Qualification of the microseismic monitoring technique applied to the risk of collapse in iron ore mines

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ABSTRACT: Experiments carried out in a working iron mine validated the microseismic monitoring technique as a means of detecting fracture noise emissions regarded as signals indicating an incipient collapse. In the experiment surface recordings were made of the microseismic signals corresponding to fractures and local collapse phenomena generated at the mine bottom by deliberately destroying pillars. The pillar removal operations and the collapse of the roof were systematically correlated with a series of microseismic events. The experiment served to validate the microseismic monitoring technique as a means of detecting surface precursors of a collapse, to demonstrate the effectiveness of the technique, and to calibrate the principal parameters of a microseismic monitoring system adapted to detection and monitoring in areas where there is a risk of collapse.

Key words: Microseismic monitoring, collapse, torpedoing, robbing of pillars.

ZUSAMMENFASSUNG : Dieser Bericht beschreibt die Validation, durch einen in einem aktieven Eisenerzbergwerk durchgeführten Feldtest, der Mikroseismik zum Abhöhren von Brüchen im Gebirge welche anzeichen für einen bevorstehenden Tagesbruch im Kammer-Pfeiler-Bergbau sein können. Der Feldtest bestand darin, an der Tagesoberfläche, mikroseismische Signale aufzunehmen, welche durch das nach der gewollten Sprengung bestimmter Pfeiler nachbrechende Hangende provoziert wurden. Die über Tage aufgenommenen Signale konnten mit den unter Tage gesprengten Pfeilern und dem nachbrechenden Hangenden sowie den darauf folgenden Brüchen im Deckgebirge koreliert werden. Dieser Feldtest hat somit bewiesen dass sich die Mikroseismik zur Überwachung von alten, nicht mehr befahrbaren, Kammer-Pfeiler Bauten eignet und dass sie dort in der Lage ist Tagesbrüche vorherzusagen.

1. Introduction

The iron ore basin in Lorraine extends between the cities of Luxembourg in the north and Nancy (France) in the south. The iron ore deposit is sedimentary Aalenian and an insertion in the geological series between the Lias and the Jurassic (Tincelin, 1958). This deposit is virtually horizontal with a regular average slope of 3% and a mean thickness of 30 metres (figure 1). The sterile rocks lying above the iron-bearing formation known as "dead ground" have an average thickness of 150 metres. In the deepest mines in the basin iron ore has been recovered some 250 metres below ground level.

Over the greater part of the deposit, recovery involved removing the roof supports and collapsing the residual pillars. However beneath sensitive zones (where there were houses and surface infrastructure) partial recovery methods were used : abandoned chambers and pillars, with islands separated by longwalls. In these areas of partial recovery, collapse phenomena have occurred several times, usually owing to the failure of abandoned pillars (Piguet et al, 1999, Vinkler et al, 1998).

The microseismic monitoring technique is used today in a number of different situations: to study seismic phenomena induced by activities in working mines (Senfaute et al, 1994, 1997 and 1999), the injection of fluids, geothermal phenomena (Moriya H., Niitsuma H., 1996), the recovery of gas and oil, and the surveillance of underground storage facilities or sensitive installations. As regards abandoned iron mines exposed to the risk of sudden and unexpected collapse affecting the surface, there has hitherto been no means of predicting or detecting these phenomena.

For this reason we undertook a research program with the objective of validating the microseismic monitoring technique to detect the noise emitted during the fracturing that constituted the first signs of incipient collapse (failure of pillars in the mine, then of the surrounding roof, and finally of the overburden). The technique was validated by means of an experiment carried out in the last working iron mine with the support of ARBED's mine. The experiment involved surface recordings of the signals corresponding to the fracturing and local collapses generated deliberately at mine bottom by destroying (torpedoing) pillars.

2. Description of the mine and the microseismic monitoring system

The usual method of mining iron in Lorraine was to separate the deposit into panels which in turn were divided into pillars, i.e., into parallelepiped blocks of the order of 10 metres in size. In cases of total recovery, the dimensions of these pillars were gradually reduced and they were then removed with explosives. This operation known as "robbing pillars" led to the collapse of the roof of the strata known as "caving".

Whenever it was considered necessary to protect the infrastructure on the surface (towns, roads, railways, etc.) the methods was then either to leave the pillars in place (the so-called "abandoned pillars" method) or to limit the dimensions of the panels (the method known as "islands"). In the latter case, the collapse height of the roof is less the smaller the size of the panel. In the Arbed mines, experience shows that the collapse cone reaches a height of about 6 metres above an island 25 metres in length.

