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Field survey of mine ventilation system for large opening underground mines: Pressure, relative humidity, and temperature

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ABSTRACT: The effects of natural ventilation on mine ventilation systems are well documented and have been theoretically studied for decades. However, quantifying and incorporating these effects into a comprehensive and effective mine ventilation plan is difficult especially for large- opening mines. This study focuses on incorporating natural ventilation into ventilation planning to optimize the airflow reaching the mining section and minimize losses throughout the system. The ventilation parameters i.e. pressure, temperature, and relative humidity, of both a single-level and multi-level mines have been monitored continuously for periods of time spanning across multiple seasons. Analysis of this ventilation data shows the effect natural ventilation has on the mine ventilation system.

1 INTRODUCTION

Many essential raw materials are extracted from large-openings room and pillar mines (opening greater than 1000 ft^2), and these materials include limestone, lead/zinc, salt, marble, lime, stone, and sandstone (Grau 2006). These earth raw materials are all integral parts of the United States economy. In 2019, the estimated domestic value of production increased by 3% overall and were evaluated at 28.1 and 58.2 billion dollars for metal and industrial minerals, respectively (Staff 2019). The seventeen non-fuel minerals in the United States are fully reliant on foreign sources and another 46 non-fuel minerals are over one-half reliant on foreign sources, with China and Canada being the top suppliers (Staff 2019). For national security, self-dependent raw material production is of importance and thus many parameters should be considered to abate these imports quantities including availability, reserve estimations, and product supply chains, and mining conditions. The non-fuel raw material mining can be mined through either surface mining or underground mining. For underground mining, the non-fuel raw materials are typically mined through large opening room and pillar mines. The ventilating system design and optimization for large opening mines are challenging. A few challenges have been recognized but have yet to effectively optimized, namely, entry resistances being extremely low, difficulty in measuring air velocities, layering of airflow within an entry, the increased and seasonal effects of natural ventilation, and the building and maintenance of ventilation controls which is both time consuming and expensive for mine operators with already limited budgets. Of these challenges, the seasonal natural ventilation for large opening mines remains unquantified and little work has been conducted regarding the effects of natural ventilation. This study aims to investigate the continuous interaction between natural and mechanical ventilation for large opening mines.

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2 BACKGROUND AND PREVIOUS WORK

Perhaps large opening mine ventilation and its associated engineering design has received less attention because it is not the primary source of fatality event (accidents) when historically compared to coal and ultra-deep mines. However, in the early 2000s, the National Institute for Occupational Safety and Health (NIOSH) conducted numerous studies of large opening mine ventilation design and standardization. Three major features were identified and considered towards improving the large opening mine ventilation systems: design of the system, fan selection, and ventilation controls (Grau 2002, 2004). There are many aspects concerned with the design of a ventilation system, Krog et al. discussed the overall ventilation scheme by introducing split, perimeter, and unit ventilation terms and discussing their feasibility in various situations (Krog 2004). From the miners' health perspective, the airborne pollutant dilution and control is a primary compliance concern for large opening mine operators. To control airborne pollutants, both source control through machine selection and enhanced airflow dilution are considered to mitigate the pollutants (Grau 2006, 2004a, 2004b, 2009). Fan selection was examined and the results suggest that the implementation of propeller fans rather than axial-vane fans can increase the airflow throughout the mine as well as the effective face ventilation (Grau 2004, 2006, Krog 2006). Ventilation controls are also an integral part of any mine ventilation system, specifically curtains, stoppings and booster fans were investigated and compared based on various criteria, such as, economics, curtain/stopping type, construction, maintenance, location, and effectiveness. Various recommendations have been made for large opening mine operators and the use of long pillars with curtains/stoppings optimally placed and designed correctly for their location showed improved airflow through the mine system (Grau 2004, 2004b, 2006 Krog 2004). While all these previous studies were necessary for general guidance of ventilation system, seasonal natural ventilation variations and their relative roles are largely ignored in these studies because it requires long-term ventilation monitoring and dynamic analysis of psychrometric evolution. Grau et al. briefly discussed natural ventilation and its sporadic and uncontrolled nature to conclude that operators must not solely rely on natural ventilation for the large opening mines but must also use mechanical ventilation as needed (Grau 2002). However, this statement may be misleading, natural ventilations flow direction while fluctuating diurnal and seasonally are predictable with only the magnitude of flow being sporadic and uncontrolled. Therefore, an in-depth study on the combined effect of natural ventilation and mechanical ventilations on a large opening mine system is needed for a complete understanding of their interactions. In this study a single-level and multi-level mine will be investigated, with an emphasis on improving airflow around working areas while leveraging natural ventilation.

