ABANDONING MINES: HYDRODYNAMIC EVOLUTION CONTROLLED IN ORDER TO AVOID SURFACE DAMAGE

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ABSTRACT

The paper outlines the consequences which would follow after the abandonment of two underground mines near built-up areas; one is a mercury mine drained through tunnels, the other is a pyrite mine drained with pumps. As far as the former is concerned, deep industrial groundwater must be stopped from rising, as a result of blockages due to landslides in drainage tunnels, and reaching a shallow water table of drinkable water. As far as the second is concerned, the reoccurrance of water on the surface in the at present built-up area, must be avoided, once the pumping of the mine has stopped.

In similar circumstances it is necessary to foresee the consequences so as to intervene with adequate measures; but as forecasts are not always precise, it is necessary to control, until stationary conditions are reached, the hydrodynamic evolution which arises after the pumping is stopped and to modify it with opportune interventions to avoid possible damage.

The control of these evolutions is here exemplified with the programmes for the two afore-mentioned mines, together with a discussion on the reliability of the systems to be used in order to avoid any unwanted events.

INTRODUCTION

Even in the case of underground mines, reciprocal influences between mining activity and territory arise: when a mine is opened, the mining work feels the effects of the specific situation of the place where is carried out, situations which often condition the carrying out of the work itself;

the latter determines changes nearby, the effects of which could reach the surface.

In the case of an area with springs and/or shallow streams, the hydrodynamics is altered as the underground mining work gradually intercepts aquifers and/or streams along fractures in communication with those on the surface - the greater the work and the longer it takes, the greater the changes - which could lead to the reduction of the water flow and even to the drying-up of the manifestations.

When a mine which has withdrawn water, or has even determined the extinction of springs, is closed, a transitory phase, as opposed to that which occurred when opened, takes place as a result of the interruption of drainage: during this phase the water which had initially disappeared could reappear even in different points to where the preexisting springs were. This latter event could occur because the hydrodynamic changes, due to mining activity, may have modified the parameters which regulate the flow of underground water; the less coherent the land is and the more intense the activity, the greater a change is provoked.

The reappearance of springs and/or the rising of water tables can cause damage to work carried out while the mine was active, which although may have been safe during the working of the mine, may no longer be so once pumping has stopped.

There now follows a description of the problems connected to closing-down of two mines, with the activity of which the surface hydrodynamics has been altered, and a discussion of the programmes suggested to resolve them.

THE ABBADIA S. SALVATORE MERCURY MINE CASE

This is an underground mercury mine, near the built-up area of Abbadia S. Salvatore, on the eastern slopes of an extinct volcano (Monte Amiata) in an area where there used to be many springs, with a moderate flow, which began to dry up as the mining work proceeded.

The mining activity began in 1896 and continued for 80 years.

The exploited cinnabar was to be found in the highest parts, often re-arranged, along contacts between trachyte and underlying impermeable ground; in the deep parts, diffused between stratified marly limestones beneath a clayay cover complex.

