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Monitoring and modelling of gas dynamics in multi-level longwall top coal caving of ultra-thick coal seams, part I: Borehole measurements and a conceptual model for gas emission zones

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ABSTRACT

The application of multi-level longwall top coal caving mining method in ultra-thick coal seams generally yields a much higher productivity and is more efficient in comparison to a mechanised single-slice longwall panel. However, the greater productivity achieved by this mining method may further exacerbate the gas emission problems often faced in longwall mining. In order to establish a thorough understanding of gas pressure regimes, and gas emission patterns around a producing multi-level longwall top coal caving face, a suite of in-situ measurements on seam gas pressure, gas composition, and ventilation environment was conducted at Coal Mine Velenje in Slovenia. This paper focuses on the analysis of these field observations which helped develop a conceptual gas emission model for multi-level longwall top coal caving mining of ultra-thick coal seams. It has been found that, at Coal Mine Velenje, the coal zone within 40 m ahead of the face can significantly contribute to the overall district gas emission. In addition, floor coal and roof goaf may both play a major role towards the total gas emitted during mining.

1. Introduction and background

Longwall top coal caving (LTCC) technique has been widely used to mine thick (>5 m) to ultra-thick coal seams. In a mechanised LTCC panel, the lower section of the coal seam is cut by a shearer supported by hydraulic shields, while the upper section of the worked seam is allowed to cave by gravity and be collected at the face. Therefore, an LTCC panel generally yields a much higher productivity and is more efficient in comparison to a mechanised single-slice longwall panel (hereafter referred to as conventional mechanised longwall panel). However, the greater productivity achieved by LTCC mining may further exacerbate the gas emission problems often faced in longwall mining, and thus poses a serious challenge for underground gas emission control.

To recover ultra-thick coal seams, multi-level (multi-slice) mining in conjunction with mechanised LTCC is normally adopted. The application of multi-level LTCC mining is expected to create distinctly different gas flow patterns as compared to conventional mechanised longwall mining of relatively thinner seams separated by coal measure rocks since the LTCC faces are fully surrounded by solid coal, and gas may migrate into the mine openings from coal at the mining horizon, the lower mining levels, and even the previously mined goaf.

The early approaches to predicting gas emissions around working longwall panels in Europe were mostly empirical and adopted the same basic principle of *degree of gas emission* function (Curl, 1978). Research carried out by the Mining Research and Development Establishment (MRDE) in the UK during the 1970s and 80s developed a methane prediction method which was unique in Europe, such that time dependent behaviour of gas emission was introduced to the predictions which used different degrees of gas emission curves for different stages of longwall extraction (age represented by number of weeks of production history). The method is based on Airey's theory of gas emission from broken coal (Airey, 1968, 1971). The rate of gas release from the fractured or fragmented coal blocks around a working longwall face was assumed be determined entirely by the emission characteristics of the broken coal, represented by a variable time constant t_1 defined as a function of distance from the face as (Airey, 1971),

$$t_1 = t_o \exp\left(\frac{x}{x_o}\right) \quad x \geq 0 \tag{1}$$

where x represents the distance ahead of the position of the maximum stress (front abutment), x_o is a distance constant and t_o is the minimum time constant in hours, which occurs at and behind the front abutment position. Therefore, the smaller the value of t_1, the larger the gas emission rate from a relatively smaller blocks of coal nearer to the working coal face. From a subsequent theoretical work in rock mechanics,

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Airey used the ratio of principal stresses σ_1/σ_3 as a criterion for coal failure around a longwall face and assumed that surfaces of equal σ_1/σ_3 would be coincident with the surfaces of equal t_1 (MRDE, 1980), thus providing the theoretical basis to his *degree of gas emission* surfaces. Using analytical solutions for the stresses around a coal face given by Berry and Sales (1967), Airey then computed the distribution of time constants around a coal face, and hence the degree of gas emission from sources seams in the roof and floor as a function of distance from the face line. As well as accounting for the emission from the roof and floor source seams, Airey proposed gas emission curves for the seam being mined, based on the weekly advance rate, and the coal being transported out of the district on the conveyor in order to calculate the total gas volume entering the longwall district. These methods were progressively fine-tuned using extensive field observations. Airey's theory and the accuracy of his degree of gas emission curves were validated through field measurements of gas emissions and residual gas contents of coal seams at a large number of UK collieries over a period several years. Based on these validation studies, the gas emission curves were modified to eliminate the observed over- and underestimates of emissions and produced the *British Coal Firedamp Prediction Method* as it is known today.

Building upon the understanding of how a longwall panel and the surrounding strata respond to progressive coal extraction, gas emission patterns associated with conventional mechanised longwall mining have been extensively studied in the past few decades (Barker Read and Radchenko, 1989; Durucan, 1981; Gray, 1987; Karacan et al., 2011; Lunarzewski, 1998; Noack, 1998). Whittaker (1974) described dynamic stress changes and the formation of stress abutments in a longwall panel ahead of an advancing longwall coal face. In response to coal extraction, three distinct zones in the overlying strata were identified according to the degree of rock deformation and fracturing; namely the caved zone, the fractured zone and the continuous deformation zone. In addition, the stress state of the underlying strata is also affected, though to a lesser degree and extent, by longwall mining.

