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A Comparison of Ground Permeability Changes Before, During, and After Longwall Panel Mine-bys Under Deep and Shallow Cover

Marcia L. Harris
NIOSH, Pittsburgh, PA

Steven J. Schatzel
NIOSH, Pittsburgh, PA

Zoheir Khademian
NIOSH, Pittsburgh, PA

James Addis
NIOSH, Pittsburgh, PA

Y Zheng
NIOSH, Pittsburgh, PA

Charlie Matthews
NIOSH, Pittsburgh, PA

ABSTRACT

Shale gas wells can sometimes drill through coal reserves. Hypothetically, the caving of the gob from longwall coal mines may deform the shale gas well casing and potentially result in a breach. NIOSH researchers studied the permeability of the surrounding ground strata that may affect the potential for an inflow of gas into an underground mine environment. An overview and comparison of measured permeability values under differing cover depths (147 m and 353 m to the Pittsburgh coal seam) and mining cycle phase will be presented and discussed in this report. The findings highlight data-driven experimental evidence that affect the interaction between gas wells extraction and mining operations that may lead to potentially hazardous environments.

INTRODUCTION

The Pennsylvania Department of Environmental Protection (PADEP) has provided guidance on the placement of gas wells near active longwall (LW) coal mining in Pennsylvania through a technical report [1]. This guidance produced a regulation which has played a very important role for coal mine operators, gas well drillers and producers, and federal and state regulatory agencies. Since the 1957 Joint Coal and Gas Committee Gas Well Pillar Study [2] predate longwall mining, unconventional shale gas wells, and current mining depths, there is a new set of safety and operational challenges being faced by coal and gas well operators, regulators, and permitting agencies. With the expectation of 1,000 gas wells that will be influenced by LW mining in the Pennsylvania/West Virginia/Ohio tristate region in the next 10 years, there is a gap in scientific information for gas well stability in modern LW environments to ensure safe practices are in place to maintain well casing stability for wells in LW abutment pillars. The scientific findings summarized in this publication are part of a research project by the National Institute for Occupational Safety and Health (NIOSH) which in turn will help miner safety and health for LW mine operators and gas well producers for casing stability in LW abutment pillars.

BACKGROUND

Within the past 15 years, unconventional shale gas wells have been drilled through current and future coal reserves in Pennsylvania, West Virginia, and Ohio. How this affects the mechanical integrity of these wells is a concern when mining occurs in and around these wells. The shale gas wells penetrate the coal seams through abutment pillars and the coal seams are subsequently mined by adjacent LW panels. Overall, the study will provide scientific evidence to the coal and shale gas industries on the impacts of LW mining on the shale gas wells, what the potential deformation may be, and what stresses are imposed on the gas wells.

In 2012, the Pennsylvania Department of Environmental Protection (PADEP) recognized the 1957 Pennsylvania Gas Well Pillar Regulation [2] was created without current data from modern day LW mining and called for research to revise the outdated regulation. Also, the 1957 Pennsylvania Gas Well Pillar Regulation has been widely used by the Mine Safety and Health Administration

(MSHA) along with CFR 75.1700 to manage gas well pillar stability issues. Therefore, given the posed concerns and the need for further scientific evidence in light of modern mining technologies and practices, the National Institute for Occupational Safety and Health (NIOSH) initiated research to address these issues.

One of the first steps in quantifying the interaction between the longwall mining and shale gas production is to determine the change in ground permeability at depths where longwall-induced deformations are of highest concern. If there was a sequence of events that could produce a casing breach, the changes in the ground permeability could potentially increase the rate of shale gas infiltration into an underground coal mine. Permeability field measurements have been conducted at two mine sites with different depths of cover. Boreholes drilled above the abutment pillar under two different depths of cover and formation permeabilities have been monitored during completion of the LW coal seam. Under shallow cover (deepest at 127 m or 417 ft), three monitoring boreholes were drilled to experimentally measure borehole permeability through water head changes over time. Watkins et al. [3] assessed these permeability changes around boreholes above an abutment pillar under shallow cover. In the same manner, two monitoring boreholes were drilled above an abutment pillar at a site under deep cover conditions (up to 238 m or 1,047 ft). Harris et al. [4] examined the initial permeability changes for a first LW panel mine-by. This paper will present additional data from the deep cover site and compare it with the shallow cover data.

SITE DESCRIPTIONS

The most commonly sought-after shale gas reserve in the southwestern Pennsylvania region is the Marcellus Shale Reserve which can be located at a depth of about 2,100 m (7,000 ft) to 2,750 m (9,000 ft). Commonly, several wells can be positioned on a single drill pad to decrease drilling costs and reduce the surface footprint of the well.

The Pittsburgh seam, a relatively flat deposit, is longwall mined in this region due to its consistent quality, thickness, and pronounced lateral extent. The stratigraphic zones monitored for possible changes in permeability due to mining-induced deformation were the Sewickley coal bed and the Uniontown coal bed, whose thicknesses vary in the region. These coal beds typically have lower compressive strengths and stiffnesses than the adjacent limestone, shale, and siltstone/sandstone units [5, 6], leading to further fracturing and horizontal displacement along their bedding plane during the mining operation [7]. This stratigraphy with a significant stiffness and strength contract among overlying units is typical of Pittsburgh seam geology at the study site with thick limestone units and thin coal beds. Consequently, zones of high ground movement and thus potential damage to the gas well casing would be associated with the coal horizons due to mining-induced deformation [8].

Based on the previous NIOSH research, cover conditions were defined as three different segments: shallow (< 152 m or <500 ft), medium (152 m or 500 ft – 274 m or 900 ft), and deep (>274 m or >900 ft) [9]. This is similar and corresponds relatively well with the cover depths listed in the MSHA risk matrix [10]. Both studies at the shallow and deep cover sites were conducted at a coal mine in southwestern Pennsylvania. The LW coal mine is part of a three-entry gate road system with 460-m (1,500-ft) wide LW panels. The panel lengths are about 3,700 m (12,000 ft). Ventilation at the mine is by exhausting airflow using bleeders and gob gas ventholes (GGVs) to extract gob gas from the mined-out LW areas. The ventilation air quantity at the active panel face is about 28 m^3/s (60,000 cfm) at the headgate.