3 METHOD

It is well documented that natural ventilation varies seasonally and diurnally; therefore, all seasons should be investigated and monitored to determine the intensity and its role on the overall ventilation system performance. Continuous monitoring the atmospheric conditions in the mines can provide reliable and time-dependent ventilation parameters. In this study, we collaborate with local mine partners to monitor the temperature, relative humidity, and barometric pressure. A single-level mine and a multi-level mine were monitored and reported. For the single-level mine eight measurement locations for continuous monitoring were identified and utilized in consultation with the mine operator. The multi-level mine was split into two smaller studies for the measurement locations to be spread across only a single-level at a time. All measurement locations are illustrated and discussed in the subsequent sections.

3.1 *Instrumentation*

HOBO micro station data loggers' (Model#: H21-USB) were purchased and chosen to collect mine atmospheric data. These data loggers are known as their small-sized feature which offers the advantage of little interruption to mine operations. Each HOBO logger can house up to 5 sensors with a user defined logging interval between 1 second and 18 hours. The logger has 512KB of nonvolatile flash data storage and uses four AA 1.5V alkaline batteries for power. Temperature and relative humidity were measured issuing a smart temperate/relative humidity sensor (Part # S-THB-M008) which has an accuracy of ±0.21°C from 0°C to 50°C and ±2.5% from 10% to 90% (with ±5% typical above and below 10% and 90%) and a resolution of 0.02° C and 0.1% for temperature and relative humidity. Barometric pressure is measured with the smart barometric pressure sensor (Part#: S-BPB-CM50) which has an accuracy and resolution of ± 3 mbar (300 pa) and 0.1 mbar (100 pa) respectively. A one-minute logging interval was defined to optimize data collection, memory storage space, and battery life. Based on this one-minute logging interval the logger's memory must be manually offloaded and reset every 86 days.

The HOBO micro-station data logger with the utilized sensors is shown in Figure 1A. In the multi- level mine all sensors were placed on the berm facing the roadway approximately 3 ft above the floor surface and in the single level mine placed on rebar attached to the ribs approximately 5-6 ft above the floor. Pictures of the HOBO data Logger placements are shown in Figure 1.

3.2 *Partner mine descriptions and sensor installations*

A quick mine ventilation survey was conducted at the start of each continuous mine survey. During these studies the barometric pressure, relative humidity, temperature, airflow quantity, airflow direction, and cross-sectional area were measured with the goal of verifying in-mine atmospheric conditions as well as in consultation with mine operators helped to determine optimal monitoring locations. Since these initial snapshot ventilation surveys were only used to help determining optimal monitoring locations, we did not report the data in this study.

3.2.1 *Single-level mine*

The single-level continuous mine study was then conducted in the summer months from June 5-August 11 with the partnered limestone mine located in western Pennsylvania. Typical entry widths and heights are approximately 43 ft. and 27 ft (13.1 m and 8.2 m), respectively. Figure 2 shows the mine map with the general airflow shown in green and red arrows for intake and exhaust air, respectively. Eight measurement locations were utilized and shown with red circles and fan locations are marked with black fan symbols. This single level mine utilizes a perimeter ventilation scheme with the temporary curtain line running parallel to the

