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DEVELOPING A NEW METHOD TO IDENTIFY THE SOURCE OF GAS EMISSIONS INTO LONGWALL AND GOAF FROM SURROUNDING STRATA

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ABSTRACT: During coal mining, strata is fractured and gas trapped in the roof and floor of coal seams travels into the workings. Depending on the extent and shape of fractured zones suitable gas drainage patterns are required to maximise the gas capture from strata but also to minimise the cost of operations. In this paper a new method to identify gas emitting zones/seams in the embedding strata and gas migration pathways is presented. The developed method was used in a coal mine in the Southern Coalfield of the Sydney Basin. Geochemical properties of gas trapped in coal seams above and below the mining horizon were analysed and compared with similar properties of gas collected from goaf areas. This study shows that using this method it is possible to identify the source of gas in goaf areas and thus determine the extent of fracturing in the strata around the mined seam.

INTRODUCTION

High gas emissions and gas surges into the coal face and goaf areas can occur rapidly due to changes in mine environmental and structural conditions. In addition to the gas released from the mined seam, much larger volumes of gas can also be released from other gas-bearing horizons in the strata above and below the mined coal seam (from fractured and de-stressed zones). Depending on the reservoir conditions and the geometry of the influenced zone, gas emitted into coal mines can be much larger than the gas contained within the mined seam. For example, Saghafi *et al.*, (1997) studied the CH₄ emissions in gassy Australian underground mines and reported that the volumes of gas released from these mines exceeded the *in situ* CH₄ trapped in the mined seam by a factor of 4. Note that Kissell *et al.*, (1973) reported that for US underground mines the volumes of gas released exceeded the *in situ* CH₄ by a factor of 7.

In order to maximise gas capture and reduce the cost of drilling the gas drainage engineer needs to know the extent of the mining-influenced zone and delineate the emissions zone. Suitable gas drainage patterns can then be designed to place gas boreholes in optimal locations and suitable angles.

One strategy for identifying possible gas migration pathways, particularly in caved areas (goaf) is to use a tracer gas such as sulphur hexafluoride SF₆. This tracer has been used to study gas and air paths in coal mines in various countries (Thimons *et al.*, 1974; Vinson *et al.*, 1980). However, the use of this gas is problematic as it has the highest Global Warming Potential (GWP) of all greenhouse gases (GWP~23,900) according to the Assessment Report on Climate Change (IPCC, 2007). SF₆ is also five times heavier than air, which leads to slow movement of this gas from its injection to the collection site for analysis.

In this study the properties of Coal Seam Gas (CSG) itself were used to identify the origin of goaf gas. For example, a component of the gas trapped in coal as an identifier of the coal seam containing that gas component can be used. An example is ethane (C₂H₆), which occurs naturally in coal. It can then be used to identify the emitting seams. However, this gas is only present in deeper seams. For this study a combination of molecular and carbon isotopic compositions of gas initially trapped in coal seams was used to identify the emitting zones/seams. The method makes it possible to identify the extent of the mining-influenced zone by comparing geochemical properties of gas accumulated in the goaf and coal face with gas desorbed from fresh cores from coal seams in the strata (delineation of mining influenced zone).

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STUDIED MINE AND METHOD OF INVESTIGATION

The studied mine was a longwall operation, located in the Southern Coalfield of the Sydney Basin. Like most mines in this region no major coal seam is present in the overburden strata and all coal seams are located in underburden; in particular, three seams are located in the floor not far from the producing seam. These seams are likely to emit their gas into the coal face and goaf. These seams are located at ~10 m, ~20 m and at ~40 m below the producing seam. While the shallower seams (Seams 1 and 2) are likely to be influenced by mining, there were doubts about whether the deeper seam (Seam 3) was also influenced by mining and if so, whether the mining-induced fracturing would have allowed the escape of trapped gas from this deeper seam into the mining area and goaf. Note that high gas content levels have also been measured previously in the producing seam and other seams with various levels of carbon dioxide (CO₂) and methane (CH₄). In Figure 1 a schematic of the mining geometry and location of potential gas emitting coal seams in the floor are shown.