Shallow Cover Site

At the shallow cover site, the location of the four monitoring boreholes drilled for this study were in the overburden directly above an abutment pillar between two planned LW panels. The boreholes were centered above a 38-m (125-ft) by 84-m (275-ft) abutment pillar that was part of a three-entry gate road system (Figure 1). The distance from the center of a borehole collar to the edge of the pillar adjacent to an active panel varied between 12 m (40 ft) and 18 m (60 ft). Using the guidance from the 1957 Joint Coal and Gas Committee Gas Well Pillar Study, this distance may be as small as 15 m (50 ft). The Pittsburgh seam mined at this location was at a depth of 147 m (482 ft) from the surface. Ventilation at the mine utilizing bleeders was controlled by exhausting airflow and provided approximately 28.3 m^3/s (60,000 ft^3/min) of airflow to the active panel face at the headgate.

Three of the four monitoring boreholes were part of the slug test portion of the previous research and were labeled

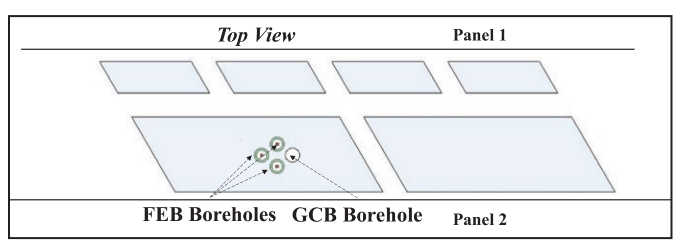

Figure 1. Three entry gate road layout

as FEB 1, 2, and 3 in Figure 1. The fourth borehole, shown as GCB in Figure 1, was to monitor ground movement in the horizontal direction. For the three boreholes specified for the slug tests, FEB 1 had a bottom hole depth of 127 m (417 ft), FEB 2 had a depth of 76 m (250 ft), and FEB 3 had a depth of 41 m (135 ft). The FEB boreholes were cased and cemented, except for the test intervals, which had screen lengths of 8 m (26 ft), 4.6 m (15 ft), and 2 m (7 ft) respectively. An isometric view of the three permeability monitoring boreholes is shown in Figure 2.

The stratigraphic zones monitored for possible changes in hydraulic conductivity, or permeability, due to mining-induced deformation were the Sewickley coal bed, the Uniontown coal bed, whose thicknesses vary in this region (Figure 2). These coal beds often have lower compressive strength than the associated limestone, shale, and siltstone/sandstone units. Therefore, it was anticipated that the coal horizons would be the main zones of potential ground movement and where higher permeabilities would be present compared to the surrounding rock units.

The overburden depth of the Pittsburgh coal seam at this location was about 147 m (482 ft) to the top of the mined seam, which is commonly at 305 m (1,000 ft) since shallower occurrences have often been previously mined and the area of the mine studied was located near a major stream valley. The coal zones in relation to the three boreholes in this study are displayed in Figure 3. The most commonly sought-after shale gas reserve in the region is the Marcellus shale which can be at a depth of about 2,100 m (7,000 ft) to 2,750 m (9,000 ft). The Utica shale with variable overburden depths, typically at depths between 2,100 m (7,000 ft) and 3,660 m (12,000 ft) in the region, can also be a drilling target. Commonly, up to 30 wells can be positioned on a single drill pad to decrease drilling costs and to reduce the surface footprint of the wells.

Ground movement and subsidence are the primary factors creating the gas transport network associated with LW gobs. From prior ground control studies [8], the primary component of movement that potentially deforms well casings in LW pillars is subsidence (vertical movement) or horizontal movement. Both vertical and horizontal movement were monitored during the study with displacement arrays positioned in the GCB borehole, which was in close proximity to the FEB boreholes (Figure 4). The caliper data showed that there was an insignificant amount of vertical movement in the borehole. However, horizontal movement measured by the monitoring array indicated significant horizontal displacement, as shown in Figure 4. This data shows that the primary zones of movement were the Uniontown and Sewickley coal seams. The Sewickley horizon measured over 16 cm of lateral movement in response to LW mining passing the pillar. Therefore, these horizons were chosen as the zones to monitor for permeability changes.

Deep Cover Site

Monitoring boreholes used to examine longwall-induced permeability changes under deeper cover were drilled in the overburden directly above an abutment pillar between two planned LW panels. The deep cover field test site is located on the top of a steep hill and has an overburden depth to the Pittsburgh seam of about 353 m (1,160 ft). The monitoring boreholes are labeled as VEP-S and VEP-U to monitor the Sewickley and Uniontown formations respectively. VEP-S was drilled to a depth of 328 m (1,076 ft) ending at the Sewickley formation and VEP-U was drilled to a depth of 291 m (955 ft) ending at the Uniontown formation equivalent.

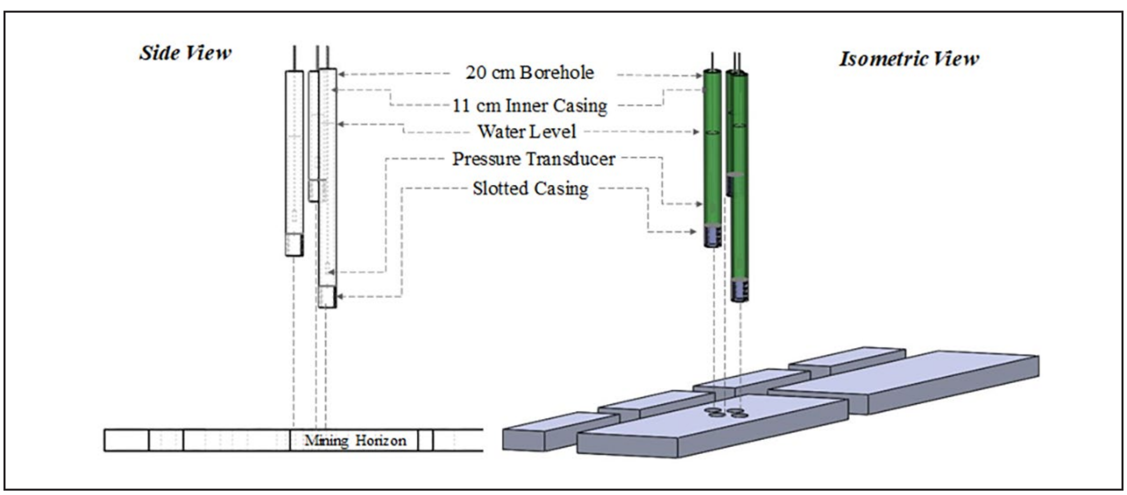

Figure 2. Borehole description and location in relation to pillar layout at the shallow cover site [11]