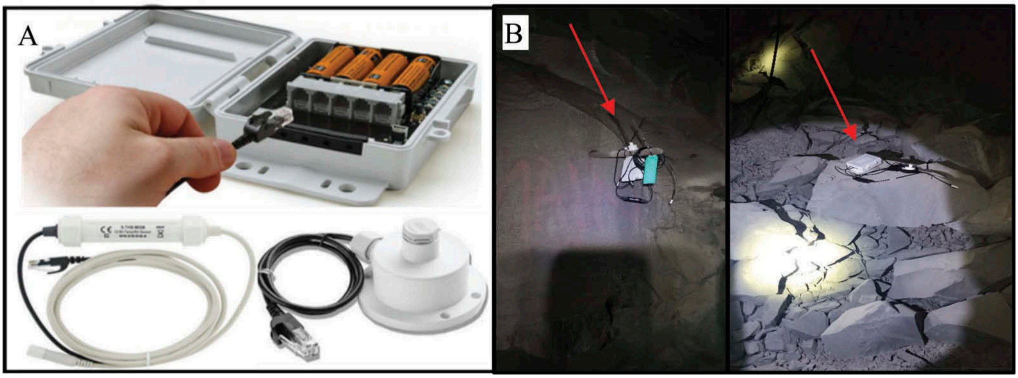

Figure 1. (A) HOBO data logger (top) along with the Smart Temperate/relative humidity sensor (bottom left) and smart barometric pressure sensor (bottom right), (B) HOBO data logger placement in mine environment, (left) shows logger placed on rebar extruding from rib, (right) shows logger placed on roadway berm.

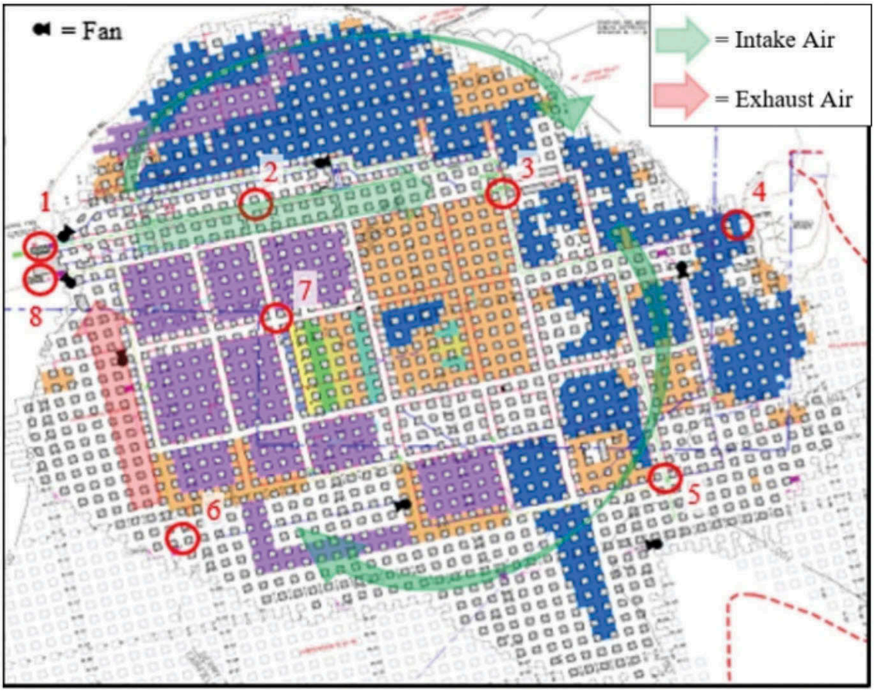

Figure 2. Single level partner limestone mine map, fan and measurement locations marked.

face; from location 5 to location 6. Location 1 is positioned along the intake canopy to monitor the surface conditions while locations 2 and 3 are located along the intake pathway. Location 4 was chosen because two new portals were being driven at this location and continuous monitoring the atmospheric conditions before and after the portal was opened is desired. Location 5 and 6 are positioned at either side of the working sections with location 7 monitoring the previously mined benched areas. Location 8 monitors the exhaust airflow and is positioned immediately before the exhaust canopy. At least 5 booster fans are utilized throughout the mine system in addition to the 2 main forcing and exhausting fans located at the intake and return portals. Location 4 is of particular interest because this is where 2 new portals were being opened, at the beginning of this study one of the two portal was daylighted but significantly blocked, however during this study both portals were fully opened by approximately June 18th. Thus, giving this study a unique opportunity to observe the effect of a mine changing from essentially a single (1 intake and 1 exhaust) to a multi poral mine.

