Irregularities in Mine Drainage : Causes and Consequences

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ABSTRACT

A brief description on the origins of the waters which can inflow into a mine is presented. The factors that influence both such waters and those drained are described analysing, also on the basis of experimental data, the mechanism by which they act on the hydrodynamics around the mine and the reciprocal influences that can intensely affect the same hydrodynamics. The irregularities that the combined action of the said factors arouses in the flow rates of the waters at issue are emphasised. In substance the effects on such flow rates owing to: raininess; interceptions of water bodies; topography; collapses of voids whether natural or mining; removals and depositions of material because of the same circulating waters are underlined. Particular importance is attached to these final factors that can change the geometry of the paths through which the water inflows into the mine so much that they are obstructed. Therefore, the causes and the effects of the obstructions, which obstruct the normal downflow of the waters and which could become the initiatory events of floodings and inrushes are discussed in detail.

After the obstructions have been classified as indestructible and removable, the causes which can give rise to the removal of the latter are listed by citing inrushes and significant increases of water flow rates attributable to the removal of obstructing material, occurring in the mines of Southern Tuscany. On the basis of specific experiments directed by the author and of historical data interpreted in the light of the latest acquisitions, the dynamics of each event occurrance is discussed emphasing the more significative aspects. Successful interventions or interventions that had to be realised in order to avoid the event or its dangerous consequences, are finally cited.

INTRODUCTION

Save in exceptional cases the motion of the waters that flow into the mines is not permanent, but is characterised by systematic or accidental variations, which would be able to cause inundations or inrushes if they consist of flow rates or pressures that are excessive.

Consequently, the study of such variations, carried out above all by considering the circumstances, can be finalised for the research of useful data in order to foresee and prevent inundations and/or water inrushes.

For such research it will be necessary to identify among all the factors that control the hydrodynamics round the mining voids the ones that modify, even if slowly, inflows and downflows so much to generate situations which can cause or favour the mentioned events. The fundamental aim of this paper is of illustrating, just, the mechanism of action of such particular factors, mechanism that sometimes has been remarked, by observing events in effect, or reconstructed, on the basis of disposable knowledge.

WATER INFLOWS IN MINE AND DOWNFLOWS

The waters that reach mine workings and generally underground or surface diggings, can

- come from the surface, through more or less long paths, which penetrate into the workings;
- be of deep origin and appear when they are intercepted during the excavations;
- come from more or less extensive, recharged or isolated, water bodies;
- be mixtures of waters of different origins.

The modality with which these waters manifest themselves and evolve vary according to their origin and the circumstances, because both the factors that determine the way of influence of the water inflows and the combined action of these factors on the same inflows are different from one case to another. So the precipitation can influence the waters which directly come from the surface and, in a more attenuated way, those that come from water bodies fed with meteoric waters, but not juvenile waters. In any case the waters in question, whatever their origin may have, transport substances in solution, in suspension and/or by drag which, from here removed there deposited, can modify the inflow regime of the waters sensibly.

In order to avoid inundations, the water which inflows into a mine must be drained by gravity or by pumping so that water cannot accumulate. In order to guarantee the continuity of an effective drainage it is opportune to foresee the effects of the various factors on inflows and downflows. When the flow rate of the water drained from a mine maintains itself always equal to the total flow rate of the inflows, like in the case of drainage by gravity through exuberant galleries, the irregularities of the inflows may be identified by the irregularities which appear, even if attenuated, in the water flow rate that is drained.

FACTORS OF INFLUENCE AND RECIPROCAL INTERFERENCES

The factors on which depend the flow rates of the waters that may inflow into a mine are outlined and the mechanism of action of the most important factors are analysed by emphasising some mutual influences.

Raininess

The system by which the precipitation influences the flow rates of waters coming into the mine from the surface depends on the: extent, topography and vegetation of the hydrographic basin; the nature and state of the outcropping rocks; the geometry of the paths through which the waters reach the aquifers and the aquifers nature. So, because the mentioned factors are numerous and sometimes variable in the time, well definite correspondences between precipitation and flow rate are seldom possible to find, not only to analogous mines, but also for the same mine.