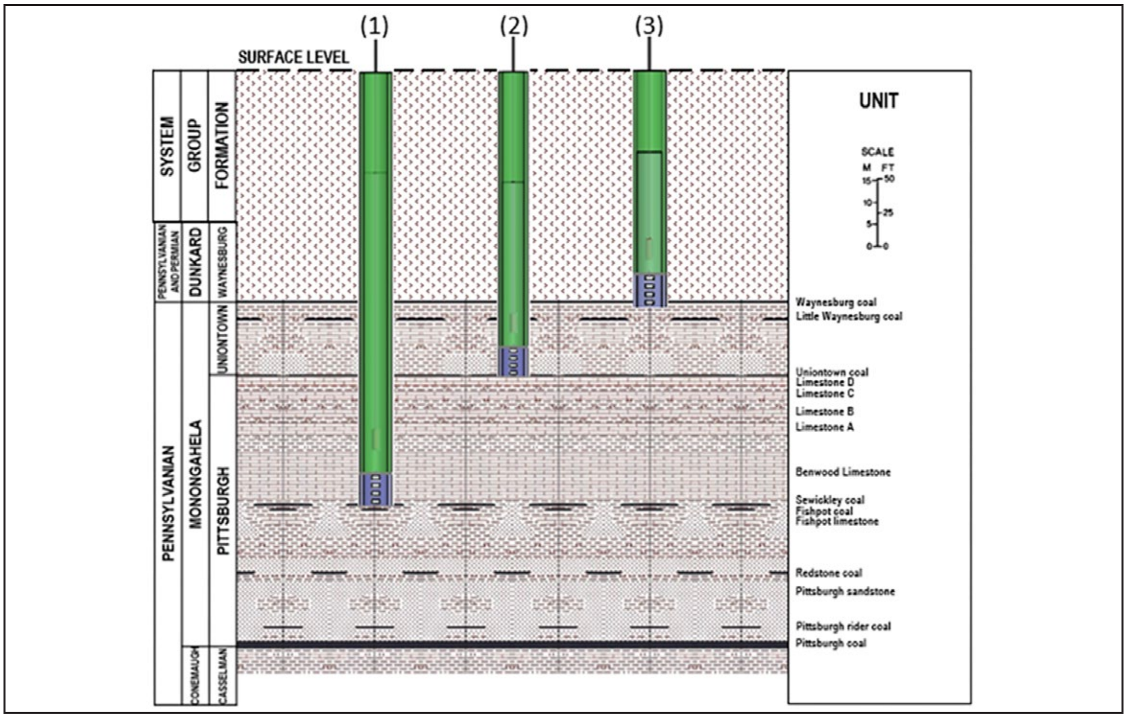

Figure 3. Geologic zone for each of the boreholes at the shallow cover site [11]

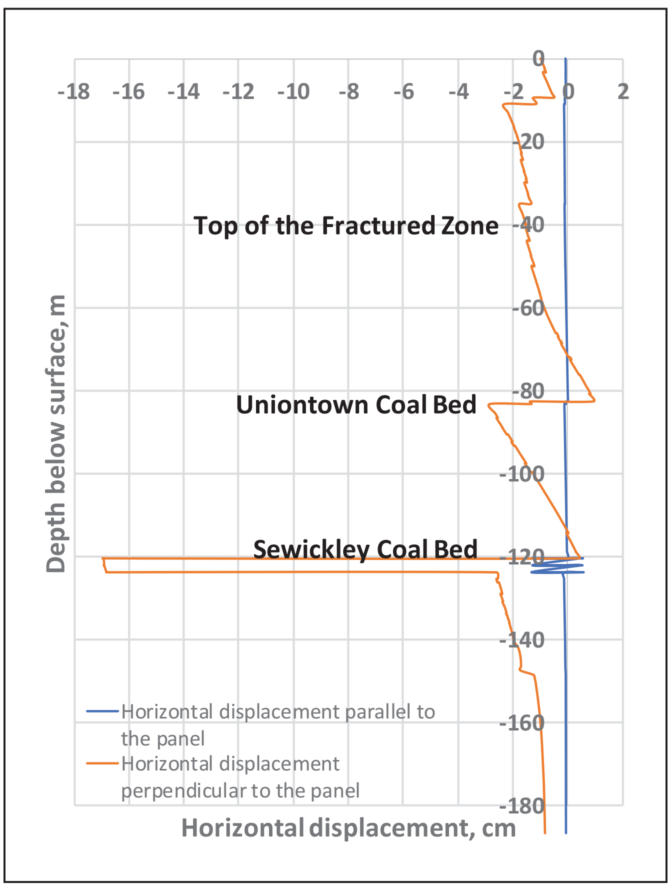

Figure 4. Horizontal displacement by depth (modified from Su et al., 2019b [8])

The borehole pattern was centered above a 38 m (125 ft) by 84 m (275 ft) abutment pillar that was part of a three-entry gate road system with 457 m (1,500 ft) wide LW panels that had lengths of about 3,660 m (12,000 ft) on both sides (Figure 5). The distance from the center of a borehole collar to the edge of the pillar adjacent to an active panel was at most 18 m (60 ft). The Pittsburgh seam is at a depth of 353 m (1,160 ft) from the surface at this location.

The VEP-S and VEP-U boreholes were drilled and cased with a steel casing and grout baskets except for the test intervals, which had screen lengths of 3 m (10 ft) and

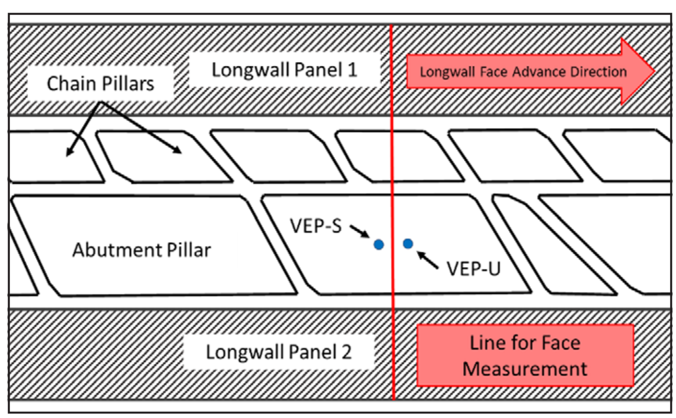

Figure 5. Top view of a three-entry LW layout for the deep cover site. Test boreholes and mining direction are shown

5 m (15 ft), respectively. Grout or bentonite were used to cement the borehole annulus outside of the casing.