3.2.2 *Multi-level mine*

The multi-level continuous mine study was conducted during the spring from April 20-May 7 with the 17 days split into two smaller studies. The multi-level partner limestone mine is located in central Pennsylvania with typical entry widths and heights being approximately 43 ft. and 28 ft (13.1 m and 8.5 m), respectively; however, entry heights can be up to 90 ft (27.4m) in some locations. The first 7 days of this study the 265 level was investigated using measurement locations: 1, 2, 3, 9, 10, 11, 12, and 13 shown in Figure 3. On the 7th day the data loggers were moved to investigate the 310 level using positions 1, 2, 3, 4, 5, 6, 7, and 8 from Figure 3. The data loggers stayed in these locations for the remaining 10 days of the study. Ventilation controls are scarce except for the permanent stoppings along the main intake and return slopes and near monitoring locations 9 and 11. The general sensor placement plan was to monitor every ramp connecting different levels and monitor locations further inby near

Figure 3. Multi-level partner limestone mine map, fan, and measurement locations, Study 1 used locations 1, 2, 3, 9, 10, 11, 12, and 13 while Study 2 used locations 1, 2, 3, 4, 5, 6, 7, and 8.

potential working faces. The surface conditions were monitored using location 1 and locations 2 is positioned at the bottom of the intake slope. From position 2 the airflow splits to either location 9 or location 3 in the 310 level. Location 9 is the intake for the northern mining section in the 265 level while location 10 is near the working sections and location 11 monitoring the exhaust from this section. Location 12 monitors the bottom of the exhaust slope while location 13 is positioned near the exhaust portal. Locations 4 and 7 were selected because they are further inby the 310 level. Location 5 is positioned on the intake ramp down to the 380 level while location 6 monitors the booster fan pulling air up from the 310 level. Finally, location 8 is positioned on the exhaust ramp up to the 265 level. The mine typically deploys 6 booster fans spread across all three levels as shown in Figure 3 in addition to the 2 main forcing and exhausting fans by the intake and return portals. This mine appears to utilize a split mine ventilation scheme but reportedly struggles to maintain company defined airflow standards in the lowest mining level (380 level). For this study, natural ventilation was first investigated, all fans in this multi-level mine section were turned off for the first 15 days of the 17-day study allowing for natural ventilation to be monitored. On the 15th day all the fans were turned on and remained on for the final 2 days of data logging.

4 RESULTS & DISCUSSION

4.1 *Single-level mine*

During this study new portals at location 4 were fully opened, this had a significant effect on the in mine atmospheric conditions and will be the focus of this section. Figure 4 shows the continuously monitored temperature and barometric pressure from June 4th to August 11th (summer season). Significant diurnal variations can be seen in the temperature data from Figure 4A in locations 1, 2, and 8 (surface, location nearest the intake portal, and return portal). However, the in-mine measurement locations show both a diurnal and weekly pattern, especially locations 3 and 5. This mine does turn off fans when no work is being conducted in the mine which explains this weekly pattern. Therefore, during some nights and the weekends only natural ventilation is being monitored and a comparison can be made between these natural ventilation times and working days where both mechanical and natural ventilation are present.

The red dashed line in Figure 4A, B shows approximately when the location 4 portals were opened. A significant variation can be seen in locations 4 of the expanded section of Figure 4A, before the portals are fully opened location 4 follows the surface conditions closely, indicating it to be acting more as an airflow inlet. The temperature and barometric pressure patterns are muted compared to the surface conditions but the difference in elevation between location 1 and 4 can account for this difference. However, in stark contrast to before the portal opened location 4's temperature and barometric pressure profiles after the openings match the mines atmospheric conditions closely; thus, these portals are acting as an airflow outlet. It is the authors understanding that no significant ventilation control changes happened during this study. Therefore, in opening this portal the natural ventilation trend may be short circuiting the active mining areas near locations 5 and 6 altogether.

The continuously monitored barometric pressure is shown in Figure 4B with the difference between the in mine measurement and the surface locations shown in Figure 5A (Positive difference indicates higher pressure, negative difference indicates lower pressure than surface). Diurnal fluctuations are observed in the expanded differential pressure and temperature graphs in Figure 5A. Before the new portal openings (red dashed line) locations 4 and 5 were the only locations with a positive difference in barometric pressure with a value fluctuating around 0.2 kPa, while all other in mine