The geometry of the mining unit monitored by the microseismic technique is shown on figure 2. In this unit, the width of the islands is 40 metres, the strips between the islands are 30 metres wide and the mining height is 4 metres. The microseismic monitoring station was installed at the surface, in a borehole 30 metres in depth and about 300 metres from the mining operations. The microseismic station is a three-directional unit consisting of sensors of the accelerometer type with a pass band of 2 to 2300 Hz and a sensitivity of 500 mV/g. The signals are fed to a local computer with a sampling frequency of 10 kHz (figure 3).

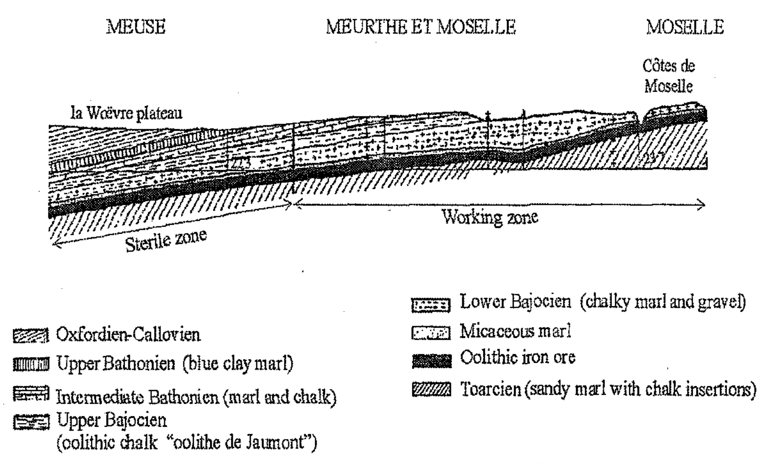

Figure 1: Simplified geological section of the Lorraine iron ore basin

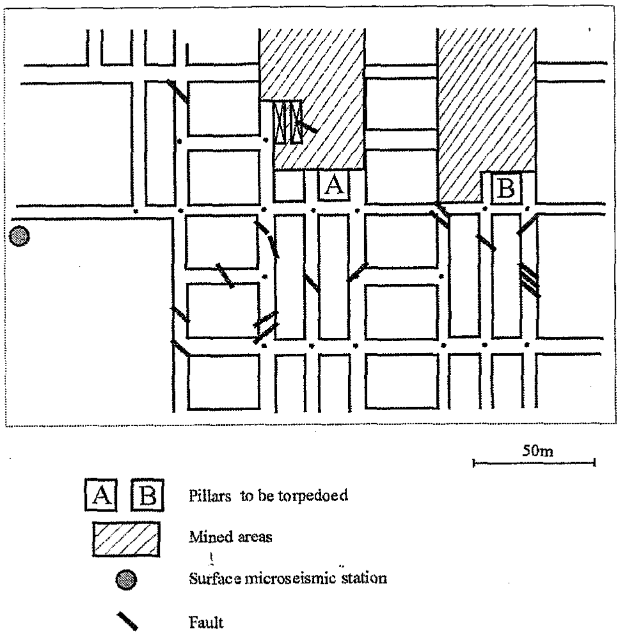

Figure 2: Plan view of the mine workings and location of the microseismic monitoring station at the surface

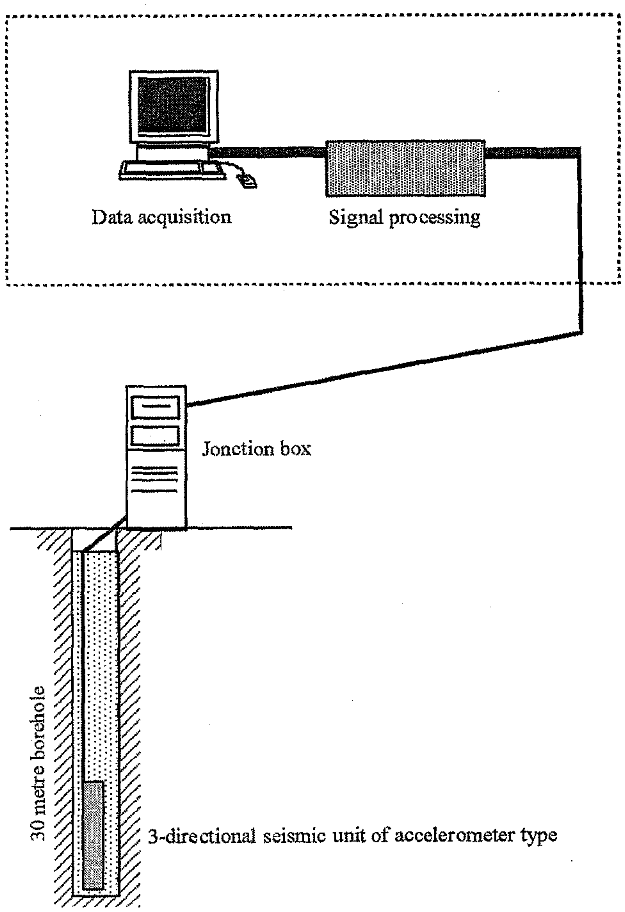

Figure 3: Microseismic measuring system

3. Microseismic events recorded

The microseismic station on the surface was left switched on for 34 days during the operations of removing roof supports and the torpedoing of pillars at mine bottom. During this period 260 microseismic events were recorded. These were classified into three types:

