Cave Ins Linked to Mine Flooding

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ABSTRACT

During the past years, and due to the close down of numerous mines, unexpected stability problems have been experienced on different mines in France. These accidents have occurred on mines which had been exploited using room and pillar type methods, but also on other mines hydraulically backfilled with fine unconsolidated materials.

As the stability of these mines had been proved adequate over several years of exploitation, the cave ins are, without doubt, linked to the close down, and more precisely with the subsequent flooding of the underground workings.

Water can have various effects on old mines. Among these can be cited:

- decrease of the mechanical characteristics of the rocks and their joints. Usually, such a decrease is of small importance, as the mine atmosphere is never dry. Consequently, only areas which had been mined out at the limit of their stability are susceptible to cave in during flooding;
- strong decrease of the mechanical characteristics of rocks which are liable to water deterioration. Rocks of this type are often close to iron ore. They can start creeping and lose their ability to support the stress due to the overburden weight applied through the mine pillars;
- transport of fine and unconsolidated backfill materials, which results in emptying of the stopes which subsequently lose their stability (as the backfilling has generally been done because open stopes were not stable);
- finally, water can also have a positive effect on the mine stability, as the weight of the overburden and consequently the stress applied to the mine infrastructure is diminished according to Archimedes' principle.

Several examples are described to illustrate the previous effects of water on mine stability.

INTRODUCTION

For many years, the economy of mineral raw materials has been far from prosperous. As a result, the mining firms, especially European, have been more involved in mine close downs rather than in the implementation of new mining projects. Unknown or at least unexpected problems have been associated with these recent close downs.

At the mine close down, the water extraction system is stopped, and as a consequence, the underground workings are progressively flooded (except rare dry mines). This often leads to several types of difficulties:

- pollution of the water which percolates through the old workings, and as a result pollution of shallow aquifers that can be occasionally used for human consumption, or appearance of polluted springs (outlets of the mine);
- stability accidents due to the influence of water on the mined out rocks or on the rocks located close to the abandoned mining stopes, or on fine unconsolidated backfill materials.

Our concern here is the stability problems linked to water. Despite the fact that this topic has been less frequently discussed than chemical pollution problems, it is of high importance since the safety of people is involved.

After a presentation of the theoretical aspects (effect of water on rocks and on backfill materials), several accidents linked to the flooding of mines are described and analysed.

PART I ; INFLUENCE OF WATER ON A ROCK MASS OR ON FINE UNCONSOLIDATED BACKFILL MATERIALS

Historically, it seems that stability accidents linked to mine flooding have been mainly experienced on two types of mines:

- room and pillar mines : in this case the stability is provided by the ore which has been left in the pillars. When an area mined out using room and pillar methods has been stable during several decades and cave ins occur during water ingress, one cannot deny the link between water ingress and the cave in, in other words between water ingress and decrease in pillar stability;
- mining operations using fine and unconsolidated backfill materials : in these cases the stability is provided by backfill when they are excavated. Theoretically, as there is finally no underground opening, no cave in can occur. Therefore, when a cave in does occur, it suggests that an underground stope has been at least partially emptied of its backfill. Which other agent than water could have done such a job ?

I Effect of water on a rock mass

In an area mined out using room and pillar methods, water can have an influence on the ore itself or on the hanging wall or on the foot wall, or finally on the joints existing in the rock mass.

I.1. Influence of water on mechanical characteristics of some rocks

The analysis of the rock mechanical characteristics shows that they can vary according to the rate of moisture content of the rocks. P.S.B. COLBACK and B.L. WILD [1] demonstrated on several rock types that the compressive strength measured on dry samples (dried at 105 °C) is on average 25% higher than the same measure done on a water saturated sample. In addition, they indicate that the decrease in compressive strength varies approximately linearly with the moisture content. As a result, they recommend a reduction in the compressive strength measured on dry samples by 20% if there is any risk that the rocks will be saturated in the future (flooding of the mine for instance).