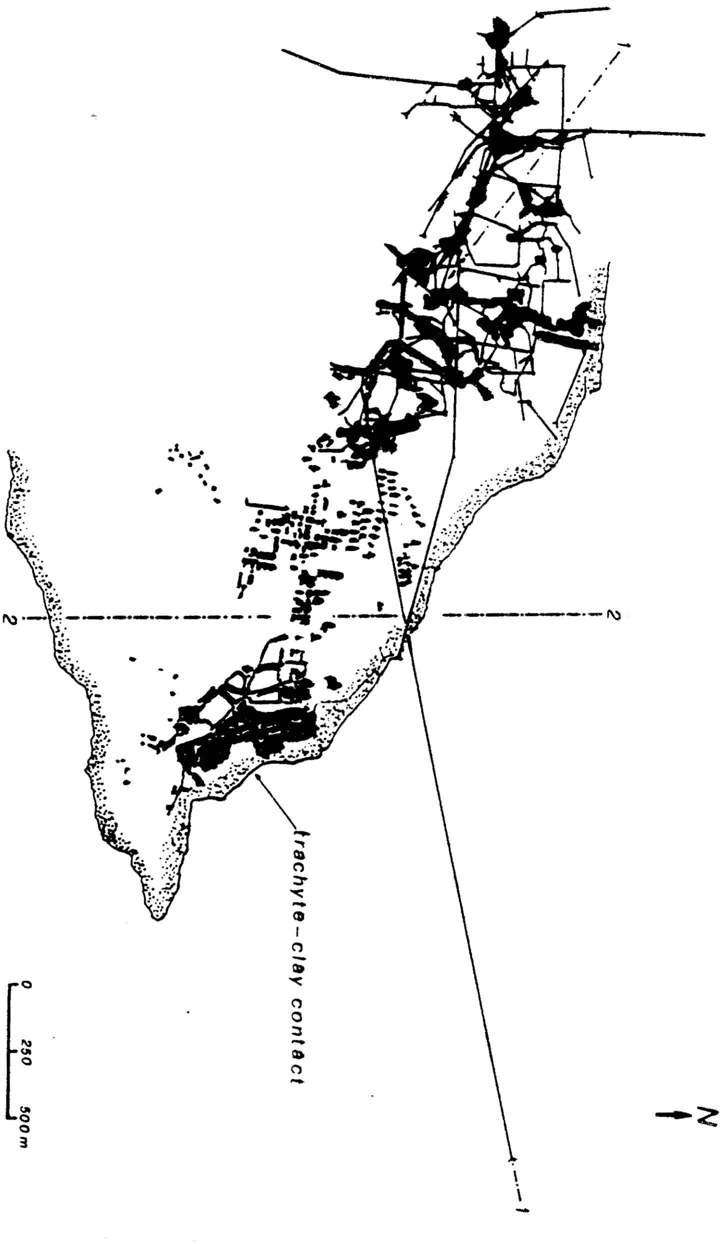

Figure 1. The Abbadia S. Salvatore mine and the nearby built-up area

Figure 1 represents a plan of the Abbadia S. Salvatore mine schematized by its tunnels, its exploitation zones, represented by black areas, and the built-up area of Abbadia s. Salvatore.

Figure 2 represents the location of the mine compared with the village, in correspondence with two particular vertical sections.

As a result of the mining work, water emegences appeared in underground in concentrated and diffused form. The former appeared in the high parts when bodies in the trachyte fractures were intercepted by the tunnels; the latter when the exploitation and/or mining activity determine openings taht permitted infiltrations of contact water.

The concentrated water emergences, are almost all used as drinkable water and introduced into the acqueduct of the nearby village; the seepage water are directed, towards the Italia tunnel and the bottom tunnel, at 786 and 511 m above sea level respectively, from which they are drained out. The flow rate drained out through the first tunnel ranges between 1555 and 5184 m3/d, while that through the second ranges between 173 and 346 m3/d, only (Società Italiana Miniere, 1988).

These tunnels ate both in communication with the Garibaldi shaft, where almost all the drifts of the mine converge.

Figure 3 represents: the mining network, with the two afore-mentioned drainage tunnels shown by thicker lines; the dripping points and flow rates, expressed in m3/d, of the concentrated water emergences, indicated with black circles; the wellholes and the flow rates of the diffused water emergences which flow into them which flow into them, indicated with white circles.

In antecipation of the abandonment of the mine, interventions aimed at maintaining the same hydrodynamics in the mine, and consequently near the mine, were carried out in underground. One cannot exclude, however, that the hydrodynamics may vary in the long term: landslides in the tunnels could reduce the downflow of the waters drained out and even block it completely; if a mine worked in clayey ground were to cave in, there would be a complete occlusion. On the contrary there could be, instead, a gradual occlusion as a result of the deposition of solid particles transported by the water along the narrow courses present after the landslides. The solid particles, mainly muddy, transported by the water and deposited in the Italia drainage tunnel, have in fact been estimated at 36 m3/y.