- Class 1: Events associated with blasting.
- Class 2: Events associated with fractures in the caving of the immediate roof.
- Class 3: Events associated with fractures away from the roof caving.

The events in class 1 were identified by the time at which blasting took place. The events in class 2 were identified by the time at which the localised slip or collapse occurred, following the torpedoing of the pillars. Experience showed that collapse might be immediate or take place a few hours or a few days after the shot was fired. The third class of events were relatively isolated incidents. They occurred at times other than those at which blasting took place to remove roof supports or for plotting purposes as well as roof collapse. Table 1 below shows all the recordings made throughout the period of microseismic monitoring.

Class 1 Events associated with blasting	*Class 2 Seismic events: fractures in caving*	*Class 3 Seismic events fractures away from caving*
26	66	168

Table 1: Total microseismic events recorded during the monitoring period

3.1 *Microseismic events associated with blasting*

All the blasting done during mining operations located 300 metres from the seismic station was systematically recorded by the seismic monitoring system. The signals recorded were of very high amplitude, leading to signal saturation. The signal frequency is about 200 Hz with peaks of up to 500 Hz.

Other blasts located about 600 metres from the monitoring station were also recorded. The maximum frequency of these events is lower (under 100 Hz) than the frequency of the events recorded during blasts located at 300 metres from the monitoring station. Finally, blasts some 900 metres from the monitoring station were not detected by the system. Figure 4 shows examples of seismic signals and of the frequency spectrum of the events recorded.

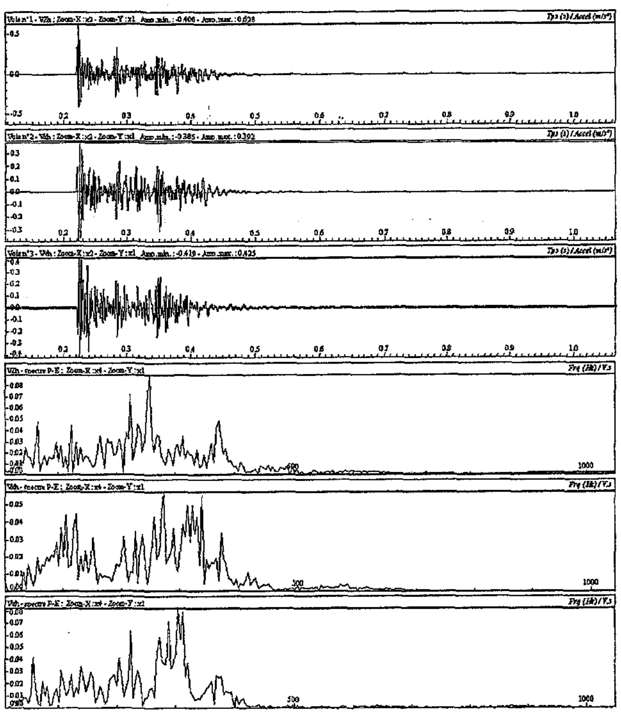

Figure 4: Examples of seismic signals and frequency spectra recorded during blasting operations some 300 metres from the seismic monitoring station on the surface.

3.2 Microseismic events associated with fractures in the caving

The collapse of the roof following the torpedoing of pillars A and B (see figure 3) generated 66 microseismic events. These events were characterised by their arrival in bursts, i.e., a number of events recorded in a short period of time. The signature of the signals and the spectral content of these events are appreciably different from those associated with blasting. They are very short events with maximum frequency peaks between 400 and 500 Hz (figure 5).

