diagenesis (Golab et al., 2013). Mineral matter may form by a number of different processes (Ward, 2002), and the formation and migration of CBM and other hydrocarbons generated during or after coalification may also be related to mineralization (Glikson et al., 2000). Tectonism and geothermal activity can produce hydrothermal fluids, which can result in epigenetic mineralization and alteration of diagenetic minerals within coals (Faraj et al., 1996; Golding et al., 2000; Hower et al., 2001).

The nature and distribution of the mineral matter have a fundamental effect on the behavior of coals when used for various purposes, including gas production, enhanced coalbed methane (ECBM) recovery and coal utilization. The mineral matter in coal may change the mechanical and petrophysical features of the coal seam, which is a factor that may be important for both primary CBM recovery and enhanced recovery. In enhanced CBM recovery, the injected CO_2 may dissolve in the brine water and create a highly reactive mixing zone near the wellbore region, where carbonate and other acid-reactive minerals are solubilized (e.g., Dawson et al., 2011, 2015; Massarotto et al., 2010). For CBM drilling and production, the mineral matter affects the process of gas production. For example, abundant clay minerals may block the gas/water flow path (pores or fractures) of a coal seam. The mineral matter in coal is a significant aspect in the design and selection of fluids for drilling and hydraulic fracturing. Furthermore, mineral matter plays important roles in coal utilization, including underground coal gasification, and may also affect the environmental impact of mining and associated health concerns (e.g., Dai et al., 2014; Golab et al., 2013; Vassilev et al., 2005; Ward, 2002).

The most common pathway for fluids (e.g., gases and formation water) in coals is through fracture networks, and the orientation of these fractures relative to the stress will control the fracture apertures

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or permeability (Cai et al., 2014; Engelder and Whitaker, 2006; Laubach et al., 1998). To stimulate gas production, hydraulic fracturing is a means of creating more fractures for fluid flow, which include the newly created fractures and increased sizes of openings of the existing ones. Usually, the underground stress can limit the development of shear cracks and also give rise to a certain shear angle. However, the presence of mineral matter may alter the way an induced fracture propagates through coal seams, as can the presence of pre-existing fractures. The created fracture modes depend on the heterogeneity of the coal and the arrangement of macroscopic pre-existing mineral bands, as well as the underground stresses. Thus, it is of great importance to study the mineral occurrence and its impact on fracture generation for CBM production.

In this paper, coal samples with varying degrees and types of mineralization were selected to examine the paragenesis of mineral matter and fractures, the modes of mineral matter occurrence, and the processes of fracture generation. The samples were divided into two sets: one set (A1–A13) was used for analysis of the paragenesis of the mineral matter and fractures and the mode of mineral matter occurrence; the other set (B1–B4) was used for studies of fracture generation in coal cores with various modes of mineral occurrence.

2. Samples and methodology

2.1. Sampling and coal analyses

The sampling sites were located in the Qinshui Basin (Fig. 1), which is the most successful commercial CBM area in China. The channel sampling method was used, as for previous studies (Cai et al., 2011, 2014). After experiencing four-stage tectonic movements, the Qinshui basin deformed in a synclinorium structure, which is comprised of 12 secondary tectonic units. These tectonic units include Unit I: Shouyang–Yangquan monoclinal structural zone, Unit II: Tianzhongshan-Yicheng fault structural belt, Unit III: Congziyu–Guyang monoclinal structural zone, Unit IV: Zhangyuan–Qinyuan banded structural belt, Unit V: Yushe–Wuxiang structural zone, Unit VI: Niangziguan–Pingtou monoclinal structural zone, Unit VII: Shuangtou–Xiangyuan fault structural belt, Unit VIII: Guxian–Jiaodi fault structural belt, Unit IX: Anze–Xiping anticline structural belt, Unit X: Fengyi–Jinyi banded structural belt, Unit XI: Tunliu–Changzhi monoclinal structural zone and Unit XII: Guxian–Jincheng monoclinal structural zone. The coal samples were recovered from the Lower Permian and Upper Pennsylvanian strata near the edge of the structurally complex Qinshui Basin (Fig. 2). Seventeen coal blocks, each with a volume of 30 × 30 × 30 cm^3, were collected from the working faces of active underground coal mines and were transported to the laboratory for this study. Core samples with different mineral matter characteristics were drilled from the coal blocks approximately parallel to the bedding plane. Basic coal analyses, including vitrinite reflectance measurements, petrographic composition analysis, mineral matter and micro-fractures frequency and orientation determination were conducted for all these samples by using the standard methods described in our previous research (Cai et al., 2011). Hereby, these methods will be briefly described. The coal blocks were crushed, and polished sections were prepared for vitrinite reflectance determination (with 500 points) and petrographic composition analysis. Chemical compositions of mineral matter were determined using SEM–EDS on naturally broken surfaces. The original micro-fracture frequency was investigated using optical microscopy.