In any case it is possible to verify always if the ratio

$$\int_{t_1}^{t_2} h_r \, dt \Big/ \int_{t_1+\Delta t_\varphi}^{t_2+\Delta t_\varphi} q \, dt,$$

where h_r is the rainfall, $t_2 - t_1$ the overall time interval considered, q the flow rate of the water that inflows into the workings, and $\Delta t\varphi$ the delay with which the precipitations manifest themselves in the workings. As a rule this has weak variations only, in order to be able to consider its eventual accentuated increase as an indicator of accumulations of meteoric water around the mining void.

Water bodies

A water body, when is intercepted, causes an inflow which adds itself to eventual pre-existent inflows and has flow rate characterised by a temporary trend of an impulsive type: it reaches suddenly the maximum value and after decreases with a trend that depends on the shape and on the dimensions of the body and with a speed that is highest for small horizontal dimensions of the body, Sammarco, 1988 [7].

Superficial morphology

This influences the underground water inflows of meteoric origin: the steeper the slopes the more important will be the speeds of downflow of the waters at surface and, consequently, the erosion, dissolution, transport and deposition of the material. On the other hand the precipitations can considerably modify the morphology by causing or favouring landslides and transport of materials.

Collapse of voids

The collapse of pre-existing voids or of voids produced by the stopings, Singh, 1986 [11], can change the hydraulic conductivity and even the path of courses through which the water inflows in mine. Vice-versa, water infiltrations around voids can cause collapses or other events which, as for them, can influence the same inflows. With regard to the reciprocal influence between collapses and hydrodynamics this is significant in the case of the La Oportuna Colliery, Spain, in which the hangingwall collapsed and the resulting intercommunication with the multilayer aquifer system caused a series of eruptions, the drainage water of which has pulled plastic clay and sand that have finally replenished the collapsed voids, Fernandez Rubio and Lorca, 1993 [2].

Erosion, dissolution, transport and deposition

The removal and the deposition of material, due to either mechanical or chemical actions, along the ducts through which the water inflows into the mine vary the conductivity of the same ducts, by increasing it in the reaches where erosions and dissolutions occur, decreasing it where depositions occur. The geometries of the ducts influence the speeds of the streams and vice versa. The higher the speeds and more soluble and less coherent the rocks are, the more marked the processes of erosion and dissolution will be, Amin and others, 1993 [1].

The deposition processes are particularly important because they could cause the total obstruction of the ducts and hence the increase of the hydrostatic pressure until obstructions are expelled or less resisting pillars are demolished. The obstructions produced by chemical depositions, or by these and by contemporaneous sedimentations of silts, sands and gravels, are compact and resistant. Whereas, the obstructions produced only by incoherent and poorly cemented characteristic materials are not so.

The transportation and deposition processes within the rivers for some time are the purpose of intensive research, carried out by examining the forces of fluids on particles and the transportation of particles which are both in suspension and deposited, Scheidegger, 1961 [10]. Equating the forces acting upon a particle suspended in a flowing fluid and the forces acting upon a particle sitting at the bottom of a stream bed, have been found, respectively, the expressions of the fluid velocity that will be able to hold in suspension the particle and of the one able to raise it from the bottom have been found. In the diagram particle diameter-flow velocity has been experimentally determined, the zones corresponding to the erosion, transport and sedimentation are shown. With respect to suspended sediment transportation it has been necessary to resort to the diffusivity theory, however, this leads to complex expressions. Subsequently, considering that the suspended sediment concentration at any depth is proportional to the total turbulent energy production at the same depth, has been expressed simply in terms of the transport rate of the suspended particles, Habibi and Sivakumar, 1993 [3].

The listed expressions pre-suppose, however, the knowledge of the hydraulic parameters that appear in them and hence they are not utilisable for forecasts with respect to the mine water inflows of which usually it is possible at the most to know the parameters at the outlets. In any case such expressions can facilitate the interpretation of possible anomalous variations of the inflows in question.

Certainly, the rates both of the inflows and of the downflows do not stay constant, but show irregularities at times hardly interpretable owing to the manner with which the various factors which influence that rates act and interact, Sammarco, 1990 [8].