The results indicated in Table 1, obtained in the laboratory of the Centre de Géotechnique et d'Exploitation du Sous-sol (CGES), show that differences can sometimes be greater than 25%. The values indicated for saturated rocks have been obtained on samples which have been immersed for 72 hours. The samples are usually cylindrical, with a height of 130 mm and a diameter of 65 mm, with the exception of the iron ore samples of the St Pierremont mine, which were 76 mm high and 38 mm in diameter.

Table 1

ROCK	Dry results	Results at saturation	Decrease due to saturation	Porosity
Soft limestone from the Vierzy SNCF tunnel	R_c = 5 MPa	R_c = 3 MPa	40 %	25.5 %
Hard limestone from the immediate roof of the Droitaumont iron mine	R_c = 45.7 MPa R_L = 25.1 MPa	R_c = 27.9 MPa R_L = 18.5 MPa	39 % 26 %	14 %
Iron ore from the red layer of the St-Pierremont mine :				
Pure ore	R_c = 49.6 MPa	R_c = 36.0 MPa	28 %	23 %
Ore with calcareous nodules	R_L = 58.6 MPa	R_L = 39.5 MPa	33 %	11.3 %

R_c : compressive strength
R_L : longitudinal elastic strength

All these results show an indisputable moisture effect. However, note should be taken of the fact that the mine atmosphere is never perfectly dry. It would be unreasonable to consider a 20% compressive strength decrease to explain the cave in of an area which had been stable over a long time. The French iron ore for instance was usually delivered to the concentration plant with a moisture content of 11%. According to P.S.B. COLBACK and B.L. WILD, a 10% compressive strength decrease should be applied in this case when flooding of the mines occurs.

But other phenomena can also interfere, mainly with rocks which are liable to water deterioration (like clay or marls). This type of rocks is commonly found close to iron ore for instance.

The examples given in Table 2 illustrate this point (this data comes from tests done in the CGES laboratory). The compressive strength noted as normal, is the one obtained on a relatively wet sample, since it is obtained by drilling with water and transported from the mine inside a waterproof seal. At the surface these were left drying in the normal atmosphere for 48 hours. The compressive strength noted as altered is the one obtained on a block which has been blasted 18 months ago and has since been left in the humid mine atmosphere.

Table 2

ROCK	Normal characteristics	Altered characteristics	Decrease
Marls from the Rochonvillers iron mine	R_c = 35.0 MPa R_L = 18.3 MPa	R_c = 17.8 MPa R_L = 10.3 MPa	49 % 44 %
Consolidated clay from the foot wall of the uranium-bearing layer of the COMINAK mine in Niger	R_c = 65.0 MPa	R_c = 20.0 MPa	69 %

When the mining conditions are such that a large area of this type of rock is exposed, these rocks can become plastic and start to creep and as a result the pillars lose their stability. This phenomenon is much more important than the 12% compressive strength decrease mentioned before.

I.2. Influence of water on joints

When water enters the joints, it can modify their friction angle, even if these joints are devoid of any filling. Table 3 is extracted from T.R. STRACEY and C.H. PAGE [2] (results on joints devoid of filling).

Table 3

ROCK TYPE	FRICTION ANGLE (in °)		
	DRY	WET	Decrease %
Basalt	38	31	18.1
Dolerite	36	32	11.1
Dolomite	31	27	12.9
Schistose Gneiss	29	23	20.7
Granite	35	29	17.1
Limestone	40	33	17.5
Sandstone	35	25	28.6
Siltstone	31	27	12.9
Slate	30	25	16.7

F.P. HASSANI and M.J. SCOBLE [3] also give results which are deduced from tests on surfaces obtained by sawing samples of 140 x 140 x 100 mm^3. The tests have been conducted at various confining pressures ranging from 0 to 2.0 MPa (Table 4).

As mine pillars are often fractured (and often in post-rupture status), there is little doubt that a decrease of friction angle of the fractures can potentially lower the support characteristics of the pillar. In terms of the compressive strength, the reduction in pillar stability will be relatively small as the fractures are never dry during mining.