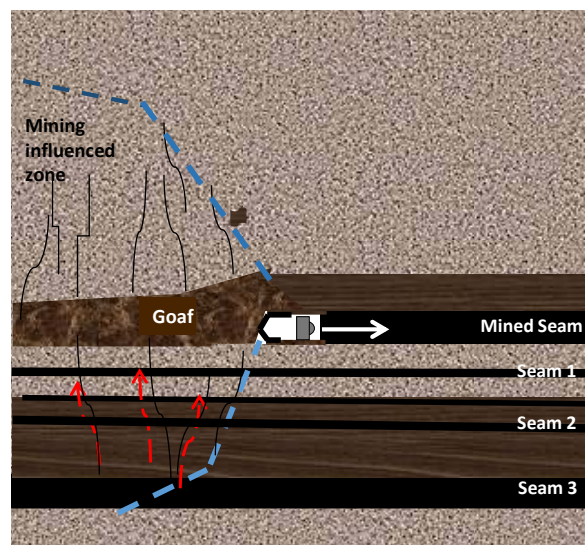


Figure 1: Schematic of mine operation and location of potential emitting seams in the floor strata based on mining induced fracture propagation

As mentioned in the previous section gas properties of coal seams can be used as their identifiers. The selected attributes are gas molecular ratio in terms of CH₄ to CH₄+CO₂ and carbon isotope ratio. Note that the carbon atom has two stable isotopes: carbon 13 (¹³C) and carbon 12 (¹²C). The latter is by far the most abundant isotope of carbon accounting for 98% of these atoms. Carbon isotope ratio ($R = \frac{^{13}\text{C}}{^{12}\text{C}}$) is conventionally expressed in terms of a normalised differential ratio ($\delta^{13}\text{C}$). It quantifies the normalised difference between the ¹³C/¹²C ratio in the gas sample (R_g) and this ratio in a reference (R_r) material. The differential ratio of carbon isotopes for the target gas sample is then:

$$\delta^{13}\text{C} = 1000 \frac{R_s - R_r}{R_r} \quad (1)$$

The differential ratio is increased by a factor of 1000 and is hence expressed as per mil (‰). For the carbon isotope the reference material is a carbonate called the Vienna Peedee Belemnite (VPDB). For VPDB the ¹³C/¹²C ratio is 0.0123 (For more details refer to Hoefs (1973)).

This differential ratio is widely used for determination of the origin of coal seam gas in terms of its generation (biogenic or thermogenic gas, see for example, Smith *et al.*, (1992); Rice (1993); Smith and Pallasser (1996); Clayton (1998)).

The method of investigation developed for this study consisted of retrieving coal cores from surface exploration drilling into the sequences of coal seams below the floor of the mine (underburden). Coal cores were then measured for gas content in the field and the laboratory using the standard method (Australian Standard AS 3980-1999). Gas desorbed from all stages of gas content testing (Q₁, Q₂ and Q₃ stages) were analysed for molecular composition (CH₄, CO₂ and N₂), however, carbon isotope composition analyses (¹³C/¹²C) were only applied to the gas desorbed during the Q₃ stage of gas

content testing. Simultaneously molecular and carbon isotope composition of gas collected from the goaf area was also analysed for molecular and isotope compositions.

RESULTS AND DISCUSSION

Two exploration boreholes were drilled across mined and under floor coal seams. Boreholes were drilled in two locations sufficiently away from active mining areas so that the virgin *in situ* conditions of gas initially trapped in the coal are preserved. From each borehole about eight fresh coal cores were retrieved, which were then measured for gas content and gas composition.

As discussed the molecular gas ratio ($\text{CH}_4/\text{CH}_4+\text{CO}_2$, %) was used as one of the identifiers of the seam. In Figure 2, the distribution of gas molecular composition against depth is shown. The depth of coal cores in this figure is not from the ground surface but from a datum level in the overburden of the mined seam. Note that in plotting this curve only the results of composition measurements for gas desorbed from Q_2 and Q_3 stages of gas content testing were used for this plot as gas collected at the Q_1 stage of gas content testing was prone to contamination and consequently associated with high errors of determination. The data show that CH_4 in the mixture increases with depth almost linearly, and therefore the molecular composition of desorbed gas is quite different for the underburden strata. Hence, for this sequence of coal seams and at this location, gas compositions for the seams in the strata are distinct, which justifies the use of gas composition as an identifier (attribute) of a coal seam in the sequence. The measured data showed that the $\text{CH}_4/\text{CH}_4+\text{CO}_2$ ratio for the mined seam and Seam 1 varied from 15 to 25%, for Seam 2 from 40 to 45% and for Seam 3 from 75 to 90%.

The carbon isotopic compositions of gases were measured using Gas Chromatography/Combustion/Isotope-Ratio Mass Spectrometry (GC-C-IRMS). The GC-C-IRMS system consists of a GC unit connected to a combustion device coupled via an open split to a mass spectrometer. Duplicate measurements are done on each of the gas components, i.e. on CO_2 and CH_4 components of coal seam gas. The results of measurements are shown in Figure 3, showing cross plots of the $\delta^{13}\text{C}$ values for the CO_2 component of the seam gas against these values for the CH_4 component of the seam gas. The data show that carbon isotope values are distinct for different seams in the sequence and hence isotope ratios can be used to identify emitting seams.