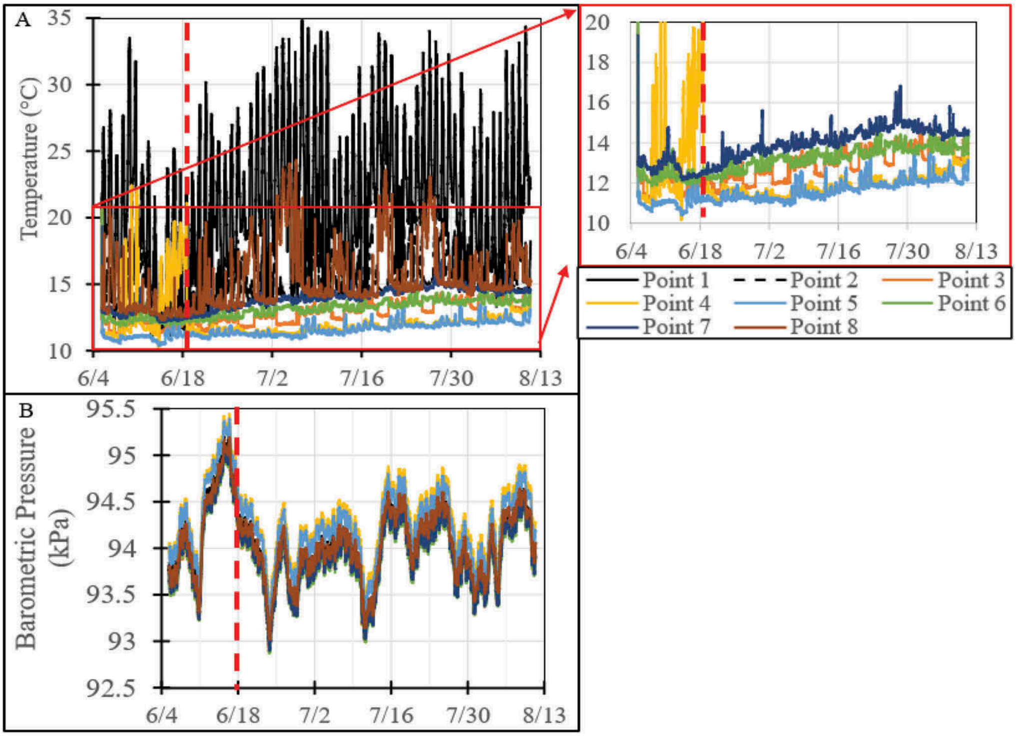

Figure 4. Continuously monitored temperature and barometric pressure from the single-level partner mine, the red dashed line indicates when the portals at location 4 were fully opened: A) continuous temperature B) continuous barometric pressure.

locations were lower than the surface barometric pressure between 0 kPa and -0.2 kPa. Once the new portals were opened locations 3, 4, and 8 differential pressure increased by approximately 0.1kPa while all other points remained stable indicating a potential short circuit from location 1 to 4. Location 8's differential pressure fluctuates around 0 indicating only a miniscule pressure differential between the intake and exhaust portals thus allowing for potential short circuiting from location 7. Similarly, the expanded section of the differential temperature graph in Figure 5B show a strong diurnal pattern with only position 4 significantly changing once the new portal is opened. Furthermore, when the difference in temperature is greatest the difference in pressure also shows a positive increase. These temperature changes as well as the increase in pressure differential indicates these portals acting as a natural outflow for the mine ventilation system.

To summarize, Pressure differences across the mine are maximized when temperature differential is highest. Further analysis between working days when the fans are on and non-working days when only natural ventilation is needed to quantify the interaction between natural and mechanical ventilation. Continuously monitored mine atmospheric data from other seasons is also required to fully quantify seasonal role natural ventilation has on this mine ventilation system.