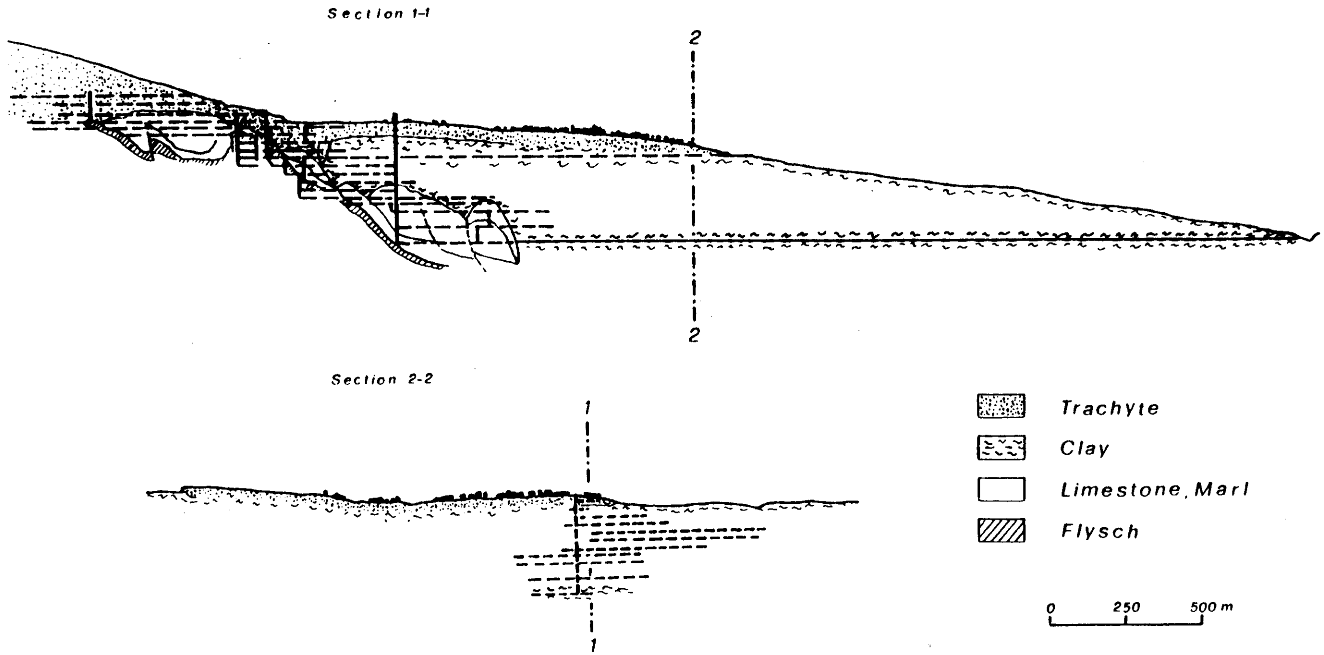

Figure 2. In correspondence with the vertical section 1-1 and 2-2 indicated in figure 1, the mine and village of Abbadia S. Salvatore.

