ARTICLE IN PRESS

International Journal of Mining Science and Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Evaluation of seismic potential in a longwall mine with massive sandstone roof under deep overburden

Mark A. Van Dyke [a,*], Wen H. Su [a], Joe Wickline [b]

[a] Ground Control Branch, NIOSH, Pittsburgh, 15236 PA, USA
[b] Coronado Coal LLC, Beckley, WV, USA

ARTICLE INFO

Article history:
Received 10 June 2017
Received in revised form 2 August 2017
Accepted 29 October 2017
Available online xxxx

Keywords:
Seismic
Mapping
Deep overburden
Massive sandstone

ABSTRACT

A recent seismic event was recorded by a deep longwall mine in Virginia at 3.7 ML on the local magnitude scale and 3.4 MMS by the United States Geological Survey (USGS) in 2016. Further investigations by the National Institute for Occupational Safety and Health (NIOSH) and Coronado Coal researchers have shown that this event was associated with geological features that have also been associated with other, similar seismic events in Virginia. Detailed mapping and geological exploration in the mining area has made it possible to forecast possible locations for future seismic activity. In order to use the geology as a forecaster of mining-induced seismic events and their energy potential, two primary components are needed. The first component is a long history of recorded seismic events with accurately plotted locations. The second component is a high density of geologic data within the mining area. In this case, 181 events of 1.0 M_L or greater were recorded by the mine's seismic network between January, 2009, and October, 2016. Within the mining area, 897 geophysical logs, 224 core holes, and 1031 fiberscope holes were examined by mine geologists. From this information, it was found that overburden thickness, sandstone thickness, and sandstone quality contributed greatly to seismic locations. After the data was analyzed, a pattern became apparent indicating that the majority of seismic events occurred under specific conditions. Three forecast maps were created based on geology of previous seismic locations. The forecast maps have shown an accuracy of within 74–89% when compared to the recorded 181 events that were 1.0 M_L or greater when considering three major geological criteria of overburden thickness of 579.12 m or greater, 6.096–12.192 m of sandstone within 15.24 m of the Pocahontas number 3 seam, and a longwall caving height of 4.572 m or less.

1. Introduction

In the United States, the tracking of mining-related seismic events has been growing significantly in recent years, especially after the Crandall Canyon Mine collapse in 2007 that resulted in 9 fatalities. This event and other similar mine events have led to a substantial increase in funding by government agencies and mining companies in an effort to better understand the science behind these large seismic events. There is no doubt that seismic events have the potential to be hazardous to both mine worker safety and mine production. Unfortunately, in most cases, not enough information is known to establish a link between the seismic locations and the geological and mining parameters that drive them.

This paper describes a collaborative study by the National Institute for Occupational Safety and Health (PMRD) and Coronado Coal researchers into the history, challenges, and mapping of 181 seismic events that were 1.0 M_L or greater and were caused by massive sandstone beds in close proximity to the Pocahontas No. 3 coal seam at a deep longwall mine in southwestern Virginia. Mining-induced seismicity has a long history in coal mining and has been tracked since the 1920s in Europe [1]. Although many subsequent research efforts have been performed in various types of mining, much is not understood about mining-induced seismicity in U.S. coal mines.

Recently, large seismic events occurring in conjunction with mining activity are coming back into the public spotlight; some of these events have been large enough to have been felt on the surface in surrounding residential areas, causing concern. Generally, these events are large magnitude events of greater than 3.0 M_L. This was the case in July 2016 when a mining-induced event occurred at the longwall operation in southwestern Virginia. This event was measured at 3.7 M_L on the local magnitude scale by the seismic network at the mine and at 3.4 M_L on the moment

---

* Corresponding author.
E-mail address: mso2@cdc.gov (M.A. Van Dyke).

https://doi.org/10.1016/j.ijmst.2017.12.014
2095-2686/© 2017 Published by Elsevier B.V. on behalf of China University of Mining & Technology.

Please cite this article in press as: Van Dyke MA et al. Evaluation of seismic potential in a longwall mine with massive sandstone roof under deep overburden. Int J Min Sci Technol (2017), https://doi.org/10.1016/j.ijmst.2017.12.014

magnitude scale by the United States Geological Survey (USGS). A few local residents felt the vibrations resulting from the event and reported it to local news stations and the USGS. Upon reviewing the lithology in the vicinity of this event and the other 180 events that were 1.0 M_L or greater that have occurred since 2009, the key similarities among these events became apparent.

2. Previous studies

A previous study conducted at the same mine in Virginia theorized that the geology and seismic activity are linked [2]. Another study mentioned that near-seam massive sandstones and overburden over 609.6 m could have been the major contributor to a large seismic event that occurred in February 2005 [3].

Two studies were carried out in 1989 and 2011 to investigate the seismicity induced by longwall mining at the same mine area in Virginia. Bollinger examined seismic activity with one geophone, so he was not able to triangulate the location of the source [2]. However, the researcher notes that seismic activity increased by a factor of seven when the longwall was in operation, and rock bursts and cavings of the strong sandstone beds in the immediate roof were the cause of seismic activity during longwall shutdowns. Warren used the mine seismic network to locate and study events based on the longwall location [4]. A significant observation noted by the researcher is that there are two distinct types of events that occurred during the longwall mining process. The first type is small gob-forming events at the longwall face that usually register in the negative range of the local magnitude scale. The second type is seismic events that occur in the roof strata overlaying the gob of the adjacent panel from the longwall face. These events are the largest type of seismic events encountered at the mine and have been recorded as large as a 4.3 M_L, which have caused injury to personnel and significant damage to mining operations.