Table 4

ROCK TYPE	FRICTION ANGLE (in °)		Decrease %
	DRY	WET	
Fine gr. sandstone	34.0	31.6	7.0
Medium gr. sandstone	32.7	30.6	6.4
Coarse gr. sandstone	28.8	25.7	10.7
Siltstone	29.6	27.6	6.8
Mudstone	29.5	27.9	5.4

In short, it is worth remembering that :

- water generally diminishes the mechanical characteristics of the rocks, but the decrease is relatively small;
- water also slightly decreases the friction angle of joints;
- the outstanding phenomemon is the effect of water on rocks like clay or marls, which are susceptible to deterioration.

In other words, as long as no rock which is liable to water deterioration is present, cave ins due to mining flooding will mainly appear in areas which had been mined out at a very high ore recovery factor, i.e. areas which were at the limit of the stability before flooding.

Finally, it should be noted that water also has a positive effect on mine stability, manifested through Archimedes' pressure on the overburden once the water level is largely higher than the mine workings. As a result, the cave in risks are most likely at the time the water arrives in the abandoned stopes, i.e. during infill : the negative effects of water are experienced when the effective stress pressure applied to the pillar cannot occur.

II Effect of water on fine unconsolidated backfill materials

Recent mines will more often use backfilling mainly due to the development of the cut and fill method. Where possible, mining firms often make savings in the application of consolidation agents (mainly cement) and use their processing tailings as backfill material. As a result, they reconstitute areas in the mine with material, which are similar to homogeneous soils (grain size generally lower than 20 μ) which if this is the case the material will have a very low cohesion. These backfills are often transported hydraulically by pipeline (mix of sand and water at around 30% solid, transported by gravity), the water being drained by dams at the lower level of the stopes or at the intersections between stopes and drifts.

Once the mine has been abandoned, the dams are no longer maintained and as they are generally made of wood, they are susceptible to break. In this case is the backfill still stable ?

As long as the backfill is dry, there is no doubt about the stability. In fact, when a dam breaks, a small flow of sand will occur towards the drift to which the dam gives access, but this flow will be limited to the creation of a slope in the drift, the angle of this slope being equal to the internal friction angle φ of the backfill (like dump raises in mines).

What can be modified by water ?

Under static conditions, nothing is changed : the internal friction angle of a sand is not modified in presence of water. On the other hand, as soon as water flow is introduced, a water thrust on the soil elements appears and can completely modify the stability of the backfill. Let us consider a drift dipping at an angle α, filled with sand (or backfill material), and in which we have a water flow at a Darcy speed v (see Figure 1). Knowing the permeability of the sand K, the hydraulic gradient can be expressed

$$\vec{i} = \frac{\vec{v}}{K}$$

The water present applied on an elementary volume dV located at the top of the drift is then given by

$$\vec{f} = dV.\gamma_w.\vec{i} = \frac{dV.\gamma_w}{K}.\vec{v}$$

where γ_w represents the volumetric weight of water (10 kN/m^3). On the other hand, dV is under its apparent weight p = dV.(γ - γ_w) where γ represents the volumetric weight of the completely submerged soil (γ - γ_w is the apparent volumetric weight of the soil in water; 16 kN/m^3 is a general value of γ). Let us consider now dS, basis of dV. This surface is subject to a normal force

$$n = p.\cos\alpha = dV.(\gamma - \gamma_w).\cos\alpha$$

and a tangential force

$$t = p.\sin\alpha + f = dV.(\gamma - \gamma_w).\sin\alpha + \frac{dV.\gamma_w}{K}.v$$

Coulomb's law can then be written as

$$t = n.\tan\varphi$$

or

$$(\gamma - \gamma_w).\sin\alpha + \frac{\gamma_w}{K}.v = (\gamma - \gamma_w).\cos\alpha.\tan\varphi$$

or

$$(\gamma - \gamma_w).(\tan\varphi - \tan\alpha) = \frac{\gamma_w}{K.\cos\alpha}.\nu$$

It can be seen that without water flow (v = 0), the equilibrium is given by $\alpha = \varphi$ (which is well known). On the other hand, with a water flow v, the stability limit of the backfill in an horizontal drift is reached when

$$\nu \geq \frac{K.(\gamma - \gamma_w)}{\gamma_w}.\tan\varphi$$

For a sand having a 10^{-4} m/s permeability and a 16 kN/m^3 volumetric weight γ, the stability limit of the backfill will be reached with a minimal water speed of 6.10^{-5} m/s.