EXPERIMENTAL METHOD

Researchers conducted falling-head slug tests to measure the permeability of the slotted casing lengths. The test zones were chosen to correspond to probable locations of high ground movement where increases in permeability were considered most likely, at the Uniontown and Sewickley coal horizons. An INW PT2X (Seametrics™) piezometer [12] tracked the long-term equilibrium water height and water slug height within the corresponding monitoring hole (Figure 6). For the falling-head slug tests, a water slug height of up to 3 m (10 ft) was added to the boreholes.

The previous NIOSH study [3] at the shallow cover site recorded the fall of water head at 5, 30, or 60 s intervals, depending on the expected drainage rate of the water. However, during the current study the rate of loss was at a much slower rate and, therefore, the data was recorded every minute, and the falling rate was later determined from the downloaded data.

Borehole slug testing at the deep cover site began when the LW face was 273 m (897 ft) away from the first panel and continued until after the completion of mining for both panels. When the LW face was 364 m (1193 ft) away from the monitoring site, the slug tests were conducted on each of the boreholes twice a week. The frequency increased to three times per week when the LW face was within 100 m (328 ft) of the boreholes. When the active LW face passed the borehole locations and was further away, the sampling rate for slug tests was approximately once per week. Once the LW panel was completely mined, long-term continuous water pressure readings were recorded every eight hours.

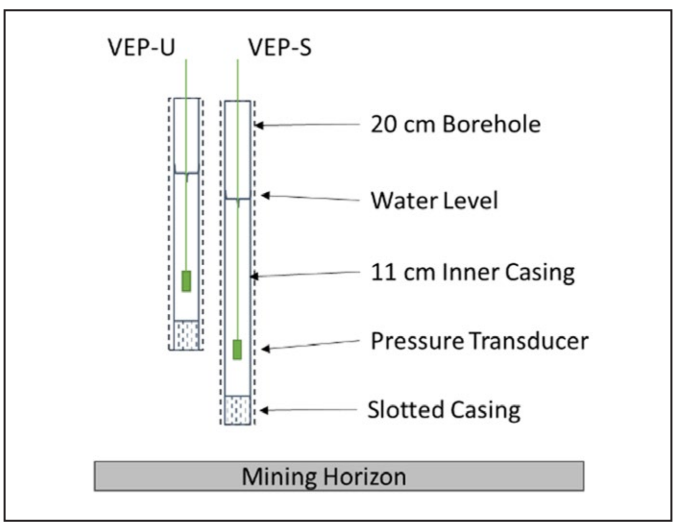

Figure 6. The sideview of the VEP-S and VEP-U monitoring boreholes (not to scale)

The piezometer readings, water slug height (H_w), and initial slug height (H_o) were converted to H_w/H_o values. For the calculation of permeability from falling-head slug tests, H_w/H_o values were plotted on a semi-log graph to determine the T_{37} time, which is the time, in minutes, in which the water slug drained to 37% of the initial water slug height [3, 13]. For a 10-ft water slug, the T_{37} time would be calculated as the time it took for the slug to drain to 3.7 ft. If the T_{37} value did not fall within the given data range, two points were chosen along the most linear section of the semi-log plot of the slug test, and the slope of those two points estimated the T_{37} time. Watkins et al. [3] details the application of T_{37} in the Hvorslev method to determine the hydraulic conductivity. The hydraulic conductivity is dependent upon the well casing radius, the well screen radius, and the length of the well screen. For both VEP boreholes and the FEB boreholes, the well casing radius is 0.052 m (2 in), and the well screen radius is 0.104 m (4 in). The well screen lengths are 4.6 m (15 ft) for VEP-U, 3.0 m (10 ft) for VEP-S, 7.9 m (26 ft) for FEB-1, 4.6 m (15 ft) for FEB-2, and 2.1 m (7 ft) for FEB-3.

Multiple assumptions about the slug test and ground aquifer are applied when conducting the Hvorslev method to calculate permeability. This method assumed that the water slug is added instantaneously, the groundwater flow is described by Darcy's Law, and the volume of water that flows into the aquifer is equivalent to the change in water volume within the well casing [3]. The aquifer is assumed to be incompressible, lithologically homogeneous, isotropic, and vertically confined by aquicludes. The injection well is assumed to have a negligible radius in relation to the size of aquifer, the well has a screen with a negligible head loss, and the water slug flow travels horizontally away from the well in all directions.

RESULTS AND DISCUSSION

Shallow Cover Results

Pre-mine-by levels at the shallow site are seen to be around 430 mD for the Sewickley horizon. During the time of the mine-by, the permeability measurements at the Sewickley horizon increased to more than 1,100 mD and fluctuated between 1,100 mD and 1,400 mD while the LW panel moved farther from the monitoring location (Figure 7). The maximum measurement occurred when the LW panel was > 305 m (1,000 ft) from the monitoring borehole location. Measurements for the Uniontown horizon exhibit a different pattern and are lower. The maximum permeability at the Uniontown horizon is 245 mD. The minimum measurement for the Uniontown is measured when the LW panel is <152 m (500 ft) from the monitoring borehole position.

Figure 8 displays the permeability measurements before, during, and after the second LW panel mine-by. As seen here, the permeability at the Sewickley horizon significantly increases during the 2nd LW panel mine-by to 5,080 mD before decreasing after the mine-by. When the LW panel is about 3,000 ft from the monitoring boreholes, the permeability measurement was just above 1,000 mD. The Uniontown horizon permeability measurements were significantly lower with a maximum measurement of 386 mD. When the LW panel was 3,000 ft from the monitoring boreholes, the permeability measurement at the Uniontown horizon was 161 mD.