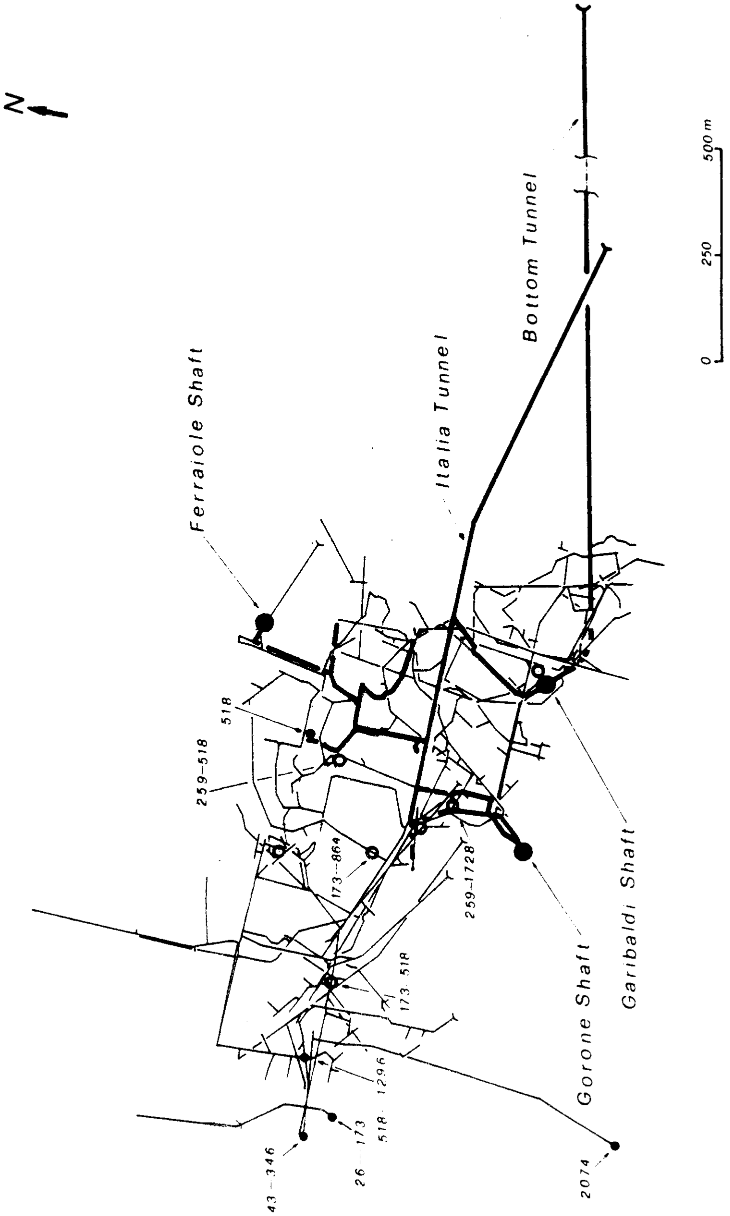

Figure 3. The Abbadia S. Salvatore mine: tunnels; location and flow rate of the underground water inflow; elements of the controlled drainage system.

It is necessary to avoid at all costs that the mine water rises and pollutes the afore-mentioned drinkable water and that it reappears on the surface in areas which have been built up (Figures 1 and 2); precautionary measures are therefore necessary in order to make the system, adopted to avoid any unwanted events, as reliable as possible.

This system is represented by: the two drainage tunnels, Italia tunnel and bottom tunnel; the Gorone and Ferraiole shafts which both reach the Italia tunnel; piezoometers and submersible motor pumps to be installed in both shafts (Figure 3).

In order to verify beforehand its effectiveness an operability analysis of the system has been carried out which may be summarized as follows:

1. If the Italia tunnel, which convoys almost all the non-drinkable water of the mine, were to be occluded, the water would descend into the bottom tunnel via the Garibaldi shaft, on purpose filled with gravel to avoid it caving in and to guarantee its permeability for as long as possible, and/or via other possible routes.

2. If also the bottom tunnel were to impede the passage of the water, the level of the latter would rise. The rise, however, would be signalled by the two piezometers in the Gorone and Ferraiole shafts.

3. Once the danger level is reached, the submersible motor pumps in the two afore-mentioned piezometric shafts would start to function.

The system is reliable because of the redundancy of the elements which would intervene during the eventual transitory phases: there are alternative drainage tunnels (Italia tunnel or bottom tunnel), signal systems (piezometers in the Gorone shaft or in the Ferraiole shaft) and pumps (submersible motor pumps in the Gorone shaft or in the Ferraiole shaft (Sammarco, 1990).

One cannot exclude, however, to utilise the empty spaces in the mine as water deposits allowing the controlled flooding of these with systems of command and control analogous to the one described; these systems will have to be able not only to limit the rising of the water level but also to limit the lowering, so as to avoid using excessively acid water (Fernandez-Rubio et al., 1988; Ralston and Williams, 1985).

THE GAVORRANO PYRITE MINE CASE

A village in correspondence with the thermal spring "Il Bagno", built after the drying-up of the zone and of the spring due to the mining activity, in this case, must be protected. It is highly probable that, after the cessation of the mining activity and of the pumping, the water will return if the water rebound in the mine is not controlled and if, consequently, the necessary measures are not taken immediately.