The same reasoning can be applied again for an elementary volume located somewhere in the height of the drift, by replacing the weight as defined before by the weight of the sand column over dS. For given conditions, the backfill flow will finally occur at a given height in the drift : this could observed on a model.

However, our reasoning is not valid once the flow in the backfill has begun, as one can not no longer consider water velocity v and soil permeability K as constants in the height of the drift. The two are much higher in the upper part of the drift where the flow occurs than in the lower part.

It finally appears that the backfill material can be displayed by hydraulic transport, from its original stope to the remaining lower voids in the mine (incline, level drifts, ...).

When confronted with this type of risk one should :

check the existence of voids located under the backfilled stopes and compare the volume of these voids with the volume of the backfilled stopes;
think about the flows of water which will contribute to the flooding of the mine. If important water flows have been noticed at some levels of the mine, they will induce a downward water flow in the mine, the permeability of the backfilled stopes being much greater than that of the rock mass;
evaluate the permeability of the workings and of the rock mass, as these will define the water velocity.

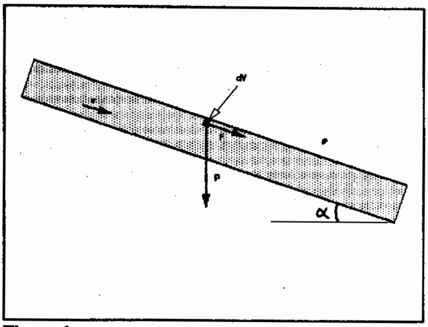

Figure 1

To illustrate our approach, some examples of accidents experienced during the flooding of old mines are presented below.

PART II : VARIOUS EXAMPLES OF ACCIDENTS DUE TO FLOODING

The following examples describe some phenomena noticed during the flooding of some mines. These phenomena can be explained by one of the reasons presented in Part I of this paper.

I The Bazailles mine - Cave ins due to marls

The Bazailles mine is an abandoned iron mine in the Lorraine basin (France). The ore was exploited in a sub-horizontal seam dipping at 3% and at a depth of 180 m. In some areas, the foot wall was composed directly of marls, whereas in other areas, an intermediary layer was intercalated between the iron ore seam and the marls. The compressive strengths measured under normal conditions are as follows : 20.8 MPa for the ore, 36.5 Mpa for the hanging wall and 16.2 MPa for the intermediate layer.

Taking into account the natural joints which were mainly horizontal and vertical, the admissible compressive strength on pillars is obtained by dividing the compressive strength measured on samples by 2.5. This leads to 8.3 MPa resulting in a 54% ore recovery factor.

The mining method employed, dubbed the tibia method, is shown in Figure 2. With this method, an ore recovery factor of 55% was achieved. Based on the finite element modelling it was shown that the long term stability of the roof could not be guaranteed. Consequently, mining under built up areas had to be done by classical room and pillar with a 49% ore recovery factor.

During the flooding of the mine, four major cave ins occurred in the areas mined out using the tibia method where the foot wall was composed directly of marls (April and December 1985, January 1986 and January 1987). These cave ins all occurred at the moment of complete submersion of the pillars under the water. The first three cave ins were spontaneous and brutal, creating earth tremors and immediate surface subsidence with cracks. The fourth one seems to have been more progressive, but also induced cracks on the surface. The first cave ins occurred in an area mined out more than 10 years earlier, which during that period had never experienced any stability problems. The day of the cave in, the surface affected by subsidence was 2.5 ha and progressively extended to 4 ha. Finally, all the cave ins occurred in critical surfaces (i.e. surfaces in which it is possible to inscribe a circle having a diameter equal to the overburden thickness), which corresponds to the minimal surface to obtain full loading of the pillars.