2.2. Optical microscopy, SEM–EDS and X-ray CT

Optical measurements for micro-fracture analysis were carried out using a Laborlux 12 POL microscope with a MPS 60 photometer system for all 17 samples, each of which is a ~4 × 5 × 3 cm^3 solid sample block.

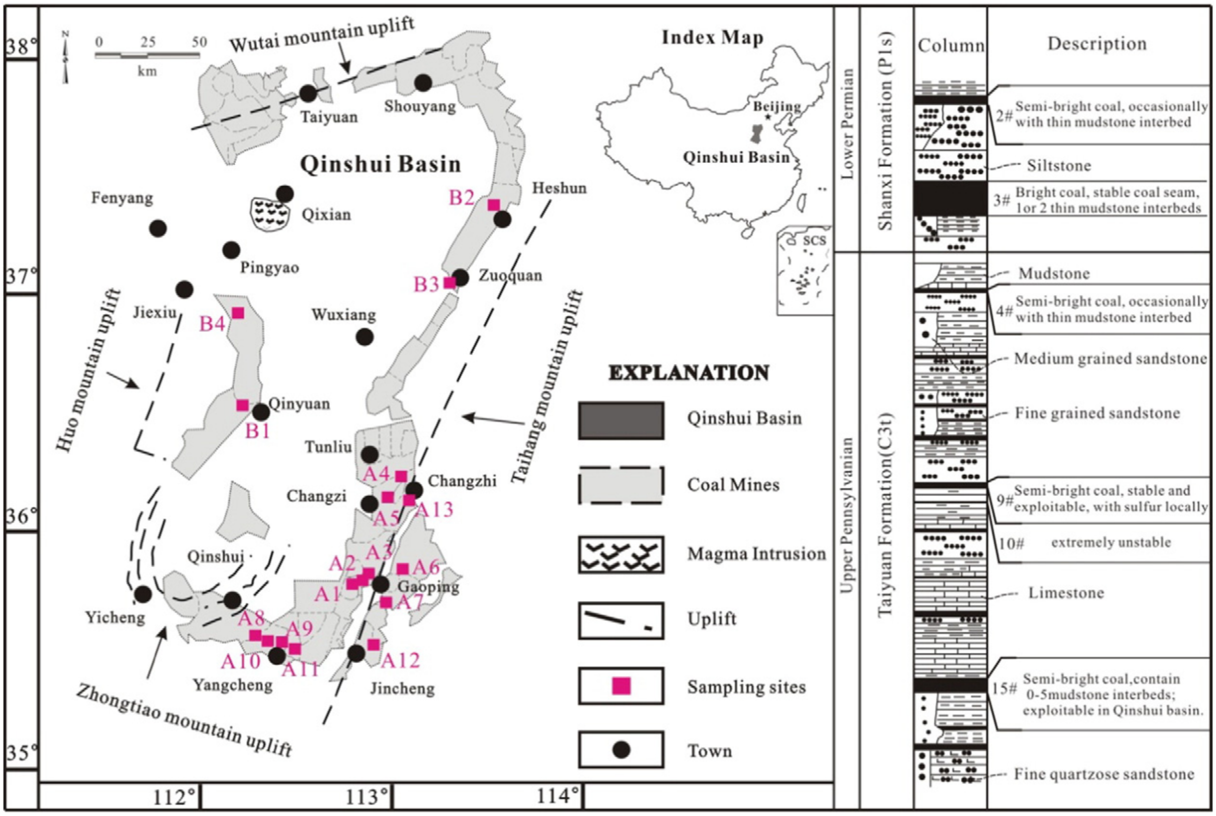

Fig. 1. Geological setting of the coal samples from Qinshui basin and stratigraphic section of coal-bearing strata.
Redrafted from Cai et al. (2011).