Dealing with the tremors of Earth's interior

Seismic events pose a serious threat to all aspects of mining and, most of all, to human lives. The shakes and rattles, whether natural or induced, of earthquakes and minor rock movements can only be endured by combining technology and know-how in the right way.

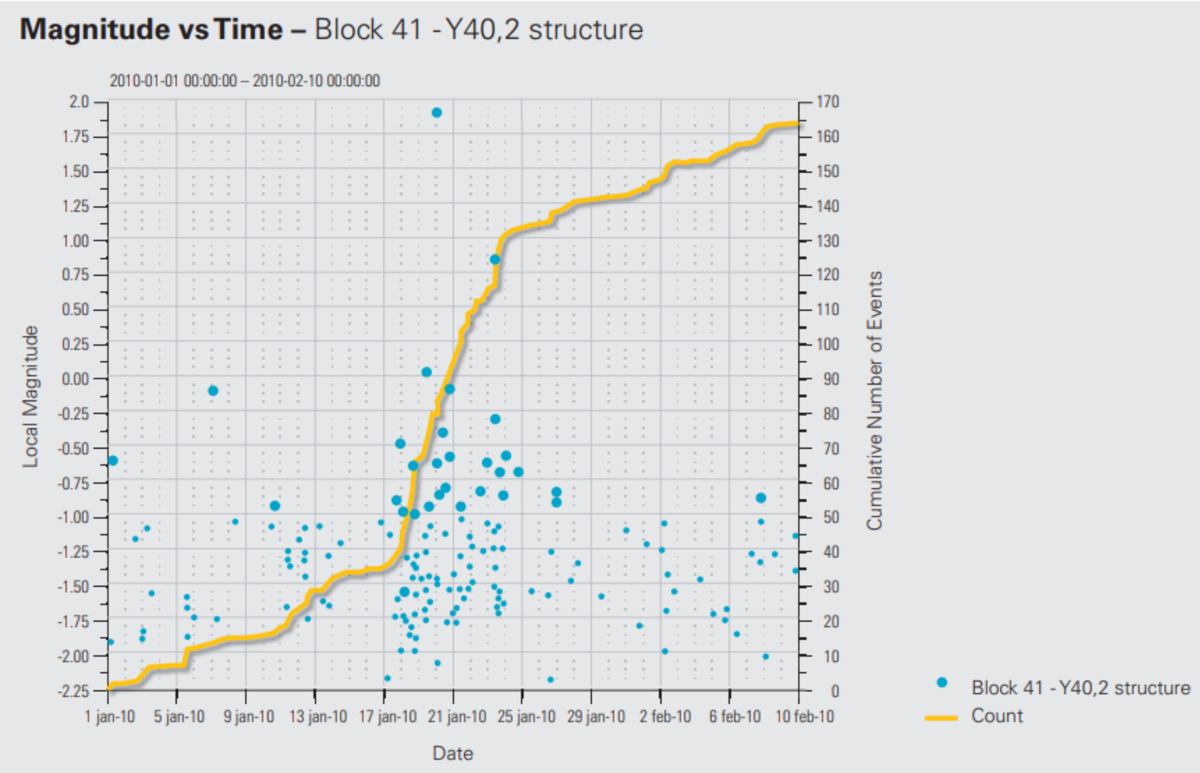

Figure 1: Microseismic monitoring is crucial for mines that are sensitive to underground activities. The blue dots indicate seismic events and rock bursts, from small to large.

For obvious reasons of safety and stability, it would be a fair assumption that areas prone to earthquakes and high seismic activity are far from attractive in the eyes of mining professionals. But that doesn't mean that miners are strangers to dealing with seismicity – on the contrary.

Although geological fault lines may be indicators of where mineralization has taken place, mines are rarely located in high-risk zones for earthquakes, yet they experience seismicity on a frequent basis. The reason for this is that seismicity not only occurs from the familiar shift of tectonic plates.

Induced seismicity is the term given to human-related activities that, in rare cases, trigger earthquakes and, more often, local tremors. Underground mining is a common cause, but there are others too. Coal mining and oil drilling have been known to induce seismic events, as have operations that involve injecting or retracting groundwater, water pumping to keep mines from flooding, as well as large scale water storage in dam construction. Seismicity manifests itself on a widely varying scale of intensity and is one of the most important and hazardous challenges in the years ahead for miners, despite their continuously improving techniques for monitoring seismic events and averting the risk of rock bursts and big rock fall.