In conclusion, one should bear in mind that all these cave ins were concomitant with water ingress and were only affected in the areas where the ore was directly overlying the marls. One can finally assume that water modified the mechanical characteristics of the marls, which started creeping thus strongly decreasing the support strength pillar.

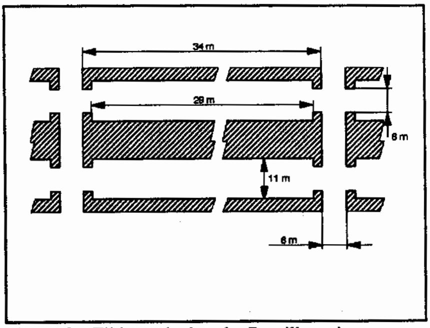

Figure 2 : Tibia method at the Bazailles mine

II The Joudreville mine - A cave in due to decrease of the mechanical characteristics of the rock and its fractures

This example is also an abandoned iron mine situated in the Lorraine basin (France), in which mining was carried out in a 5 to 6 m thick horizontal seam at a depth of 230 m. In this example, the foot wall of the ore seam was composed of a very competent limestone of 1.5 m thickness. The overall mining method employed was caved room and pillar, with the exception of an area located under the mine township, where only drifting had been done. In this area 6 m wide drifts separated by 14 m thick pillars, with cross cuts driven every 50 m was assumed to be capable of providing long term stability. The compressive strength measured on samples under normal circumstances of 23 MPa gave an admissible compressive strength for the pillars of 9.2 MPa. The mining method lead to an ore recovery factor of 40%.

After the closing down of the mine and the cessation of dewatering (1987), the water level reached the area mined out at 40% under the township in 1989. This area had been perfectly stable for more than 50 years, but became subsequently surrounded by areas which had been mined out and caved between 1968 and 1970. These areas imposed high, though difficult to evaluate, stresses on the large pillars left under the township. When the pillars were submerged under 20 m of water, they collapsed suddenly, resulting in the damage 50 flats of the township (the damaged area had a maximal length of 250 m and a maximal width of 180 m).

The Jourdreville mine cave in can be explained as follows:

- abandoned pillars under the township were overloaded. They were at the limit of their stability, probably in post rupture status especially those bordering the areas mined out by caved room and pillar. It is sufficient to mention also that the geometry of the mined out area was very unfavourable (see Figure 3); and that the ingress of water contributed to the destabilization of the pillars, as a result of the decrease of the compressive strength of the rock and the friction angle of its fractures.

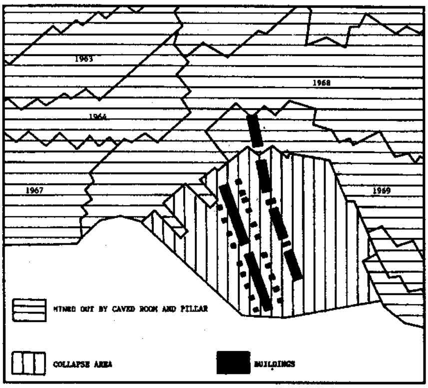

Figure 3 : Geometry of the Joudreville mine

III The Ferriere aux Etangs mine - A cave in due to decrease of the fractures friction angle

This example again describes an iron ore mine, situated this time in Normandie (France). The mineralisation was embedded in a mono-clinal flank oriented NW-SE, its thickness varying between 2.5 and 5 m and its dip being of around 45° close to the surface (the dip was only 30° at 300 m depth). The mineralisation was outcropping.

Room and pillar mining method was used with a high ore recovery factor of 85%. During mining, an area located at a 300 m depth caved in progressively (between 1966 and 1967), resulting in surface subsidence of 0.3 to 0.4 m. The acceptable stress on the pillars can be deduced from this accident and were estimated at 54 MPa (lab tests showed values between 170 and 220 MPa; as the rocks are tectonized, the factor to obtain the admissible compressive strength for the pillars is around 3.5 to 4). This cave in progressed to areas at a depth of 100 m, where it was blocked by larger pillars.

