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Characteristics and evolutions of gas dynamic disaster under igneous intrusions and its control technologies

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ABSTRACT

Globally, thermal events related to igneous intrusions are widespread in major coal-producing countries. The occurrence, size and distribution of these events play important roles in coal mining safety. The sill distribution area is relatively large in China, which has a particularly serious influence on the damage of coal seams and mining safety. In the Haizi coal mine, magmatic activity is intense and widely distributed and has resulted in 11 coal and gas outburst accidents under a 120-m-thick igneous sill. To study the effect of sill intrusions and their relationship with gas outbursts, samples from the outburst coal seams (Nos. 7, 8, 9 and 10) were taken from the Haizi coal mine at various distances from the sill. We found that under the effect of entrapment and thermal evolution of the igneous sill, the coal pore structure was developed, the gas adsorption capacity was enhanced, and gas outburst risk was increased. The rules of bed separations evolution under the sill were analyzed which indicated that large separation quantities are developed as gas enrichment areas in the bending zone after mining, which brings dynamic disasters risk and good drainage conditions at the same time. The gas pre-extraction technology for the first mining seam and the pressure relief gas drainage technologies via surface wells and distant penetration boreholes were established. Given the practice in the Haizi coal mine, it was determined that the gas drainage technologies could eliminate gas outbursts and promote mining safety under this unique geologic condition.

1. Introduction

In China's long geologic history, magmatic activity has been frequent and widespread since the Yanshan movement in the Mesozoic (Yang, 1996; Yang and Tang, 2000). Igneous intrusion provides a high-pressure and high-temperature environment for coal seams, which promotes the thermal evolution of coal seams, speeds up the generation of gas, and brings enormous changes in coal metamorphism, pore structure, and adsorption-desorption characteristics (Golab and Carr, 2004; Stewart et al., 2005; Wang and Zhang, 2006; Dai and Ren, 2007; Saghafi et al., 2008; Rimmer et al., 2009; Jiang et al., 2011; An et al., 2013). Generally, with the enhanced of coal metamorphism degree caused by igneous intrusions, gas content and gas diffusion rate correspondingly increase (Gurba and Weber, 2001), which often causes safety problems related to gas control in coal mines. Of the numerous coal and gas dynamic disasters worldwide, a large number have been caused by igneous intrusions, including occurrences in South Africa, Australia, Ukraine and China (Anderson, 1995; Saghafi et al., 2008; Jiang et al., 2011; Sachsenhofer et al., 2011).

The distribution area of sill is relatively large in China, which causes particularly serious influence on mining safety. Current research has focused on the rule of bed splitting development under thick hard rock masses via the thin-elastic-plate bending theory, physical simulation, numerical simulation and field measurements (Teng and Yan, 1999; Guo, 2000; Zhao et al., 2002; Wu et al., 2011), as well as associated factors and evaluation indexes (Palchik, 2005; Tan et al., 2013). However, few researchers have investigated the gas disaster evolutions mechanism under the thick sill.

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The gas drainage technologies could eliminate gas outbursts and promote mining safety (Noack, 1998; Creedy and Tilley, 2003; Cheng et al., 2009), which are expected to become increasingly challenging as deeper and more gassy coal seams are mined (United Nations ECE and Methane to Market Partnership, 2010). Nowadays, regional gas control techniques must be firstly adopted before tunneling or mining in outburst coal seams which include protective seam mining and pressure-relief gas drainage for multiple seams and regional gas pre-drainage for a single seam, among which the protective seam mining technology is the most economical and effective method (Brandt and Sdunowski, 2007; SAWS, 2008; Cheng et al., 2009). Effective gas drainage in the adjacent more gassy seams could turn them into less gassy seams, thus realizing the objective of extraction of both coal and gas in a safe environment (Cheng et al., 2009; Wang and Cheng, 2012; Daniel et al., 2013). It is considered that appropriate technologies chosen would be the key for coal mining safety and economy in outburst coal seams.

Igneous rock is dense and hard, has good integrity, and is usually in unconformable contact with the surrounding rock mass. The occurrence, size, and distribution of the intrusive igneous rock play important roles in coal mining safety. When a thick-hard igneous sill exists in the overlying strata, the physical characteristics of the underlying coal seams change, and the collapse and failure development rules take on new meanings, which could increase the risk of gas outbursts in the underlying coal seam. Based on theoretical analysis, laboratory testing, and field observations, we analyzed gas disaster characteristics and evolutions rules under the igneous sill in the Haizi coal mine. Gas control methods for safe and high efficient exploitation of coal and gas were proposed and tested. The research results could provide useful references for gas dynamic disaster control under similar geologic conditions.