OBSTRUCTIONS AND THEIR EFFECTS

Examining the irregularities of the water flows drained from the stopes due to obstructions more or less gradually formed, it results that, even if the modalities with which the downflows can be obstructed are various and complex, the obstructions are so classifiable:

- coherent and withstanding obstructions formed along the downflow paths in consequence of chemical depositions and therefore spontaneously indestructible;
- obstructions consisted of incoherent material, formed owing to sedimentation and dragging of material and/or due to swelling of clays and cave-ins; such obstructions on account of their state could be removed.

Stable obstructions

The obstructions of the first type definitively stop the downflow along the same paths obstructed by them and if the water pressure behind them should increase, the water could be canalised along other paths. So, new outflows, in extreme cases also rushing, could form or the yielding of pillars, that are not sufficiently resisting to withstand the thrusts corresponding to the increase of the hydrostatic pressure, could occur. The typical depositions of calcium carbonate, in consequence of the release of carbon dioxide from calcareous waters due to the decrease of pressure along the downflow paths and above all at their outlets, are examples of obstructions of such type.

In the small Siele mercury mine, Southern Tuscany, at present closed, some drainage pipes, after a few months of operation, were wholly occluded in consequence of compact travertine depositions. This stopped the water downflow and as a consequence caused increases of hydrostatic pressure and inrush risks especially on the working faces less resistant and deeper. Such inconvenience was avoided by putting the drainage water, in rather long canals which, allowing the downflow at atmospheric pressure, favoured the release from the water of CO_2 which was led away to avoid the ventilation air. This treated water could then be fed into the pipes.

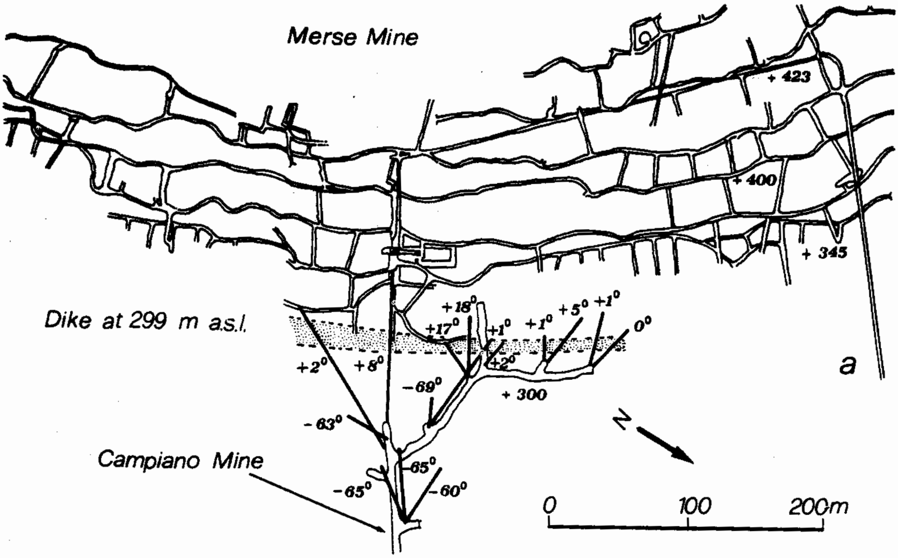
Removable obstructions

The obstructions of the second type, contrary to the first, are not permanent. They can be removed, at times unexpectedly since the evolutions of the circumstances which decidedly influence their yielding are often unforeseeable and since premonitory signals could be absent or not perceived. The causes which produce the removing of such obstructions can be so sub-divided:

- increase of the hydrostatic pressure behind the obstructions because of excessive rainfall;
- increase of the aforesaid pressure because of the same obstructions;
- weakening of the obstructions owing to water seepages into the obstructed ducts;
- thinning of pillars which decreases the length of the obstructed ducts and therefore the resistance of the obstructions.

However, more causes among these can concur to the expulsion of such obstructions by acting also simultaneously. In outline some water inrushes and significant increases of flow rate of drained water, still occur in mines of Southern Tuscany, with regard to which gradual or sudden removals of obstructing material have had a determining role. The mechanism of such events has been possible to examine, by acquiring little by little data from opportunely carried out observations, or by reconstruction, on the basis of historical data.

