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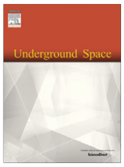

# Microseismic monitoring and analysis of induced seismicity source mechanisms in a retreating room and pillar coal mine in the Eastern United States

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## Abstract

A microseismic monitoring system was installed in an underground room and pillar coal mine in the Eastern United States to analyze the occurrence and characteristics of induced seismicity during the retreat of two panels in the mine. This study is the first microseismic monitoring effort at an underground coal mine in nearly 30 years. During the retreat of the first panel, an array of eight uniaxial geophones, installed 10 ft. into the roof, recorded events and their magnitudes. The second panel was monitored using an array of twelve uniaxial geophones and two triaxial geophones, also installed 10 ft. into the roof. Comparing the results of these studies, it has been found that the magnitude of seismic events is minimally affected by immediate roof geology or depth of cover. However, it was observed in both studies that the rate at which seismic events occurred did vary with changing roof geology and depth of cover. Using the seismic data from the second panel retreat, focal mechanism solutions were generated for 50 hand-picked events in order to determine if the failure was in compression, tension, or shear. Results of the focal mechanism solutions show that stress relief resulting in dilational events occurs at significant depths, 150–200 m in this case, beneath the active mining face.

*Keywords:* Deep mining; Induced seismicity; Coal mining; Rock mechanics; Source mechanisms; Subsidence

## 1. Introduction

Ground control is a major issue in underground coal mines. The “soft” nature of the rock, nearby bedding, and seam depth are just a few of the factors that make coal extraction dangerous. In the United States between 2006 and 2012, over 3300 injuries (fatal, non-fatal days lost, no days lost) were reported as a result of a fall of a roof or rib in the underground coal mine industry. This represents over 16% of all reported underground coal incidents during this period (MSHA, 2015). Forty-two of these injuries resulted in deaths. In comparison during this same time frame, underground metal mines had 13.5% (240 injuries) and underground nonmetal mines had 6.7% (55 injuries) of all injuries resulting from the fall of a roof or rib. Over the years, the number of injuries have decreased, but as of 2012 there were still 376 yearly injuries in underground coal mines across the United States.

Commonly accepted mining methods, such as longwall and room and pillar retreat, allow overburden to cave. This creates highly variable stress conditions that can be difficult to predict. From both the safety and production point of view, unplanned ground falls resulting from these condi-

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tions are unacceptable. Not only can fatalities and injuries occur, but falls can obstruct escape ways, block ventilation, cause stoppage in operations, damage equipment, and cause lost ore reserves. Proper mine design and safe operating procedures are critical to prevent ground control issues from happening.

## 2. Literature review

### 2.1. Microseismic monitoring

### 2.1.1. Introduction to microseismic monitoring

A common way of determining instability and changing stress conditions in underground mines is to monitor mining-induced microseismic events. A microseismic event occurs when a rock under a critical amount of stress fractures and emits an energy wave of short duration and small amplitude (Obert & Duvall, 1967). Each waveform contains a grouping of elementary wave signals that represent particle velocity initiated by individual pulses of stress wave energy (Descour & Miller, 1987). The energy pulse's shape details the amount of stress released at the source and the effect of non-uniformities in the rockmass along its travel from the source to a microseismic sensor such as a geophone. The polarity of a waveform from both man-made and natural sources can be used to determine whether an event's driving force was shear or compressional (Swanson, Stewart, & Koontz, 2008). Individual waveforms are analyzed to determine the time, location, and magnitude of a single event. A seismic event with a moment magnitude of typically less than 2.0 is considered "micro" (Spence, Sipkin, & Choy, 1989). Over time, the failure process of a monitored area can be studied from the progression of the located events.

At least three microseismic surveys have been completed and analyzed in longwall coal mines (Alber, Fritschen, Bischoff, & Meier, 2009; Ellenberger, Heasley, Swanson, & Mercier, 2001; Luo, Hatherly, & McKavanagh, 1998; Swanson et al., 2008). These studies and analyses verified that microseismic monitoring is a useful tool for understanding stress redistribution in an underground coal mine setting. In contrast, room and pillar retreat mines have had only one published microseismic study. This study, completed in 1987 by Descour and Miller, monitored various parts of a retreat mine section over a 10 month period. The mine layout however was not the same as what is currently found underground. Modern rectangular retreat panels, which incorporate five to seven entries encompassed by barrier pillars on both sides, were not employed. Instead, an entire section of the mine was extracted. Much smaller barrier pillars, approximately the size of 10 production pillars, were placed in vital areas of the section.

Microseismic events are the results of changes in the stress distribution of a rockmass, where the physical event is a slip or shear of the rock. These events are too small to be felt on the surface of the earth but can be detected and measured by equipment such as geophones or accelerometers. This is considered a passive method as the instruments are monitoring seismic activity already taking place, also known as induced seismicity (ESG Solutions, 2016). This monitoring can provide results in real-time, providing knowledge of what is happening underground at exact points in time (Ge, 2005).

Microseismic monitoring can reveal information such as when and where the microseismic event occurred underground, and the event's magnitude (Ge, 2005). The main goal of such monitoring is to observe these events over time and identify patterns and correlations between events and production activities. Monitoring seismic activity in mining operations can improve mine safety through risk management, and be used to study overall ground conditions.

### 2.1.2. Planning the monitoring system

Efficient mine microseismic monitoring can be summarized in three aspects: monitoring planning, data processing, and event location (Ge, 2005). Thorough planning is essential for establishing an efficient and lasting monitoring system. In planning, it is important to assess monitoring objectives, including target areas, accuracy, and conditions of the area being monitored. The size of the monitoring system is another important aspect to the design. The degree to which a monitoring system is effective is proportional to its ability to pick up signals. Large channel systems, therefore are the most effective as they can record more signals a relatively higher number of signals due to the decrease in distance between potential event locations and sensors (Ge, 2005). Initial and regular calibrations should be conducted on the sensor array to ensure the most accurate data. As mining environments are very dynamic and potentially harsh on monitoring equipment, regular equipment and signal checks should be performed to allow for uninterrupted data collection.

### 2.1.3 Event location and processing

These microseismic events are detected in the form of an energy wave that travels from the point of origin outward through surrounding rock (ESG, 2016). The waves travel by elastic deformation of the rock medium, creating compressive and shear stresses. The types of waves that are monitored are called body waves. There are two types of body waves: P-waves, or primary waves, and S-waves, secondary waves. P-waves are fast traveling seismic waves, and move through a medium in the longitudinal direction by compression, pushing and pulling the material. S-waves are much slower and move through material causing vibrations perpendicular to the direction of the wave propagation, as opposed to parallel with P-waves. P-waves can move through solids and fluid, while S-waves can only travel through solids. Because P-waves travel faster, the greater the distance between the arrivals of the two waves, the greater the distance between the sensor and location of the microseismic event (ESG, 2016).

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