A summary of the measurements is listed in Table 1. At the Sewickley and Uniontown horizons, permeabilities increase as the first longwall face approaches the measurement site. After the mine-by, permeability in the Uniontown horizon reduces to close to its pre-mining values but climbs back to the maximum values. However, permeability values at the Sewickley keep climbing to 1,360 mD. Previous NIOSH works [14] showed that permeability changes are directly related to the proximity to the mining level and inversely related to the depth of cover. The depth of

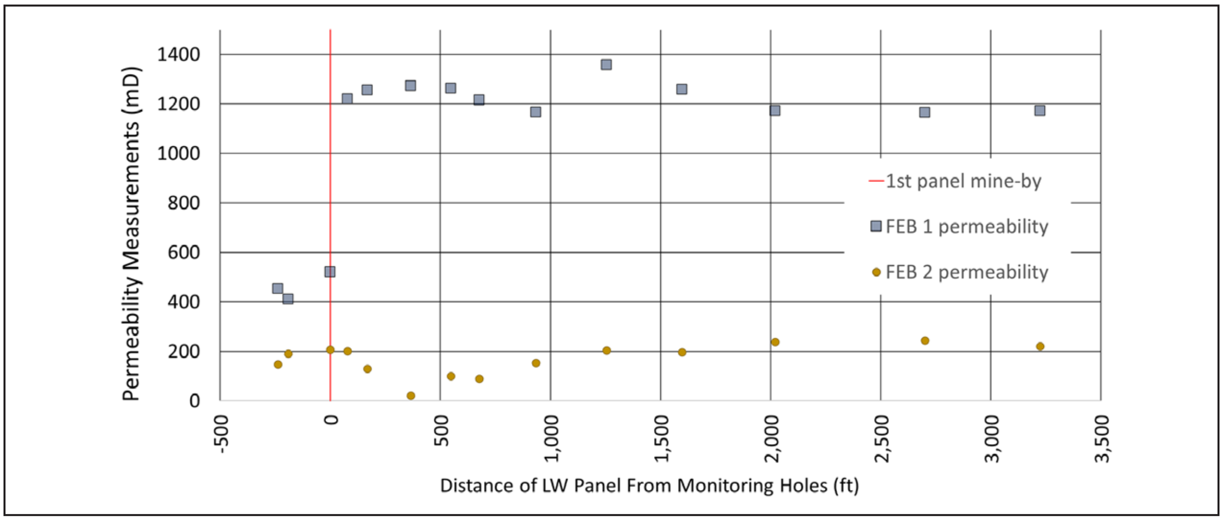

Figure 7. Permeability measurements at a shallow cover site during the first LW panel mine-by. Negative distances are the LW panel approaching the monitoring boreholes

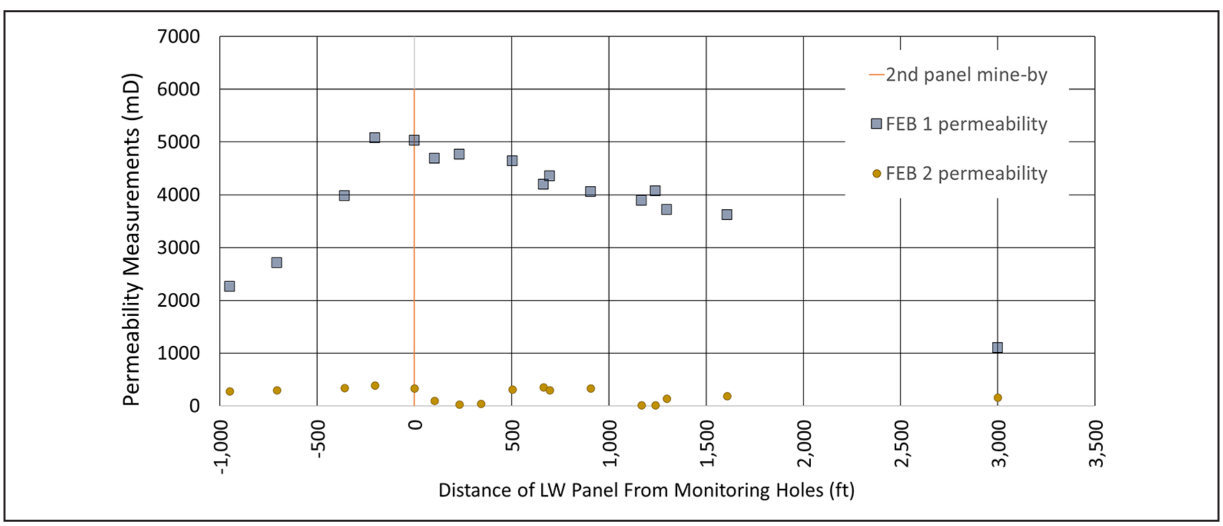

Figure 8, Permeability measurements at a shallow cover site during the second LW panel mine-by. Negative distances are the LW panel approaching the monitoring boreholes

Table 1. Measured permeabilities during LW panel mine-by at a shallow cover site

Measured Permeabilities		LW Panel 1		LW Panel 2	
Borehole ID	Horizon	Min (mD)	Max (mD)	Min (mD)	Max (mD)
FEB 1	Sewickley	411	1,360	1,100	5,080
FEB 2	Uniontown	22	245	11	386
FEB 3	Top of Caved Zone (Waynesburg)	2,730	32,900	38,500	132,000

cover could increase vertical and horizontal stress on fractures and bedding planes and thus reduce their permeability. However, the caving process close to the mine level enhances fracture permeabilities. At the Sewickley horizon, although deepest amongst the measurement intervals, the proximity to the cave zone caused elevated permeabilities.

Depth of cover has more dominating effects at the Uniontown horizon because of the relative distance from the mining horizon. The measurements for permeability at the top of the caved zone at the Waynesburg coal horizon show the highest values, implying the effects of depth of cover on the pre- and post-mining permeabilities. Previous NIOSH works [14] show that at shallower depth, bedding planes provide a low resistant path for water flow leading to an increase in the pre-mining permeability. After mining, the shearing and opening of subvertical fractures due to caving only enhances the permeability values.

At the Sewickley horizon, this is the greatest depth for measurement, and more effects from compression and more effects from proximity to the caved zone are observed. At the Sewickley horizon, the permeability measurements do not return to the original pre-mine-by levels. At the Uniontown horizon, there is less influence due to caving. The measurements for permeability at the top of the caved zone are included in Table 1. At the top of the fracture zone, due to the proximity to the surface, there is a potential for a large horizontal fracture. This is reflected in the much larger measurements.