The important increases of flow rate of the water drained from the abandoned Merse mine, overhanging the Campiano mine (Figure 1), which are registered after intensely rainy periods must be attributed to the removal of obstructions in consequence of the increase of the hydrostatic pressure behind them. In the Campiano mine, the downward continuation of a vein of ore bodies at a depth greater than 500 m from the surface mainly composed of pyrite is exploited. In the Merse mine the upper part of this vein was exploited. In both the said mines, the excavation resulted in influxes of both hot and cold water at the points indicated in Figure 1. The most significant among these influxes was the one that occurred in January 1977 in the Campiano mine at 38 m a.s.l., where the water flowed out from a blasthole, just completed on the face of the main ramp, and flooded the whole mine. The aquifer intercepted with the blasthole included the fractures in the dike and the ones in the evaporites and in the phyllites near the contacts, as well as the voids originating from the exploitation of the overhanging Merse mine, which was drained during the dewatering of the Campiano mine. In order to maintain as much as possible depressurisation of the aquifers which could be intercepted by the diggings of the Campiano mine, from galleries at 300 m a.s.l. of this mine boreholes were carried out,



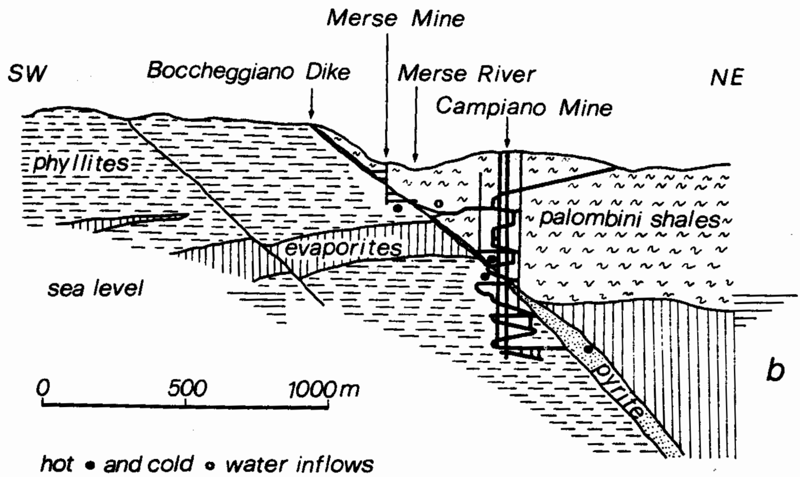


Figure 1. Merse and Campiano Mines.
Drainage system of the Merse mine (a); and
geological cross-section of the Boccheggiano orebody (b).