2. Geological setting

The Haizi coal mine is located in the north of the Linhuan mining field in the Huaibei coal field, Anhui province, China, and its designed production capacity is 1.2 million tons per year, with a mining depth ranging from 500 to 1025 m. The Nos. 7, 8, 9 and 10 coal seams are the primary mineable coal seams. Since the early period of the Indo-China movement, the depth of coal seams in the Haizi coal mine has reached about 3000 m. Coal seams were affected by hypozonal metamorphism and the degree of coalification reached gas or fat coal stage (maximum vitrinite reflectance R_{omax} ranged from 0.7% to 0.9%), which then entered the main period of gas generation (the primary generation) with the amount of generated gas reaching 220 m^3/t. Strata of this area were uplifted after the Indosinian tectonic movement. During the early-middle period of Yanshan, magmatic activity has become more widespread in the Huaibei coal field, and deep crustal magma gushed along the Su-Bei Fault and intruded into the Haizi coal field along the Daliujia Fault (Yang, 1996). The thick igneous rock that intruded the No. 5 coal seam had a great influence on the underlying coal seams due to a temperature of approximately 300 °C. This regional thermal metamorphism increased the coalification degree of the underlying coal seams, which were turned into the stages of coking coal, lean coal, and even anthracite (R_{omax} ranged from 2% to 2.8%). Meanwhile, coal seams generated large amounts of gas for a second time (Secondary generation), with the amount of generated gas reaching 340 m^3/t. The coal seam gas generation history of the Haizi coal mine is shown in Fig. 1.

The igneous rock is distributed as a sill in the middle and western part of the Haizi coal mine, as shown in Fig. 2, and its strike is 6.5 km long. This igneous sill is in a stable condition in the II102

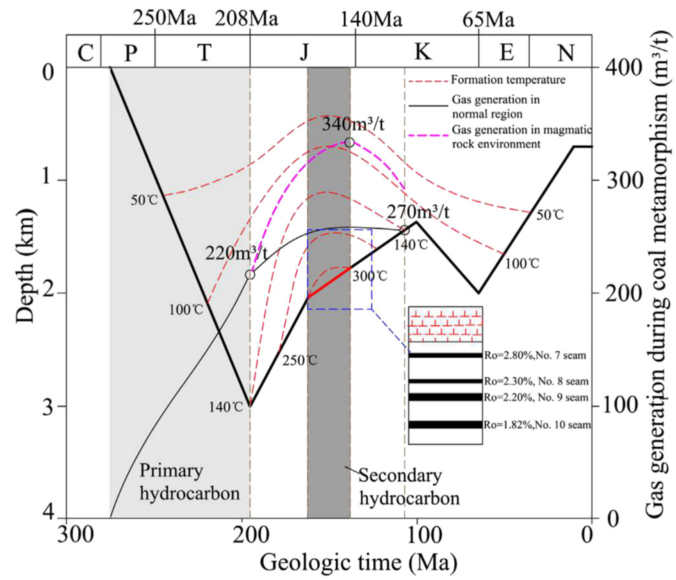

Fig. 1. Coal seam gas generation history of the Haizi coal mine.

mining area above the roof of the No. 7 coal seam and is usually more than 120 m thick. The rock is mainly diorite and diorite-porphyrite and appears as either light gray or green–gray with a plaque-like structure, which is clearly shown in the whole-block structure characteristics.

3. Gas disaster characteristics under the sill in the Haizi coal mine

The study of the mechanisms of coal and gas outbursts is at the qualitative comprehensive effects hypothesis stage, and the argument is that an outburst is caused by comprehensive effects, including ground stress, gas and the physical mechanical properties of coal (Yu, 1979, 1992). In the Haizi coal mine, magmatic activity is intense and widely distributed which has brought great influence on coal, gas and ground stress, and has resulted in 11 gas outburst accidents under a 120-m-thick sill.

3.1. Coal structure characteristics under the sill

Four samples were collected in the Haizi coal mine from the No. 86, II102 mining areas which were covered by the sill, and one sample was chosen from the normal region (II101 mining areas) without sill covering for comparison. The test results showed that thermal evolution effect of igneous intrusions promotes coal metamorphism (Fig. 3). Generally, the R_{omax} increases with depth, whereas the R_{omax} of Nos. 7, 8, 9, and 10 coal seams become smaller with increasing distance from the sill, mainly due to thermal metamorphism. However, the vitrinite and R_{omax} of the coal sample, collected from the II101 mining area without sill covering, are smaller than the area covered by the sill.

The high temperature baking effect of the sill on the underlying coal seam makes the number and scale of stomata in coal significantly increase. The stomata are mainly elongated linear, honeycomb or flower-shaped pores, and their number, pore diameter, pore axis and the porosity of coal increase with the duration time and increasing temperature. Meanwhile, the thermal stress generated by thermal expansion and the tensile stress generated by contraction of organic volatile matrix in local area superimpose and accelerate the formation and expansion of micro-cracks in the coal