Deep Cover Results

At the deep cover site, the permeability measurements were not above 1 mD for both the Uniontown and Sewickley horizons prior to the LW panel mine-by, VEP-U and VEP-S respectively. As the LW panel passed the monitoring boreholes, the permeability increased to a maximum of 5.4 mD at about 183 m (600 ft) from the Uniontown horizon monitoring location (Figure 9). The permeability values soon returned to below 2 mD afterward. The permeability values for the Sewickley horizon increased to almost 18 mD when the LW panel was about 244 m (800 ft) from the monitoring location. The permeability values for the Sewickley soon decreased to <2 mD.

At the deep cover site, the permeability measurements start to increase as the second LW panel approached the

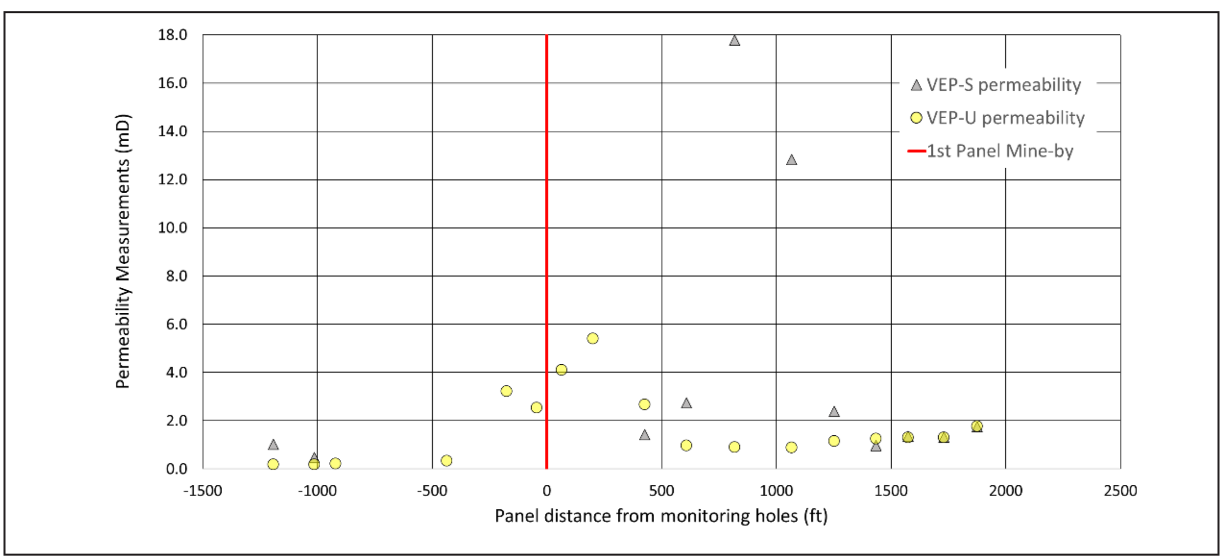

Figure 9. Permeability measurements pre-, during, and post- first LW panel mine-by under deep cover. Negative distances are the LW panel approaching the monitoring boreholes. VEP-U is at the Uniontown horizon and VEP-S is at the Sewickley horizon

monitoring boreholes (Figure 10). The Uniontown and Sewickley horizons both reached a maximum measured permeability of 6.6 mD and 8.8 mD, respectively, before decreasing again to <2 mD after the second LW mine-by.

Researchers were able to monitor the deep cover site between LW panel mine-bys. Figure 11 shows the period between the first and second LW panel mine-by. The permeability measurements during this time frame did not change much at each horizon and remained at or below their respective pre-mine-by values (shown in Figure 11) by the green and grey horizontal lines. Table 2 lists the average permeability values for the pre-, post-1st LW panel, and post 2nd LW panel mine-bys. The pre-mining values of permeabilities at the Sewickley and Uniontown horizons are close but VEP-S shows higher values although under deeper cover. This might be related to the degree of bedding and laminations at the Sewickley horizon. Evaluation of mechanisms leading to high permeabilities showed that bedding plane permeability is generally several orders of magnitudes larger than the permeability of subvertical fracture [15]. This is because the horizontal stress (perpendicular to the mining direction) in the Pittsburgh coal seam

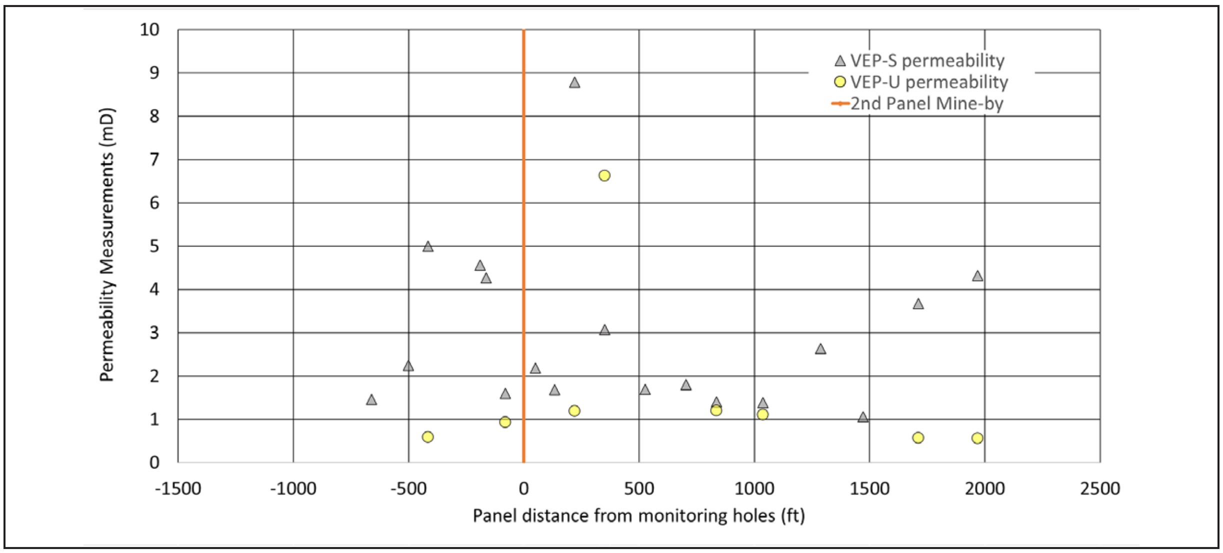

Figure 10. Permeability measurements pre-, during, and post- second LW panel mine-by under deep cover. Negative distances are the LW panel approaching the monitoring boreholes. VEP-U is at the Uniontown horizon and VEP-S is at the Sewickley horizon