3. Geographic and lithologic information

The longwall mine is located in Buchanan County, Virginia, and operates in the Pocahontas No. 3 seam within the Lower Pennsylvanian Series of the Pocahontas formation. The Pocahontas formation is approximately 213.36–274.32 m thick in the study area and consists of sandstone, sandy shales, shales, clysa, and coal. These rock intervals occur in what are known as cyclothems, which are sequences of cyclic depositional environments based on sea level [5].

The mine is in the Appalachian Plateau physiographic province; however, the faulted and folded Valley and Ridge province is in close proximity to the mining area to the south [5]. The mine is within the Virginia overthrust area, and the major fault within the mining area is the Keen Mountain fault, which is a strike-slip fault with compressional overthrusting [6]. The fault has caused a few mining difficulties in the past, and future mining should not be directly affected by the Keen Mountain fault. However, the fault has caused additional minor thrust faulting within the coal seam, and this condition has created thinning and thickening sequences of the seam, which negatively impacts local roof control. The coal seam averages approximately 1.8 m in thickness but can range anywhere between less than 0.6 m and greater than 3.048 m, depending on local geologic conditions.

The roof geology consists of various sequences of silty to sandy shales, sandstones, and coal. Shales usually make up the immediate roof followed by sandstone and then the Pocahontas No. 4 coal seam, which is on average 15.24 m above the top of the Pocahontas No. 3 seam. The immediate roof shales can range from 0 to 3 m of thickness; however, on rare occasions the thickness can exceed 6 m. The sandstones above the immediate roof shale are unnamed but have been referred to as Sandstone 1 (the first encountered sandstone above the Pocahontas No. 3 seam) and Sandstone 2 (the second sandstone unit encountered after small shale lenses above Sandstone 1 [5]. In limited areas, sandstone 1 is not present and is replaced by a larger interval of silty shale. The shale lens between Sandstone 1 and 2 that typically ranges 0.3–1.5 m can be absent, resulting in the two sandstones acting as one massive unit (Fig. 1).

The sandstone units are typically medium to massively bedded, and fine to medium grained with few micaceous streaks, sparse coal debris, shale streaks, and iron nodules (Fig. 2). Where these sandstones become massive, potential longwall caving issues may be present [5]. Axial and diametral compressive strengths of the sandstone averaged 174.76 and 132.05 MPa, respectively, and the maximum strength was 241.31 MPa for axial tests and 218.56 MPa for diametral tests.

4. Seismic activity

The combination of deep overburden in excess of 579.12 m and massive sandstone lithology creates conditions conducive to mining-induced seismic events. Seismic events of 3.4, 4.3, and 3.4 occurred in 2005, 2006, and 2007, respectively, which caused a fire propagated by a reversal of ventilation due to damaged stoppings. This prompted the mine to install a surface seismic monitoring network, consisting of seven stations, in January 2009. These stations are in a radial pattern around the active panels to provide

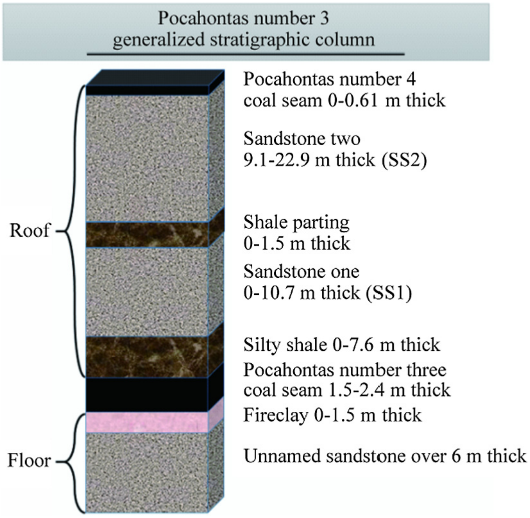

Fig. 1. Generalized stratigraphic column.

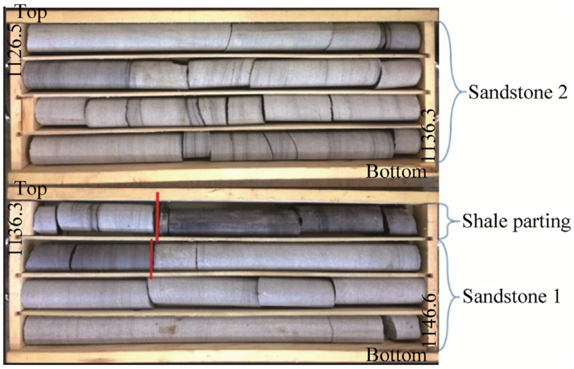

Fig. 2. Core from Sandstone 1, shale parting, and sandstone.

Please cite this article in press as: Van Dyke MA et al. Evaluation of seismic potential in a longwall mine with massive sandstone roof under deep overburden. Int J Min Sci Technol (2017), https://doi.org/10.1016/j.ijmst.2017.12.014