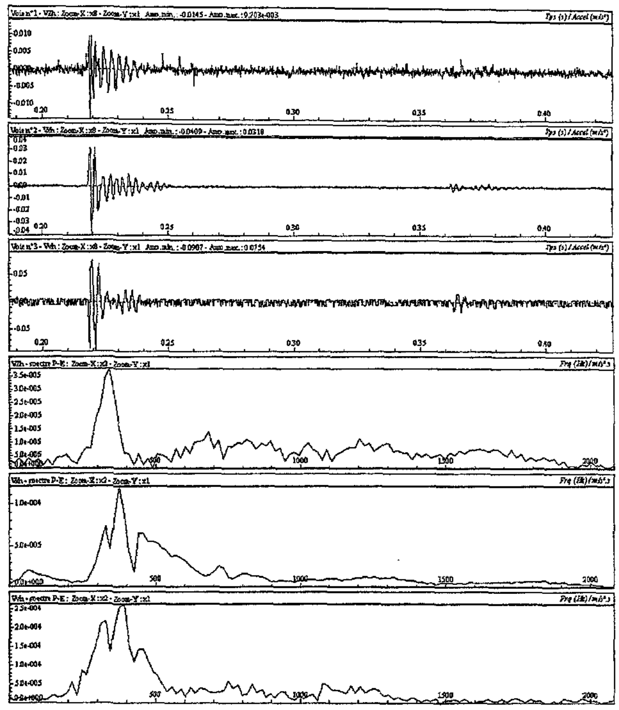

Figure 5: Examples of seismic signals recorded during the collapse of the roof. The difference with the signature of the seismic events associated with blasting can be clearly seen (see figure 4)

Collapse following the torpedoing of pillar A

The area left unsupported by the torpedoing of pillar A is about 500 m². If the height of the collapse cones is assumed to be of the order of 6 metres, the volume of collapsed material is estimated at about 2800 m³. A series of microseismic events was recorded in the minute following the final blast, corresponding to the removal of the pillar. Observations made at mine bottom confirmed the immediate collapse following the torpedo shot making it possible to correlate the microseismic events recorded with the rockbursts generated by the advent of collapse.

Collapse following the torpedoing of pillar B

The area left unsupported by the torpedoing of pillar B is of the order of 625 m², the configuration of this pillar being different from that of pillar A. Pillar B is about 6 metres from a pillar already torpedoed. This configuration means that the dimensions of the collapse cone of this pillar are greater than those associated with pillar A. This new collapse cone added to the collapse cone of the neighbouring pillar. The volume of the collapse cone during torpedoing of pillar B was estimated directly on the spot at about 3000 m^3.

At the moment when pillar B was torpedoed, no microseismic event (apart from the blasts) was recorded. Observations at mine bottom confirmed that there was no collapse after the blasts torpedoing the pillar. Further shots were fired 24 hours later, without immediate collapse. A burst of events was recorded 7 hours after these torpedo shots (20 microseismic events in 40 minutes). Verification at mine bottom showed that these events were concomitant with part of the roof collapse. However observations showed that the collapse was not complete. A further burst of events, greater than the previous one (40 events in an hour) was recorded 16 hours after this first collapse. Checks at mine bottom showed that these events were associated with the occurrence of a second collapse. Following this second burst of events, no other events were recorded and the collapse ceased spreading.

3.3 Microseismic events associated with fractures away from the roof collapse

These events were characterised in that they were all recorded at times other than those of the blasting and roof collapses. These events did not occur in bursts, but were isolated in time and could arrive at any time, including during the night. The signature and spectral content are similar to the events associated with collapses. These events were interpreted as being subsequent adjustments in the rock in the vicinity of the mined zone (failures of the roof or pillars).

3.4 Sensitivity of the monitoring system to the seismic events recorded

In view of the frequency range of the events occurring at mine bottom and that of the sensors installed to record them, it appeared that no blasting event taking place at more than 900 metres away was detected by the experimental monitoring station. However every blast taking place at a distance within 600 metres was detected by the seismic station.

Also, fractures occurring in the mined strata at a distance of about 300 metres from the seismic monitoring station tripped the system and recorded interpretable seismic signals. For this reason the sensitivity radius of the system was fixed at 400 metres as a first approximation.

4. Conclusions

The operations to remove roof supports at mine bottom and in particular the fracturing as the roof collapsed were unambiguously correlated with a characteristic series of microseismic events recorded by a 3-directional seismic station on the surface. The microseismic events associated with fractures in the roof collapse are very short events with maximum frequency peaks between 400 and 500 Hz. Other events, producing signals similar to those of the collapse of the roof but more isolated in time were interpreted as later adjustments within the rock.

The experiment made it possible to validate the microseismic monitoring technique as a way of detecting precursor signs of the collapse process before the phenomenon produces surface effects, to demonstrate the effectiveness of the technique and to calibrate the principal parameters of a microseismic monitoring system adapted to the detection and surveillance of zones exposed to the risk of collapse in the Lorraine iron ore basin.

The system was applied for the first time at the towns of Joeuf and Homecourt. The subsoil of these towns is entirely undermined by mine workings that are now abandoned. A continuous microseismic monitoring system was installed on this site and on the basis of the results from these preliminary qualification tests, a warning procedure has been set up.

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