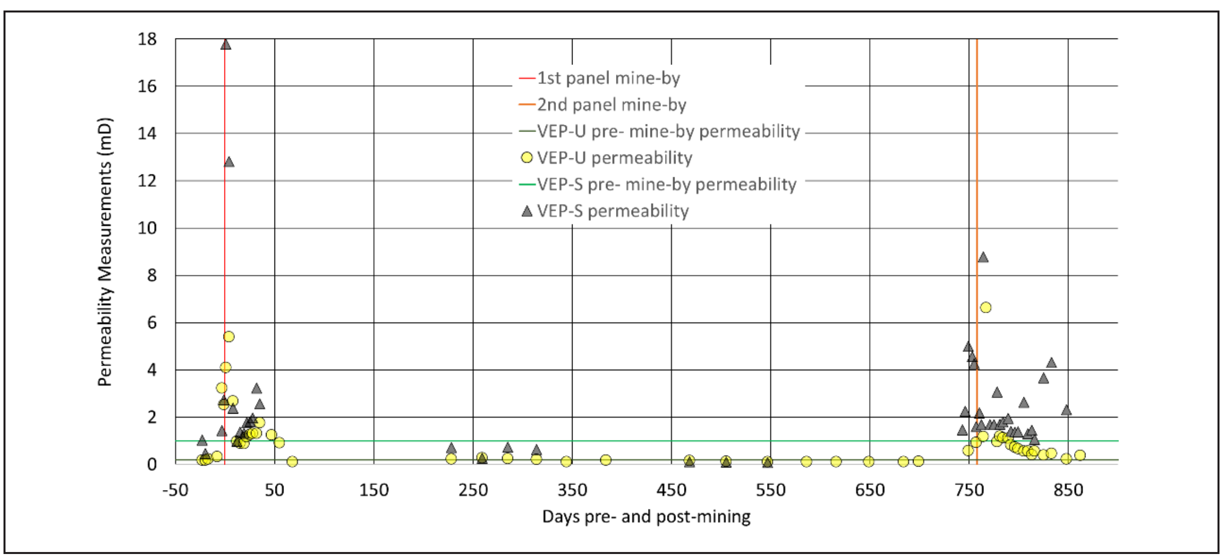

Figure 11. Permeability measurements pre-, during, and post- LW panel mine-by under deep cover

Table 2. Average pre- and post- LW panel mine-by and minimum and maximum values measured during a LW panel mine-by at a deep cover site

Borehole ID	Pre-Mine-by Average (mD)	During 1st LW Mine-by		Post-Mine-by Average (mD)	During 2nd LW Mine-by		Post-Mine-by Average (mD)
		Min	Max		Min	Max	
VEP-S	0.8	0.5	17.8	1.2	1.4	8.8	2.2
VEP-U	0.2	0.2	5.4	0.5	0.6	6.6	0.5

is about two times larger than the vertical stress. Higher horizontal stress can further close apertures of subvertical fractures compared to the bedding planes.

During first panel mine-by, permeability values in both the Sewickley and Uniontown horizons increase as the face approaches the site and drops close to the initial values after mine-by. The same pattern is repeated for the second panel mine-by. Overall, permeability values at the Sewickley horizon stay at a higher level compared to those at the Uniontown horizon, showing that proximity to the mine level can dominate the depth of cover effects.

Comparison of Sites

Figure 12 and Figure 13 compare the permeabilities measured at the shallow and deep cover sites after the first and second LW panel mine-bys, respectively. Table 3 displays the average values pre- and post- LW panel mine-by as well as the minimum and maximum measured values during the LW panel mine-by. At the deep cover site, the permeability values return to the pre-mine-by values within 305 m (1,000 ft) of the LW panel passing the monitoring site.

The deep cover values are two orders of magnitude smaller than those for the shallow cover. The observed difference is the physical locations of the two sites with the shallow cover site located in a stream valley and the deep cover site located at the top of a hill. However, another large difference is the time to achieve a T_{37} value. At the shallow site, a T_{37} value was gained in a matter of minutes or sometimes seconds. At the deep cover site, days or weeks were necessary to obtain the T_{37} value. That is why there is a difference in the measured permeabilities between the two sites.

Apart from the fact that permeability values in the shallow cover case is overall at a higher level compared to the deep-cover case, the main difference between deep and shallow cover site measurements is the return of permeability to the pre-mining values. In the deep cover case, permeability in both the Uniontown and Sewickley horizon reduced to their pre-mining values after peaking to a maximum permeability during mine-bys. This pattern was not observed in the shallow cover case. Instead, permeability stayed up after the mine-bys. This could be due to the

