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# An analysis of reservoir conditions and responses in longwall panel overburden during mining and its effect on gob gas well performance

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ABSTRACT

NIOSH conducted a cooperative research study to provide direct measurements of changing reservoir conditions in longwall panel overburden. The field measurements documented changes in permeabilities, methane concentrations, fluid pressures, and the effects of adjacent gob gas ventholes (GGVs) on NIOSH boreholes drilled in the study panel. Three different stratigraphic horizons were monitored by the NIOSH boreholes. Results indicated that the gob gas venthole fracture network formed 24 to 46 m (80 to 150 ft) ahead of the mining face. Overburden permeabilities within the same overburden test zones were ~1 md prior to undermining, increasing to hundreds or thousands of md during undermining. Permeabilities measured seven months after undermining showed additional increases. The relationship between changing reservoir conditions, longwall face position, and surface movement is discussed. Recommendations are made to optimize GGV performance by evaluating changes in subsidence produced by mining, resulting in rock stresses that substantially influence induced fracture permeability. Mechanisms to account for the observed changes in reservoir conditions are reported.

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## 1. Introduction

The National Institute for Occupational Safety and Health (NIOSH) is active in ventilation and methane control research to improve worker safety in underground coal mines. Methane emissions from longwall gob gas reservoirs must be effectively managed to maintain safe mine operations since they produce an estimated 80–94% of total mine emissions (Curl, 1978; Schatzel et al., 1992). The collapse, caving, and fracturing of adjacent rock units during undermining greatly influence changing reservoir conditions for coal mine gob gas. Gob gas is typically controlled in the US with stimulated vertical boreholes, in-seam boreholes, and gob gas ventholes (also known as "gas vent boreholes"). Less common in the US are cross-measure boreholes as a means of capturing gob gas.

The control of gob gas can be enhanced by reducing the methane content of the mined coal bed and the adjacent coal units. A range of in-seam boreholes is in use within the US coal mining industry for this purpose, including short (less than 150-m [500-ft]) in-seam boreholes, long directionally drilled holes collared and drilled from within mine workings, and holes directionally drilled and collared at the surface.

Although the performance of individual methane drainage boreholes can be numerically simulated, the degree of interaction between multiple holes and their cumulative effect on methane emissions underground can be difficult to establish. The complexity of the methane migration and removal scenario is exacerbated by substantial changes occurring in the reservoir due to longwall mining-induced caving and fracturing of strata near the mined coal bed. The extent of caved and fractured zones has been discussed in previous research, but can be strongly influenced by site-specific variables (Singh and Kendorski, 1981). A range of modeling methods are being used to predict methane drainage borehole interactions and changing underground emission rates (Zuber, 1998; Balusu et al., 2001; Karacan, 2007, 2008). These techniques will continue to evolve and measured field results will further develop and calibrate the simulations.

This research was designed to provide direct measurement of changing reservoir conditions during longwall mining that can enhance methane removal and control methods, thereby improving underground mine safety. To achieve these goals, NIOSH and a cooperating mine operator began a collaborative research effort to monitor reservoir parameters from gob gas ventholes (GGVs). During the experiment, other measurements were also made to determine surface movements and longwall face locations. The planned research outputs reviewed in this paper include an enhanced understanding of trends in changing gob reservoir conditions during mining, a correlation of surface deformation and face position to changes in reservoir conditions, a summary of mechanisms that produce the observed trends, and recommendations for GGV design parameters.

### 1.1. Background

#### 1.1.1. Gas and air movement in gobs

Successful management of coal bed gas emissions into mine workings requires knowledge of the flow and flow paths of methane gas

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and ventilation air in the gob. Techniques to determine these rates and movements include direct measurements of gas concentrations and flow rates and numerical modeling methods (Lunarzewski, 1998; Karacan et al., 2007). Tracer gas studies can yield similar gob gas migration information when compared to the measured concentration and flow data (Timko and Thimons, 1982; Vinson and Kissell, 1986; Young et al., 1997).

Behaviors of gob gas movement which are agreed upon by previous investigations include the following: permeability in longwall panel overburden increases after mining; after undermining, the surface above the longwall panel subsides to a lower elevation as the void space formerly occupied by the mined coal is partially in-filled by broken overburden; a zone of increased permeability exists in longwall overburden above the caved zone of a longwall panel. This increased permeability zone parallels the gateroads and resides near tailgate and headgate gateroads.

#### 1.1.2. Subsidence theory

Longwall mining-induced fracturing associated with strata subsidence creates a distribution of high permeability pathways in gobs that greatly influence gob gas and ventilation air migration (Esterhuizen and Karacan, 2007). Investigations of surface subsidence and predictive models have predicted the depth and shape of the subsidence trough (Adamek et al., 1987). The generation of predictive mine subsidence models was the subject of multiple investigations in the Northern Appalachian Basin (NAB) (Jeran et al., 1986; Matetic and Trevits, 1990). Pre-existing formation and fracture permeability are likely overcome by the magnitude of mining-induced fracture permeability. Consequently, in all portions of the gob fractured by the mining process, gas movement is primarily dictated by ground movement of the collapsed and fractured rock associated with removal of the mined coal bed.