Between a 100 m depth and the surface, ancient workings were present with record ore recovery factors of around 95% (the miners had only left rare and small pillars). It has to be noted that the roof was made of a very strong sandstone. With the exception of some small roof bursts in local areas where the range was over 30 m, the stability of this workings had been very good for more than 70 years.

The mine has been closed, and the water pumping stopped in April 1970. No notable stability accident had been experienced until April 1974. At this time, the water level reached a depth of 68 m, which means that approximately two thirds of the ancient workings were flooded. A brutal cave in occurred then, affecting 1.7 ha at the surface, with formation of large cracks. The caved in area was close to a relatively strong fold and it had been noticed in the mining reports that the roof was fractured. It has to be noted that in the area concerned, no further mining had been done under a depth of 100 m.

In this case, we have an area in which the stability under normal conditions had been proved for 70 years, but we also have a lot of other ancient workings which are similar (between a depth of 100 m and the surface, mined out at 95%) and which did not create any stability problem during flooding. The only peculiarity of the caved in area lies in the proximity of the fold and the fractures in the roof (the fractures are described as relatively infrequent, but noticeable because they were quite large and filled with unconsolidated material). We assume that in this case the cave in is due to the loss of the roof resistance, which is a consequence of the fact that the friction angle was lower in the fractures.

IV The Plömnitz mine - An example of stabilisation by flooding

This mine, located in Germany, exploits a big salt layer at a depth of 400 m. The mining method results in the building of long, 20 m thick pillars separated by 20 m wide and 9 m high stopes. This is done on three superposed levels (see Figure 4). This mining scheme provides a good short term stability, but cannot avoid long term deformations of the salt, which induce surface subsidence. A surface control has been implemented. As soon as the biggest measured subsidence reaches 2.5 m, the phenomenon has to be stopped (the mining takes place under cities, and the experience has proved that big damage to houses occur when the surface subsidence goes over 3 m).

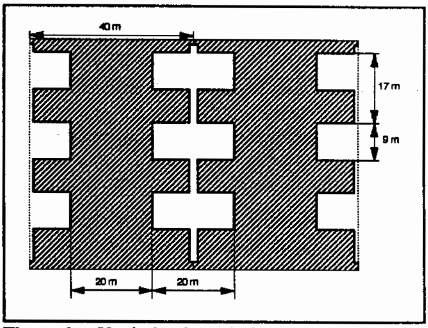

Figure 4 : Vertical schematical cut of the Plömnitz exploitation

Flooding the mine with a salt saturated solution is the technology used to stop the surface subsidence (a new mine is then opened in another area). Through flooding, the stresses applied to the pillars are diminished by Archimedes' effect on the flooded overburden rocks. The pillars are also confined by the saturated solution (this would not be true for fractured or very permeable rocks). As a result, the surface subsidence is stopped.

It is well illustrated by Figure 5, which shows the surface subsidence at the point where it has been biggest. It can be noticed that after complete flooding (370 m from the bottom of the mine, flooding done between 1970 and 1974), the surface subsidence has been quickly stopped.

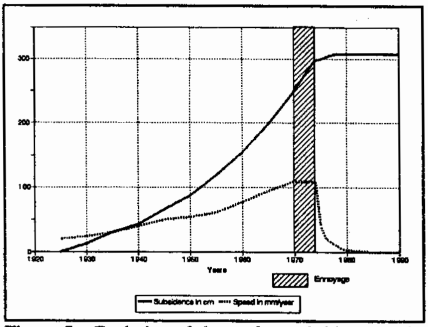

Figure 5 : Evolution of the surface subsidence at the Plömnitz mine

V The Chardon mine - An example of backfill transport by water

The Chardon mine was a uranium mine belonging to the ancient Division Minière de Vendée (France) of COFEMA. Mining had been done partially in open pit (from 1977 to 1983, to a pit depth of 80 m) and partially underground (from 1957 to 1991). Cut and fill and backfilled square set mining method were used underground. The backfilling was placed hydraulically, using the processing tailings (granulometry approximately homogeneous of around 500 μ with a d_{80} of 600 μ).