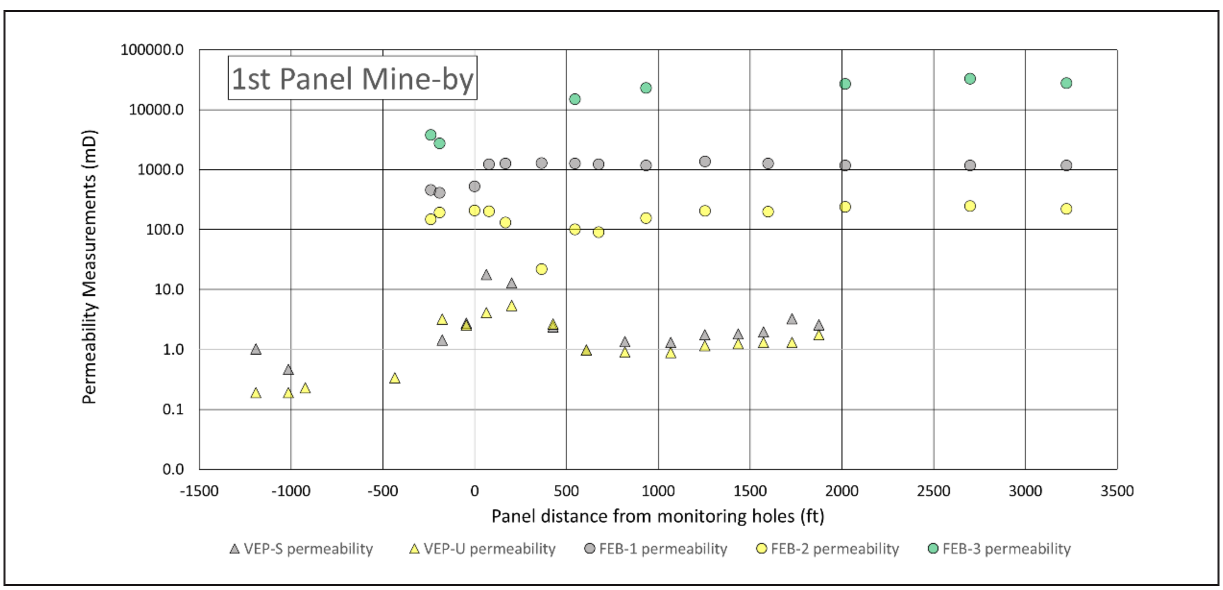

Figure 12. Graphical comparison of measured permeabilities at a shallow and a deep cover site after a first LW panel mine-by

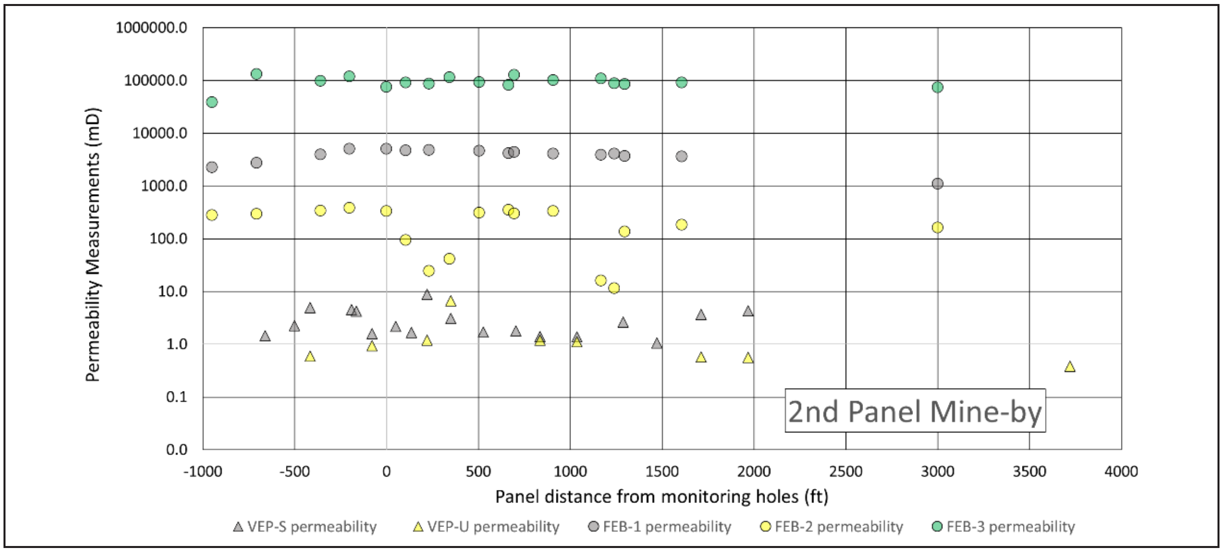

Figure 13. Graphical comparison of measured permeabilities at a shallow and a deep cover site after a second LW panel mine-by

Table 3. Comparison of permeability values under shallow and deep cover pre-, during, and post- LW mine-by

Comparison of Permeability Data				Pre-Mine-By Average (mD)	During 1st LW Mine-By (mD)*		Post-Mine-By Average (mD)	During 2nd LW Mine-By (mD)*		Post-Mine-By Average (mD)
Cover	**Depth (ft)**	**Borehole ID**	**Horizon**		**Min**	**Max**		**Min**	**Max**	
Shallow	417	FEB-1	Sewickley	432	411	1,360	1,220	2,260	5,080	3,630
Shallow	250	FEB-2	Uniontown	169	22	245	193	16	386	187
Shallow	135	FEB-3	Top of fracture zone	3,250	2,730	32,900	27,500	38,500	132,000	94,500
Deep	1,076	VEP-S	Sewickley	0.8	0.5	17.8	1.2	1.4	8.8	2.2
Deep	955	VEP-U	Uniontown	0.2	0.2	5.4	0.5	0.6	6.6	0.5

*"During mine-by" defined as the LW panel being within ± 1.2 times the Pittsburgh seam depth of the monitoring boreholes

difference in the longwall abutment loading in these two cases. Previous NIOSH works [16, 17] showed that higher abutment loading in a deep cover site reduces the aperture of bedding panes and subvertical fracture. However, similar work on the shallow-cover case showed that the proximity to the mining level was the dominating factor due to shallow overburden.

CONCLUSION

For the two cases evaluated in this study, the range of permeability values is wide. Permeability under shallow cover is at least two orders of magnitude higher than those under deep cover. In the deep-cover case, the depths of cover is the dominating mechanism for controlling post-mining permeability so that under deep cover, the permeability values return to pre-mine-by values within about 305 m (1,000 ft) of the LW panel mine-by. This is reassuring since deep cover conditions are a common occurrence in southwestern Pennsylvania. Under shallow cover, the caving process is the dominating factor in controlling post-mining permeability so that the permeabilities do not reduce down to the pre-mining values.

The information from these studies can help understand potential gas transport through ground strata and the numerical prediction of potential inflow amounts. The next steps include the continued monitoring of the long-term permeability values under deep cover for potential changes. Also, an intermediate or medium cover site will be monitored for permeabilities before, during, and after a first and second LW panel mine-by.

LIMITATIONS

In this research, the collected data was limited to two sites targeting shallow and deep cover. Although the site locations were targeting the same coal horizons, the geology, surface topography, site conditions, groundwater table, weather conditions, and mining conditions varied for each site. The data demonstrates the effects of LW panel mining on permeabilities within the two targeted coal horizons and the potential differences due to overburden depth. However, lateral lithological variations in the same coal horizon could play a role in difference in the permeability values between the two sites. The stream valley association at the shallow cover site produced a set of enhanced permeability conditions. Therefore, applying the findings outside of these boundaries is not advised with the data presented.

DISCLAIMER

The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH.

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