This is an underground mine in which, from 1898 to 1981, isolated lodes of massive pyrite were exploited almost uninterruptedly along a fault (Gavorrano fault) and which are to be found generally between Lias limestone on the top and granite on the bottom. From a depth of 200 m above sea level the works were acrried out down to 240 m below sea level.
Forty-one Mt of raw mineral have been extracted. During the exploitation filling and concrete filling methods were used: the total volume of then spaces filled should be around 70% of the mineral extracted.

The cavernous Karst phenomena, and fractured limestone presents a high capacity of accumulation and is highly conductive; the granite is permeable only along the faults and fractures that sometimes cross it (Filippi, 1986).

Figure 4 shows a plan of the main continuous springs. A (Il Bagno spring), and intermittent springs, B and C, in existence before the mining works began, and the network of the mine, in the underground of which were found: cold water emergences filtered through the limestone, generally diffused; thermal water emergences, indicated in the figure with black circles, in correspondence with tectonic contacts.

As the works deepened and proceeded the total flow of the cold water and thermal water which flowed into the mine rose, while the flow of those on the surface gradually decreased and disappeared.

In the same figure 4, above, the flow-rate of the spring "Il Bagno", s, the flow-rate of the water pumped out from the mine, u, and the altitude of the ground water table in proximity to the afore-mentioned spring, p, on the basis however of few historical data, have been represented versus time, as the marked fall in the flow-rate and the drying of the spring were contemporary to a marked rise of the flow-rate pumped out from the mine, it is to be assumed that the interception of mining excavations by the

