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Microseismic signals of double-layer hard and thick igneous strata separation and fracturing

Cai-Ping Lu [a,b,*], Yang Liu [a], Hong-Yu Wang [a], Peng-Fei Liu [a]

[a] School of Mining Engineering, Key Laboratory of Deep Coal Resource Mining (Ministry of Education), China University of Mining and Technology, Xuzhou, Jiangsu 221116, PR China
[b] Department of Geosciences and Center for Geomechanics, Geofluids, and Geohazards, Pennsylvania State University, University Park, State College, PA 16802, USA

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ABSTRACT

In order to analyze the microseismic (MS) effects of hard and thick igneous strata separation and fracturing and the corresponding evaluation index of fracturing intensity, the temporal-spatial evolution of the MS sources generated by igneous strata fracturing in the 10416 working face of the Yangliu coal mine (YCM) was dynamically recurred, and the waveform and frequency-spectrum distribution characteristics of primary and igneous strata fracturing were clearly investigated, respectively. In addition, the relationship between the MS dominant frequency, the energy ratio in low-frequency band and the intensity of igneous strata fracturing was revealed, and the energy ratio of MS event in low-frequency band can be verified as an effective index for evaluating roof fracturing intensity. The work may put forward a certain reference for early warning and evaluating hard and thick roof fracturing and the induced coal-rock dynamic disasters based on in-situ MS observation.

1. Introduction

Igneous rocks are those formed by magmatic activity. In coalfields, the coal beds in sedimentary strata can form and/or be metamorphosed into cokeite through the intrusion of magmatic rocks. Igneous rocks are widely distributed in the coal mining areas of China, and especially in the Huaibei and Huainan coalmines. Hard and thick igneous strata, which are characterized by high tensile strength, form large hanging areas for coal extraction, and lead to higher static stress concentrations in the surrounding coal and rock. When these igneous rocks fracture, an intensive dynamic load is induced, and the superposition of static and dynamic loads can trigger coal-rock dynamic disasters (e.g., rock bursts, coal and gas outbursts, water inrush, and intensive roof caving), seriously impacting on coalmine safety and efficiency. For example, on 21 May 2006, a serious water inrush disaster occurred on the 745 working face of the Haizi coal mine (HCM), where 3887 m^3/h of water mixed with >400 m^3 of fragmented rock. A drilling survey confirmed the existence of a separation zone between the igneous rock and the underlying stratum, which were connected to the adjacent loose fourth aquifer. On 25 April 2009, a coal and gas outburst occurred during drilling in the headentry of the II1026 working face at HCM, located beneath an igneous rock layer. The disaster clogged ~74 m if roadway and extruded >600 m^3 coal. On 17 July 2011, a dynamic water–gas extrusion with a maximum water inflow of 46 m^3/h occurred from the #2 ground gas drainage hole of the Yangliu coal mine (YCM) 10414 working face, located beneath two-layer hard and thick igneous strata. Based on theoretical analysis and field investigation, it was verified that water in the separation area between the igneous rock and its underlying stratum was instantaneously released following subsidence of the igneous rock. These examples highlight the need to investigate the fracturing processes and intensity of hard and thick igneous rock layers in order to identify the precursory signs of coal-rock dynamic disasters triggered by igneous rock fracturing and movement.

The emplacement of igneous intrusions is accompanied by the formation of joints and fractures that can cause roof and wall instability during mining excavations and can increase coal permeability, allowing more seam gas and ground water to emerge from the coal during mining (Golab et al., 2007). Intrusions can also thermally and geochemically alter coal to form coke, methane (CH_4), and carbon dioxide (CO_2), increasing the threat of spontaneous combustion and outbursts (Golab and Carr, 2004). The influence of localized igneous intrusions on coal rank, petrology, geochemical/stable isotopic composition, and microstructure/microconstituents has been extensively investigated (Cooper et al., 2007; Dai and Ren, 2007; Finkelman et al., 1998; Gröcke et al., 2009; Murchison and Raymond, 1989; Raymond and Murchison, 1989; Rimmer et al., 2009; Sarana and Kar, 2011; Schimmelmann et al., 2009; Ward, 2002; Zhao et al., 2011). However, few studies have considered the effects of igneous rock fracturing on triggering microseismic (MS) activity in coal mines.

Rock fracturing is a brittle process and because deformation prior to onset may be very small, it is difficult to detect precursory signs with traditional displacement measurements. General stress and roof fracturing processes have been retrieved through the analysis of mining-

* Corresponding author.
E-mail address: cplucumt@126.com (C.-P. Lu).

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induced MS (i.e., fractures in coal and rock that radiate detectable seismic waves), which are common phenomena associated with coal and rock deformation and with fractures in coalmines. Although seismic waves are a type of complex random vibration, their wide spectra can reveal separation and fracturing mechanisms of roof strata. Therefore, by using broadband MS monitoring systems, MS effects and precursory signs of igneous rock separation and fracturing can provide effective early warning of coal-rock dynamic disasters.