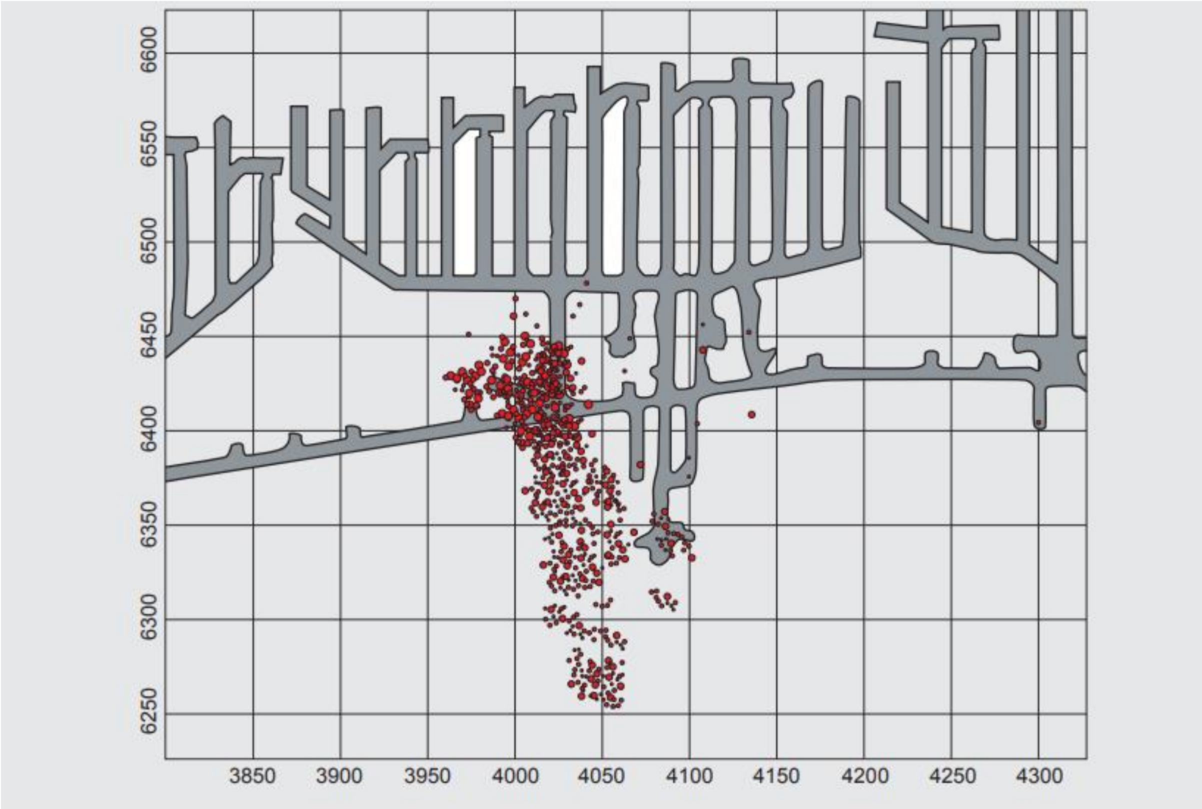

Figure 2: By measuring the magnitude and arrival time of seismic events using geophones, their location can be calculated which, in turn, enables pinpointing of seismicity-prone structures.

Mining induced seismicity

Many mines, large or small, experience some degree of seismicity, and in most cases, it is caused by the human factor, the changing of stress fields, rather than the natural shifting of tectonic plates.

As explained in the previous chapter, the impact of seismicity on mining becomes greater the deeper operations go, typically at 800–1 000 m or more, and miners will increasingly have to learn to mitigate the threat of Earth's violent tremors. In the worst-case scenario, seismicity can result in wall convergence, rock bursts and rock fall, potentially resulting in injuries or even fatalities and a devastated mine infrastructure.

Most of the rock movement in mines occurs on a minor scale, but not necessarily without serious repercussions. In Australia in 1989, more than 200 years of coal mining triggered the most damaging earthquake in the country's history. In this case, it is claimed that the removal of millions of tonnes of rock is what ultimately reactivated a fault. But hazardous incidents can also occur on a smaller scale, and the process of sequencing (how the mine is mined) is known to be a large contributor to seismicity as stress accumulates to high levels in pillars.

At the same time, it is important to remember that there will be a redistribution of rock stresses in all forms of underground mining, and preparation is the only remedy. It is not, however, always possible to avoid all problems along the way, but with seismic systems, miners can locate seismicity-prone structures and plan the sequencing and rock reinforcement in a way that makes the operation safe.

Impact of seismic events

When it comes to earthquakes, the release of energy in the Earth's crust creates seismic waves that travel through the layers of rock. The two main types of seismic waves, measured using seismometers, are known as body waves and surface waves, of which the latter type has the largest amplitude and most destructive power for man-made structures.

When seismicity is triggered by mining, however, there are two subtypes of body waves known as P and S waves that cause the majority of problems and must, therefore, be carefully monitored.

How seismicity will impact mining operations is calculated by measuring the magnitude of the seismic waves. A key challenge is to predict and identify the exact location of rock movements in or near the mine using geophones and other instruments. With a known location of the geophones and a known velocity of the seismic wave in the rock, the magnitude and risk areas can be identified, as shown in Figure 2.