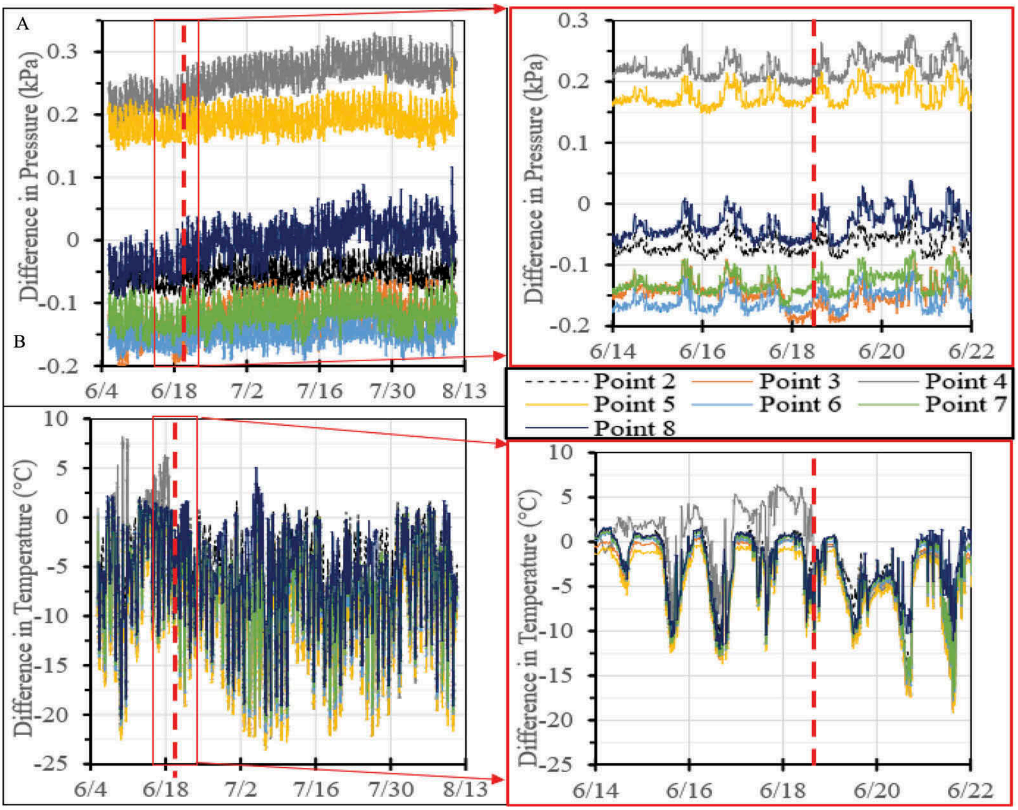

Figure 5. Difference in pressure and temperature between the in mine monitoring locations and the surface conditions from the single-level partner mine, the red dashed line indicates when the portals at locations 4 were fully opened; A) difference in pressure B) difference in temperature.

4.2 *Multi-level mine*

The continuously recorded temperature from each of the 13 selected measurement points are plotted in Figure 6A, B. Figure 6A shows the first study focusing on the 265 level while Figure 6B shows the second study which focuses on the 310 level. The diurnal temperature pattern can be observed at the surface measurement location (point 1 in all graphs) and a similar but muted diurnal fluctuation pattern can be seen in the highlighted section of Figure 6A expect for location 10. Location 10 is the furthest inby monitoring location with locations 9 and 11 acting as the intake and exhaust for location's 10 section. Since location 10 is consistently 1°C higher than locations 9 and 11 this shows with natural ventilation alone airflow short circuits from location 9 to 11 without reaching location 10.

During the second study an extreme cold night was monitored on April 28th, the impact of which can be seen in the expanded section of Figure 6B even at point 5 which is the deepest monitoring location. Indicating large volumes of air is moved throughout the mine when surface temperature is lower than in mine locations. However, when the temperature increased the following day the in mine temperature does not quickly return to an equilibrium value but rather slowly increases over the course of the study. It is not until May 4th when all fans were then turned on did a significant in mine change happen. Initially increases in temperature at location 2, 5, and 7 are seen with a temperature decrease at location 3. Location 8 (the exhaust slope) remained stable during this initial period which implies that these increases in temperature may be localized and not related to the full ventilation system flow. After this initial increase in temperature another cold night time occurred dropping the temperature of all in mine locations significantly. Even when the fans were on Location 6's (exhaust slope from 380 level) temperature remained stable except for time of extreme night time decreases in