Recognising the impact of stress on coal permeability, McPherson (1975) was the first to consider dynamic changes in permeability of a worked seam in response to longwall coal extraction. Later, and based on his laboratory investigations into stress–permeability relationship of coals and numerical modelling of stresses around working longwall faces, Durucan (1981) derived models for permeability distribution and associated gas flow around an advancing longwall coal face (Fig. 1).

With the advancement of modern computational techniques, gas emissions into an advancing working face were numerically represented by fluid simulators (Ediz and Edwards, 1991; Lowndes et al., 2002; O'Shaugnessy, 1980; Ren and Edwards, 2000) or coupled geomechanical-fluid simulators (Esterhuizen and Karacan, 2005; Whittles et al., 2006). An interesting attempt by developing an artificial neural network-based methodology to predict gas emissions in ventilation airflow from longwall mines has also been made by Karacan (2008).

Although extensive research has been carried out on gas emissions from longwall panels operated in relatively thin coal seams, only a very few studies have been reported on multi-level or LTCC operations, which mainly focused on strata geomechanics (Alehossein and Poulsen,

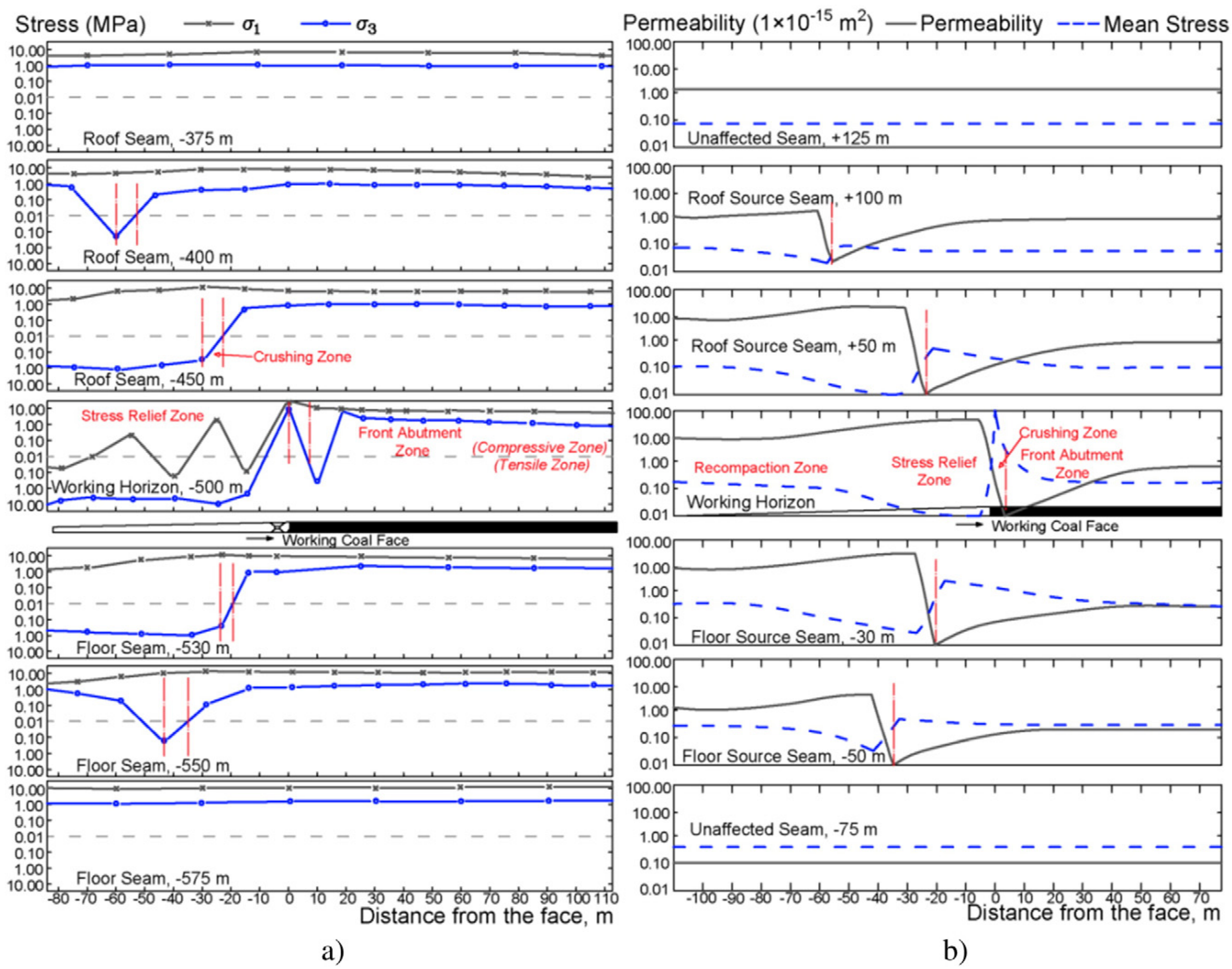

Fig. 1. (a) Numerically simulated maximum and minimum principal stresses, and (b) mean stress and permeability profiles around a 500 m deep longwall face (after Durucan, 1981).