The prediction of surface subsidence is largely based on strata subsidence models including Bals' theory, which states that forces acting on the overburden are in response to the mined-out coal bed void spaces (Bals, 1931, 1932; Adamek et al., 1987). However, the pathway by which forces are expressed from the mined unit to the surface is not well defined by Bals' theory. The development of tensional and compressional zones during longwall mining is highly influential in defining gas migration pathways in fractured rock. When undermined, the strata near the panel margins are under tension and regions near the center of the panel development, near the long axis centerline, are under compression. In general, the fractures under tensional stress tend to be held open, increasing permeability, compared to those areas under compressive forces that tend to close rock fractures (Diamond et al., 1994). Therefore, the distribution of tensional and compressional zones in the overburden is strongly related to fracture permeability and GGV performance during panel extraction.

## 2. Description of the borehole monitoring experiment (BME) methodology on an active longwall panel

The field experiment consisted of three boreholes, BH-1, BH-2, and BH-3, drilled from the surface above a longwall panel into three different stratigraphic zones. The study panel dimensions were 442 m (1450 ft) in width and 3456 m (11340 ft) in length. The distance to the tailgate gateroads for each borehole was 101 m (330 ft), the same distance that the mine used for its GGVs so that they would be in the same mechanical behavior zone and in a similar stress field (Fig. 1). One of the operator's GGVs was located 76 m (250 ft) from the most outby borehole in the study, and was included in the BME monitoring activities. The spacing between each of the NIOSH monitoring boreholes was 15 m (50 ft).

The collar elevations of BH-1, BH-2, and BH-3 were 418.61 m (1373.4 ft), 414.65 m (1360.4 ft), and 410.23 m (1345.9 ft), respectively, with a coal elevation of 158 m (519 ft). The first borehole intercepted by mining (BH-1) was drilled to a total depth of 220 m (721 ft) to monitor the Sewickley Coal bed (Fig. 2). The second, or middle-range borehole (BH-2), was drilled to a depth of 230 m (755 ft) and monitored mostly shale sequences below the Sewickley Coal bed. The deepest borehole (BH-3), closest to the GGV, was drilled to 245 m (803 ft) for monitoring shale and sandstone horizons above the Pittsburgh Coal bed that would be retained in the caved zone of the gob after undermining. Boreholes were drilled with a 15-cm (6.0-in) diameter bit with water as the drilling fluid. The boreholes were cased with 13-cm (5.0-in) steel casing. They were cemented using conventional grout and cement baskets, except for the bottom 6.1 to 9.1 m (20 to 30 ft). These sections were cased with slotted casing and were the primary monitoring zones for each hole. The length of slotted casing was 9.1 m (30 ft) in BH-1 in order to monitor both splits of the Sewickley Coal bed. The slotted section of BH-2 was 6.1 m (20 ft) long. The last 2.4 m (8.0 ft) of the hole below 3.7 m (12 ft) of slotted casing of BH-3 was cut and left open-hole in order to keep the casing as high as possible above the gob (Fig. 2).

After the completion of drilling, the deepest borehole (BH-3) was logged open-hole with density, gamma ray, and sonic tools to identify formations, to refine drilling depths, and to calculate porosity, density, and some of the mechanical properties of the rock. The drilling of the boreholes was started and completed when the longwall face was 760 m (2500 ft) away from the BH-1 location.

The experimental boreholes were configured to be completed in a manner similar to the mine operator's GGVs. Both borehole designs included flame arrestors, shut-in valves, and long, vertical PVC pipe stacks. However, unlike the experimental boreholes, the GGVs were cased with 61 m (200 ft) slotted casing at the bottom of all boreholes. The NIOSH test boreholes were shut-in throughout the monitoring duration.

### 2.1. Instrumentation and monitoring

An important portion of this study involved measurements of in-situ permeability before and after the undermining of the NIOSH borehole sites. These tests also provided valuable data on water production from the slotted casing sections. The initial pre-undermining findings present data on the initial water saturations of the formations of interest. Boreholes were equipped with submersible, downhole transducers which were positioned within the downhole monitoring zones. Downhole transducers were installed underwater in the boreholes to record transient changes of the water head in the boreholes with a downhole data logger and an attached cable. A set of slug tests was designed and performed in each borehole using water to determine formation permeabilities. The water head drop was monitored for about a week on each borehole using the submersible transducers before the boreholes were undermined. After the conclusion of the slug tests, the downhole transducers were repositioned above slotted sections in each borehole.

The slug tests were performed by filling the boreholes with additional quantities of water so that a change in water head could be observed. This water monitoring interval was included to provide input on pre-mining permeabilities, strata disturbances, fracture initiation with respect to the position of the longwall face, and the transient fracture permeabilities induced by mining. The submersible transducers recorded changes in water head until the water drained completely from the boreholes. The final set of slug tests was run after the completion of the panel for determining post-mining permeabilities.

The wellheads on BME boreholes also were equipped with surface pressure transducers for continuous data recording of pressure changes at the tops of the boreholes. Tiltmeters were installed on the BME wellhead stacks for recording subsidence and strata-response profiles before, during, and after mining. Conventional