The geological environment of the ore body is as follows (from North to South, all units being oriented East-West and dipping at 80° to the South) :

- the Fromont adamellite. Safe rock. No stability problem in the underground workings, even without any support;
- the North granite strip. This structure takes place over an approximate thickness of 50 m, and the stability of the underground workings was again good (without support);
- the median strip. This structure is made of an alternation of mylonite, granite and adamellite with a thickness of 5 to 15 m. The stability of the underground workings was bad, and a systematic support was needed at least in the first 120 m from the surface;
- the South granite strip, similar to the North granite strip, with a thickness of 50 to 100 m;
- the F1 fault (0.5 to 1 m thickness) and the South strip, made of mylonite and adamellite with a 10 m thickness. Rock conditions in these structures were very bad;
- the Mortagne granite, having very good mechanical properties.

The mineralisation was located in sub-vertical veins with the main extension North-South, between median strip and F1 fault. The mining was continuous from 240 to 50 m depth. A 6 m high barrier pillar had been left at a depth of 240 m, and the mining continued down to 280 m. The average opening of the stopes was 4 m. Dump raises and access raises had been rebuilt in the backfill with deal shuttering. The dams put in order to retain the hydraulic backfill were also made of deal.

The mine has been closed and the water exhaust stopped in 1991. At the beginning of March 1992, the water level was 55 m deep, approximately at the top of the highest stopes. During the night of 24th - 25th March 1992, a brutal and spontaneous cave in (750 m^2 and 25 m visible depth) occurred slightly to the North of the top of an area which had been mined out continuously from 240 to 47 m deep. At the same time, a brutal increase in the water level in the open pit had been noticed, corresponding to a volume of 10000 m^3; the brutality of the phenomenon is confirmed by the fact that a dam which had been implemented in a drift making the link between the stope and the open pit had been ejected into the open pit, and two raises providing the same link had been partially emptied of their backfill. Finally, the water ejected into the open pit seemed to be clear : no sand sedimentation has been noticed in the open pit.

Those remarks lead to a first conclusion : when the cave in occurred, the stope was at least partially emptied of its backfilling. The maps of the mine show several links between the considered stope and the incline (dipping 15 to 20%). On the other hand, the voids due to the infrastructure and the incline would permit to empty all the stopes to a depth of 240 m.

As soon as part of the backfill has been removed, the stability of the stope becomes uncertain. As the surface subsidence affected an area located in the median strip just at the North of the underground workings, the most probable scenario is the following:

- because of a complex geometry of the mineralisation (two parallel veins at a short distance one from the other), the stope was approximately circular with an integral nucleus (like a pillar). Consequently, the median strip was opened over a length of 20 m and a height of 40 m. In addition, the upper part of the median strip was sometimes undermined by the previous slices. One should remember that the median strip was of low mechanical quality;
- the water ingress diminished the qualities of the median strip, which probably first caved in into the stope, creating a complete opening of the median strip at atound 50 m deep. Finally, the part of the median strip located between the surface and a depth of 50 m caved in like a drawer.

CONCLUSIONS

One should finally remember that water generally diminishes the mechanical characteristics of the rocks and their joints, but the decrease only threatens the stability of areas which were already at the stability limit before flooding. If the cave in does not occur during the flooding or immediately afterwards, the long term stability will be improved by Archimedes' effect on the overburden.

The situation is completely different if rocks liable to water deterioration are exposed. The characteristics of this type of rock can be strongly modified by water saturation. One should always leave a small ore barrier to isolate these rocks from mining voids.

Finally, the water subterranean streams during the flooding can displace the fine unconsolidated backfill materials towards voids at the bottom of the mine. The stability of the emptied stopes is then jeopardized, and the stopes can cave in. If the stopes are located at a great depth, the cave in will not be noticed in surface, as it will be blocked by swelling. On the other hand, if the stope is closer to the surface, brutal surface subsidence can be experienced.

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