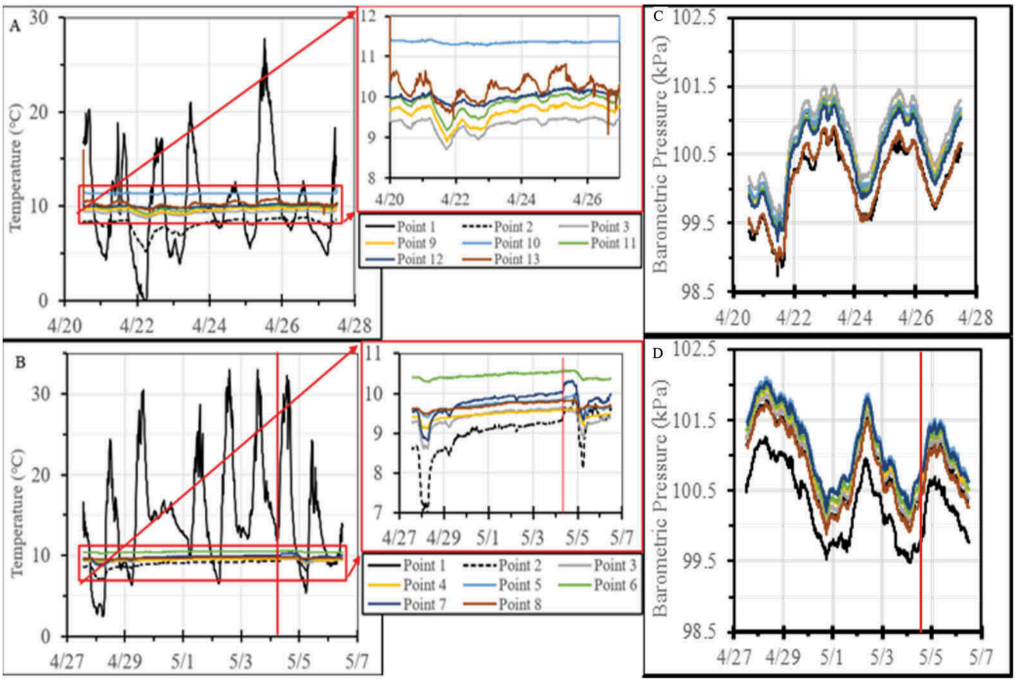

Figure 6. Continuously monitored temperature and barometric pressure from the multi-level partner mine; A & C) shows the temperature and barometric pressure from study 1 (265 level) B & D) shows the temperature and barometric pressure from study 2 (310 level), the red indicates when the fans were turned on.

temperature, indicating either thermal equilibrium is reached in the 380 level or little airflow is exchanged between the 310 and 380 level.

The continuously monitored barometric pressure is shown in Figure 6C, D with all in mine locations closely following the surface fluctuation pattern. Minimal changes in barometric pressure were observed after all the fans are turned on as shown by the red line in Figure 6C, D on May 4th.

5 CONCLUSION

Large opening mine ventilation systems are dynamic and strongly influenced by natural ventilation in ways that are unique to each mine specific situation; conclusions from this initial study include:

1) In the multi-level mine, natural ventilation accounted for much of the pressure differential seen throughout the mine because only subtle changes in the mine environment occurred when the fans were turned on.
2) In the single-level mine, opening a new portal at location 4 significantly altered the mine atmospheric conditions, positions 3, 4, and 8 altered the most indicating both this portal had a system wide impact and may be acting as a natural exhaust portal.
3) Daily analysis of mine atmospheric data is needed to quantify the impact of mechanical ventilation on natural ventilation.
4) More mine atmospheric data is needed to quantify how the mine ventilation system dynamically changes with seasonal changes

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REFERENCES

Grau R, Mucho T, Robertson S, Smith A, Garcia F. 2002. Practical techniques to improve the air quality in underground stone mines. Mine Vent.

Grau III RH, Robertson SB, Krog RB, Chekan GJ, Mucho TP. 2004a. Raising the bar of ventilation for large-opening stone mines. Proc 10th US/North Am Mine Vent Symp.

Grau RH, Robertson SB, Mucho TP, Garcia F, Smtih AC. 2004b. NIOSH Ventilation Research Addressing Diesel Emissions and Other Air Quality Issues in Nonmetal Mines. SME Trans.

Grau RH, Krog RB, Robertson SB. 2006. Maximizing the ventilation of large-opening mines. Proc 11th US/North Am Mine Vent Symp - 11th US/North Am Mine Vent Symp.

Grau IH, Krog R. 2009. Using mine planning and other techniques to improve ventilation in large-opening mines. Min Eng.

Krog RB, Grau III RH, Mucho TP, Robertson SB. 2004. Ventilation planning layouts for large opening mines. Soc Mining, Metall Explor.

Krog RB, Grau RH. 2006. Fan selection for large-opening mines: Vane-axial or propeller fans - Which to choose? Proc 11th US/North Am Mine Vent Symp - 11th US/North Am Mine Vent Symp.

Staff 2019. U.S. Geological Survey. National Minerals information. USGS mining review. Min Eng.

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