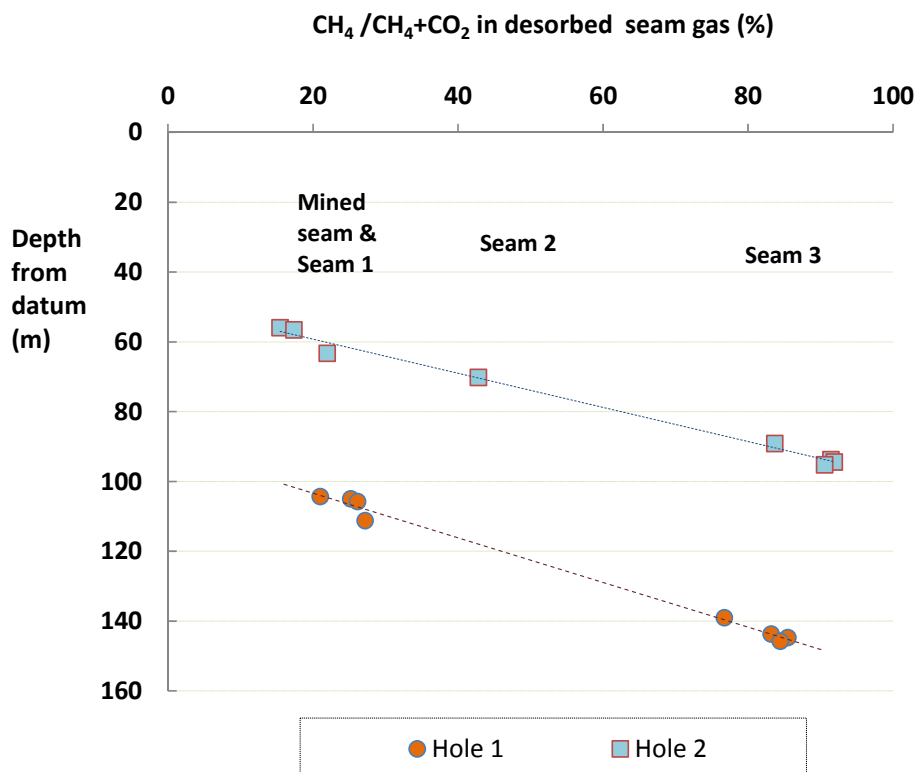


Figure 2: Molecular gas ratio ($\text{CH}_4/\text{CH}_4+\text{CO}_2$) of desorbed gas from cores from two boreholes drilled into strata not affected by mining

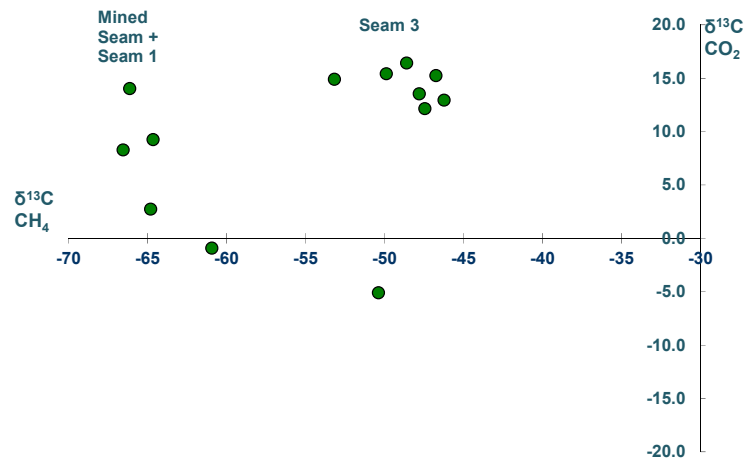


Figure 3: Cross plot of carbon isotope ratio for CO₂ and CH₄ for gas desorbed from coal samples for different seams

In order to determine whether any gas in the goaf is sourced from Seam 3, a number of gas samples were collected from the collar of a goaf drainage borehole and measured for molecular and carbon isotope compositions. The results showed that the ratio of CH₄/CH₄+CO₂ in the goaf was about 40%, $\delta^{13}\text{C}$ for CH₄ was about -61.5‰ and for CO₂ it was -6.4‰. Comparing these data with the data in Figures 2 and 3 suggests that gas emitted into goaf originated from the mined coal and from Seam 1.

CONCLUSIONS

A new method is described whereby geochemical properties of gas were described, namely molecular and isotopic composition, may be used to trace the source of gas emitted into goaf areas in underground coal mines. The method was applied to a participating mine in this study in the Sydney Basin. Results of the study showed that molecular composition and carbon isotope composition ($\delta^{13}\text{C}$) for gas initially trapped in coal seams in the sequence were markedly different. Thus, these values can be used as identifiers for the source of gas emitted into goaf areas.

Although the method is still in its trial stage, the preliminary use of the method shows that it could be effective in identifying the extent of the gas emissions zone in the underburden strata.

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