To date, studies of the MS effect with regard to common roof fracturing have focused on source location, energy calculation, wave velocity tomography, and the macro-evolution of MS activity. For example, Li et al. (2007) proposed a set of basic rules for mining-induced seismic activity at Laohutai coal mine. Durrheim et al. (1998) discovered the seismic events that resulted from the failure of the remnant with attendant movement into the workings. Eneva et al. (1998) used in-seam seismic (ISS) data to reveal the seismic response of a rock mass to blasting and its relevance to rock burst potential. Abdul-Wahed et al. (2006) identified a close correlation between the location of seismic activity and induced stresses in the ground surface of working areas subjected to rock burst hazards. Ge et al. (2008) developed an ISS-based void detection and stress distribution identification technique. Murphy et al. (2012a, 2012b) investigated the relationship between radiated seismic energy and the explosion size of rock using the seismic signatures of underground explosions. Chen et al. (2012) used in-situ MS observations to show that MS energy and event counts steadily increase with increasing coal-rock stress. Friedel et al. (1996) used active 3-D seismic tomography to show that high-velocity regions reflect elevated levels of compressional stress. Lesniak and Isakow (2009) demonstrated the potential of clustering techniques for the evaluation of seismic hazards over a limited area. Holub et al. (2011) showed that seismic wave amplitudes decrease with distance from rock burst foci. Murphy et al. (2012a, 2012b) considered the possible insights gained from attenuation and duration measurements on future seismic signatures. Srinivasan et al. (1997) established linear empirical relationships between the seismic energy released by a rock burst, the total tonnage of ore mined out, and the total number of rock bursts. Boler et al. (1997) determined source parameters and seismic energy using four three-component stations. Friedel et al. (1997) established relationships between P-wave velocity and stress, and attempted to evaluate ground stability hazards. Shen et al. (2008) showed that MS and roof stress signals could provide warnings of imminent roof falls earlier than roof displacement signals. Finally, Lu et al. (2012a, 2012b, 2013) investigated the evolution of MS frequency-spectra during combined coal-rock deformation and failure, and the low-frequency precursors of bursting failure.

Table 1
Set-up of in-situ geophones.

Geophone	x/m	y/m	z/m
#1	39,476,942	3,724,735	−567.85
#2	39,477,512	3,725,213.2	−564.34
#3	39,478,030	3,725,654	−563.55
#4	39,478,817	3,725,283.5	−612.93
#5	39,478,359	3,724,970.7	−594.12
#6	39,477,242	3,724,339.7	−598.88
#7	39,478,663	3,724,608.3	−635.6
#8	39,478,592	3,725,542.7	−614.2
#9	39,478,341	3,725,566.3	−610.4
#16	39,477,020.11	3,724,206.84	28.17

Despite the previous work and the need to identify possible precursory signs of rock instability, little attention has been paid to characterizing MS signals associated with the gradual separation and fracturing of hard and thick igneous rock due to coal extraction. In this study, we investigated the processes and evolution of igneous strata separation and fracturing, and the corresponding MS signals, at the 10416 working face of YCM using in-situ MS observations combined with theoretical analysis.

2. Geological setting and MS monitoring system

2.1. Description of the 10416 working face

The 10416 working face, which has a maximum mining depth of ~600 m, is located in the 104 mining district and employs a fully mechanized longwall (Fig. 1). The adjacent 10414 working face was depleted in May 2012, and the width of pillar between the working faces is 5 m. The mining seam of the 10416 working face is the #10 coal, which is characterized by a gas outburst property. The panel length and width are ~1100 m and ~170 m, respectively. The mean thickness of the #10 coal seam is 3.2 m, and mean average inclination angle is 2–11°. According to a borehole survey, the immediate roof has a thickness of 1.79–5.48 m and is mainly composed of sandstone and mudstone

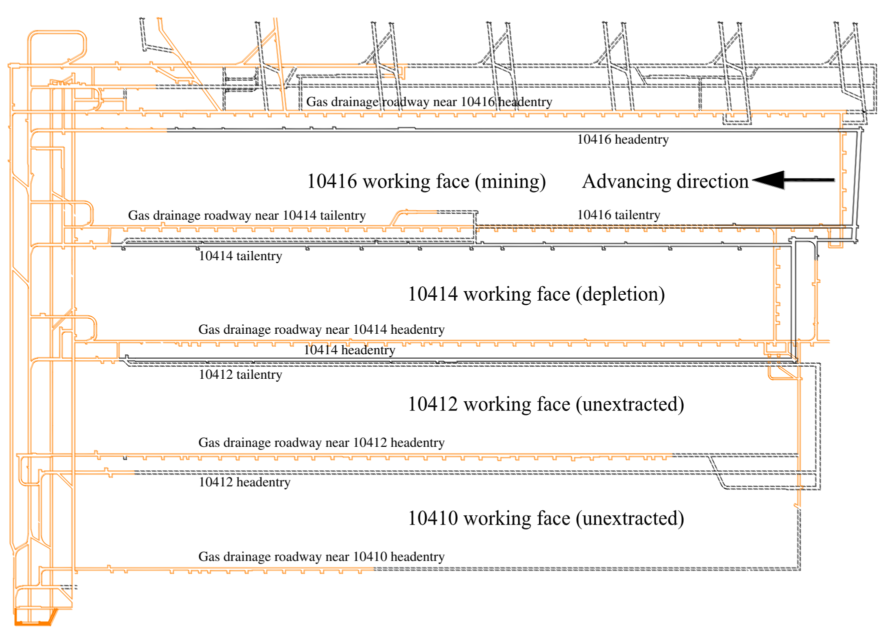

Fig. 1. Plan view of the 10416 working face of the 104 mining district (owing to size limitations, the four working faces below 10410 have been omitted (i.e., 1042, 1044, 1046, and 1048).