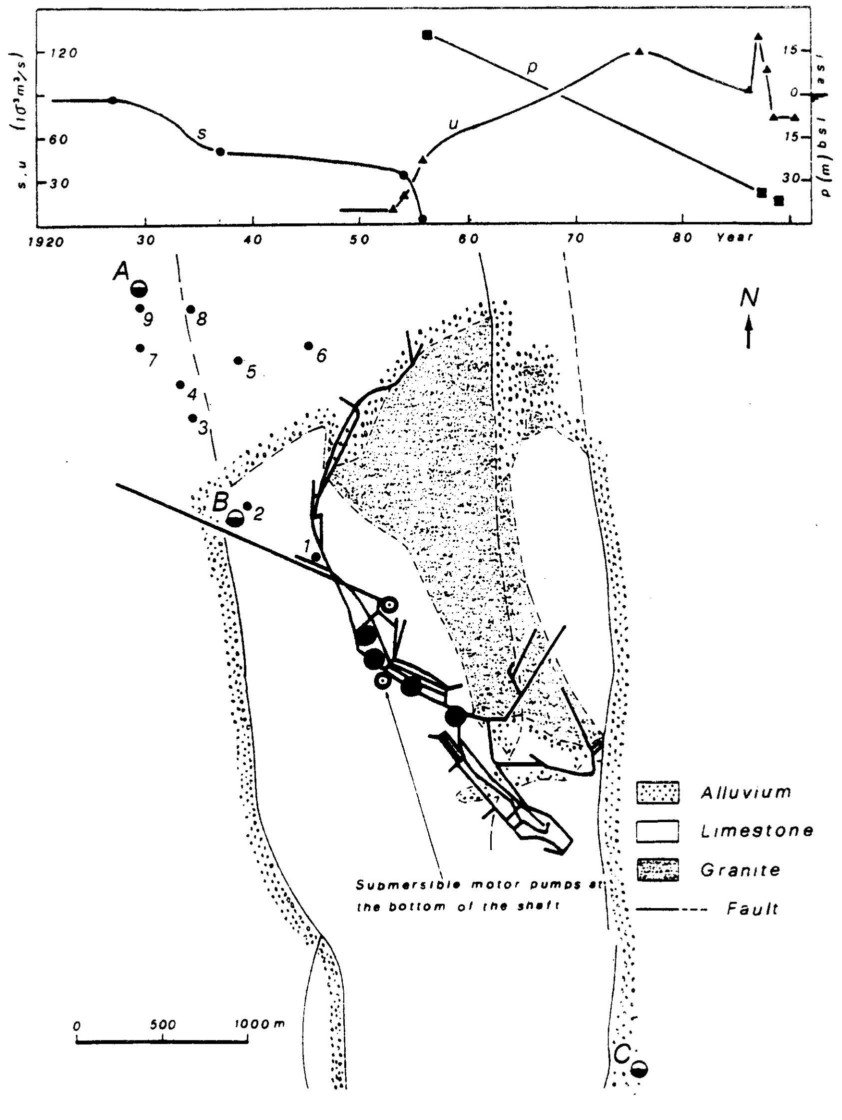

Figure 4. The Gavorrano mine. Below: network of the mine, water emergences and piezometric wells. Above: correlation between the flow-rate pumped out, u, and the hydrodynamics of surface, s and p.

courses of water which fed the spring, rather than the gradual lowering of the ground water table, determined the disappearance of the spring.

The fact that the spring "Il Bagno" disappeared as a result of the withdrawal of its water towards the northern part of the mine, which is nearer to the spring itself, can be deduced from the rate of water-level rises in the years 1944 and 1945; these occurred when the pumping of the three mining units, which exploited the afore-named lodes and which were non connected at the time, was suspended: the water level stabilized in the most northern unit while it continued to rise in the others.

In 1960 the three afore-mentioned units were connected via a bottom tunnel 200 m below sea level, through which all the water which inflows into underground is conveyed towards a non-submersible motor pump plant, with a total power of 1400 KW. situated at the base of the central unit. The water is pumped to the surface by this plant.

The interruption of drainage would cause water to accumulate in the mine, and the rise of the water-level would determine:

- the reappearance of preexisting springs and/or the formation of others;

- the rise of the torrents flow, as points, across which cold water penetrates into underground, would be submerged.

As it must be avoided that the water rising to the surface, once the mining activity has stopped, worsens the mechanic characteristics of the ground, thereby facilitating landslides in steep zones and, above all, subsiding of built-up areas, works are being carried out to keep the rise of water under control and to be able to intervene in case of need.

Wells with piezometers placed inside have been made (numbers 1-9 of figure 4) upriver from the village built in the zone where the spring "Il Bagno" used to spring from.

A pumping system with submersible motor pumps, which has the same hydraulic characteristics as the one currently in operation, has lately been completed. During the phase of flooding in the mine this will permit the rising or lowering of the water level with velocities as desired in the mine, and block its rise to the position and for the time requested.

This system would permit: a study of the influence on the surface of all the possible situations which could occur when the mine is flooded; it would allow, in particular, to keep the drainage power value as low as possible, but sufficient to limit the piezometric levels in the afore-mentioned wells at acceptable values, also with the use of automatic regulation.

As it is necessary to avoid at all costs that the above events or others possible, but improbable, occur, this system must be as reliable as possible.

The system, therefore, has been supplied with redundancy in regard to all the elements of which it is composed. elements which can consequently guarantee continuity of service and the possibility to adapt the system according to the situations it has to face; there are therefore: submersible stand-by pumps already installed to enter automatically into action should one in function break down; stand-by pumps and equipment which permit immediate substitution; alternatives as far as electrical supply, drainage tunnels and drainage pipes, and access routes at all levels for maintenance. The plant will be supplied with remote control and command systems which will permit the safe observation of possible events, such as landslides in submerged pits, and the subsequent interventions deemed necessary (Sammarco, 1987).

CONCLUSIONS

The uncontrolled blockage of drainage of a mine, whether it be immediately after the cessation of the mining activity. when drainage is carried out by pumps, or whether it occurs afterwards, when tunnels are used for drainage, may cause great damage on the surface. It is therefore necessary to control in both cases the effects of the water rise in order to interrupt it as soon as it is necessary.

The control and regulation of drainage can also be used to draw water deposits from the worked-out mines which are very useful in desert areas or during drought periods: once the spill was, during the rise of the water-level, have been installed, the water must be lowered to permit the impermeabilization of the ground around them using grounting techniques.

This paper, however, is not just relevant to teh close down of mines currently exploited using the afore-mentioned technique but also useful for reducing the need of drainage and allowing the hydrodynamics of the surface to remain undisturbed (Kipko, 1988; Singh et al., 1987).

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