This is often done using triaxial geophones of 14Hz or lower, which capture micro-seismic data in three dimensions. The lower the frequency, the larger the event and the greater is the risk for collapse of drifts. By identifying dangerous rock structures along which seismicity occurs and by looking at the sequencing, mining-induced seismicity can be controlled to a degree. If any human cause of seismicity is to be preferred, it is blasting as it usually involves no personnel in the mining area. Experience shows that the largest events that occur are often related to rock structures and not necessarily triggered by blasting.

Rock bursts and rock fall

The natural stress fields of rock mass can build up to dangerous levels leading to fractures in the rock wall and eventually, if the pressure accumulates in concentrated areas, to a release of pressure that can be experienced as an explosion of small rocks.

There are, as we have learned, two types of seismicity: rock bursts, which occur due to increased pressure at the face or in the drift, and shock waves, which occur as a result of a seismic event some distance away that causes rock fall if the area is not sufficiently reinforced. Rock bursts are a frequent danger in mines that are either deep or located in seismic risk zones.

In order to cope with the energy released by rock bursts, ductile rock reinforcement is often a must, involving ductile rock bolts, shotcrete and meshing. This is of particular importance if the mine is subjected to bigger seismic events.

Using comprehensive risk analysis, advanced monitoring and rock reinforcement, mines that are prone to seismicity can maintain safe operations provided they have contingency plans and are able to evacuate personnel on short notice. The length of the evacuation period can vary. Sometimes there will be a large seismic event, and at other times nothing occurs at all. It is also essential to employ rock-reinforcement systems that are specially designed to meet the unique challenges of each individual mine and its measured seismicity.

Monitoring systems

A comprehensive monitoring system to detect and process data from seismic events is recommended in all mines that are deeper than 800 m, depending on local conditions.

In principle, keeping a track on seismic activity underground is quite similar to earthquake monitoring on the surface. The difference is that miners put continuous efforts into identifying high-risk areas. In mines that are prone to mining-induced seismicity, there are normally routines for how to evacuate a work site in an orderly fashion as monitoring data will have provided enough time for a planned withdrawal of personnel and equipment from underground workings.

Small rock movement is common in all mines and will generate sounds that are sometimes referred to as “talking rock,” but if any greater event triggers the warning systems, miners will immediately want to know, firstly, if all teams have been evacuated safely, and secondly, if installations, predrilled holes for blasting and other aspects of the operation are still intact. The back-end function of seismic systems is to gather data about the seismic event that has just occurred, answering questions such as where it originated and what damage it may have caused.

Modern seismic systems will assist on all these levels provided that enough instruments have been installed to cover the mine’s extended environment. Micro-seismic systems will collect data for the smallest of rock movements and monitor any events, large or small, that may influence mining operations.

This enables micro-seismic mapping using 3D models that indicate where, when and how large, a seismic event has been. Micro-seismic mapping gives, together with geomechanical modelling, a better chance to see where the seismic-prone areas are and where to expect stress increases based on layout, mining sequences and measured seismicity.

Proactive measures

In addition to relying on technology in the form of monitoring and recording systems, mines need to adopt a proactive approach when it comes to reporting procedures and how seismic events are evaluated.

It is of the utmost importance that all relevant data quickly reaches the most qualified staff at every level, from rock mechanical specialists to mine managers, so that evacuation can take place effectively and any necessary restructuring of rock reinforcement is conducted with the most reliable results.

Impact of seismicity on mining

Approx. Richter Magnitude	Qualitative Description
-3.0	Small bangs or bumps heard nearby. Typically these events are only heard relatively close to the source of the event. This level of seismic noise is normal following development blasts in stressed ground. Events are audible but the vibration is likely too small to be felt. Not detectable by most micro-seismic monitoring systems.
-2.0	Significant ground shaking Felt as good thumps or rumbles. May be felt remotely from the source of the event (more than 100 meters away). Often detectable by a micro-seismic monitoring system.
-1.0	Often felt by many workers throughout the mine. Should be detectable by a seismic monitoring system. Major ground-shaking felt close to the event. Similar vibration to a distant underground secondary blast.
0.0	Vibration felt and heard throughout the mine Bump may be felt on surface (hundreds of meters away), but may not be audible on surface. Vibration felt on surface similar to those generated by a development round.
1.0	Felt and heard very clearly on surface Vibrations felt on surface similar to a major production blast. Events may be detected by regional seismological sensors located hundreds of kilometers away.
2.0	Vibration felt on surface is greater than large production blasts. Geological survey can usually detect events of this size.-
3.0	Event is detected by earthquake monitors throughout Australia.
4.0	Largest mining-related seismic event ever recorded in Australia.

Source: Hudyma, M.R. (2008) Analysis and Interpretation of Clusters of Seismic Events in Mines. PhD Thesis, The University of Western Australia, Perth.