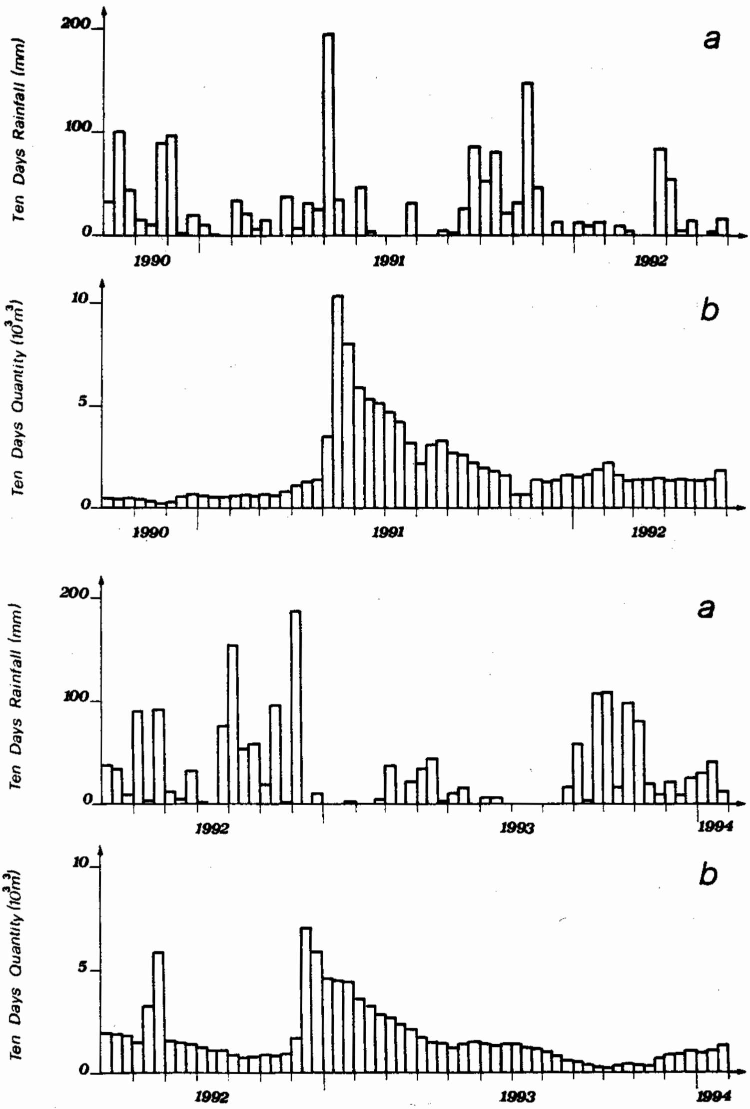


Figure 2. Merse and Campiano Mines.
Ten days rainfall (a); and
ten days quantity of water drained from the Merse mine (b).

inclined as it is shown in Figure 1, which reached the Merse mine and points of the dike and of its walls. The water was so drained was above all constituted of cold water. The Figure 2 shows the correlations between existing rainfall and quantity of water drained from the Merse mine, during a period of more than three years. It is apparent above all that only after particularly intense rainy periods, 1 - 10 May 1991 and 1 - 10 December 1993, have there been registered a considerable increase of drained flow rate. After every increase, the flow rate remained for some months sensibly higher than the average value even almost gradually decreasing. For these reasons, and since in detail such increases and analogous behaviour appear decidedly abruptly and since simultaneously there were increases in the concentration of solid material, the above mentioned water flow rate increases must be attributed to demolitions and removals of obstructions due to increases of hydrostatic pressure, in their turn owing to excessive rainfall and/or to the same obstructions. Preliminarily, through the said obstructions the water would have seeped. Such seepages would have been due to the same aforesaid pressure increases.

At the working faces of the bottom tunnel of the Selvena mercury mine, recently closed; on 17 April 1963, 27 March 1969, 27 June 1973, 24 April 1974 and 6 January 1976 water and mud inrushes occurred. These were preceded by gradual increases of the flow rate and of the turbidity of the water coming from weak inflows constantly present at the faces, Sammarco, 1986 [6]. Such increases by forewarning of coming inrushes made possible the timely removal of the workers. During these episodes the water flow rate, even slightly oscillating, increased with continuity, arrived at a maximum value and after decreased, sometimes also quickly. The rushing effect manifested itself in a billow which, after coming out of the gallery, dispersed rapidly on the square and on the bed of the Fiora River in front of the mouth of the same gallery, having dissipated its energy and hence deposited the transported solid material. None of the first three mentioned inrushes occurred straight after phases of drilling or blasting. The other two inrushes were quite spontaneous since the mining was not continued after the inrush of 1973. The temporal positions of the said inrushes with respect to the trends, since 1962 to 1977, of the monthly rainfall and of the cumulative rainfall relative to the mean trend of the whole period:

$$\sum_{1}^{j} R_m - \frac{j}{192} \sum_{1}^{192} R_m \quad ,$$

where R_m is the rainfall in the month j, are shown in Figure 3. The inrushes occurred when the working face was in correspondence with contacts between clayey formations and limestones or near them. Before the inrushes, water in upper levels and excessive hydrostatic pressures behind the working face have been detected. Therefore on the basis of such events and circumstances it may be deduced that the rainfall was not the determining factor for the inrushes. The determinant factor would be: the interception of contacts, since a piezometric discontinuity could occur on these; the occlusions of natural draining ducts due to material depositions, occlusions which would have caused the aforesaid water pressure increases behind the faces; the decrease of the length of the obstructed ducts, by the degrees the gallery was dug. The described inrushes could have been avoided if there had been permanently preserved behind the face sufficiently long and adequately equipped holes which would have ensured the continuity of the drainage.

On 17 August 1935 an inrush of water and clayey material occurred in the Ribolla lignite mine killing 14 miners. The initiatory event of the inrush was the thinning of a pillar. It was

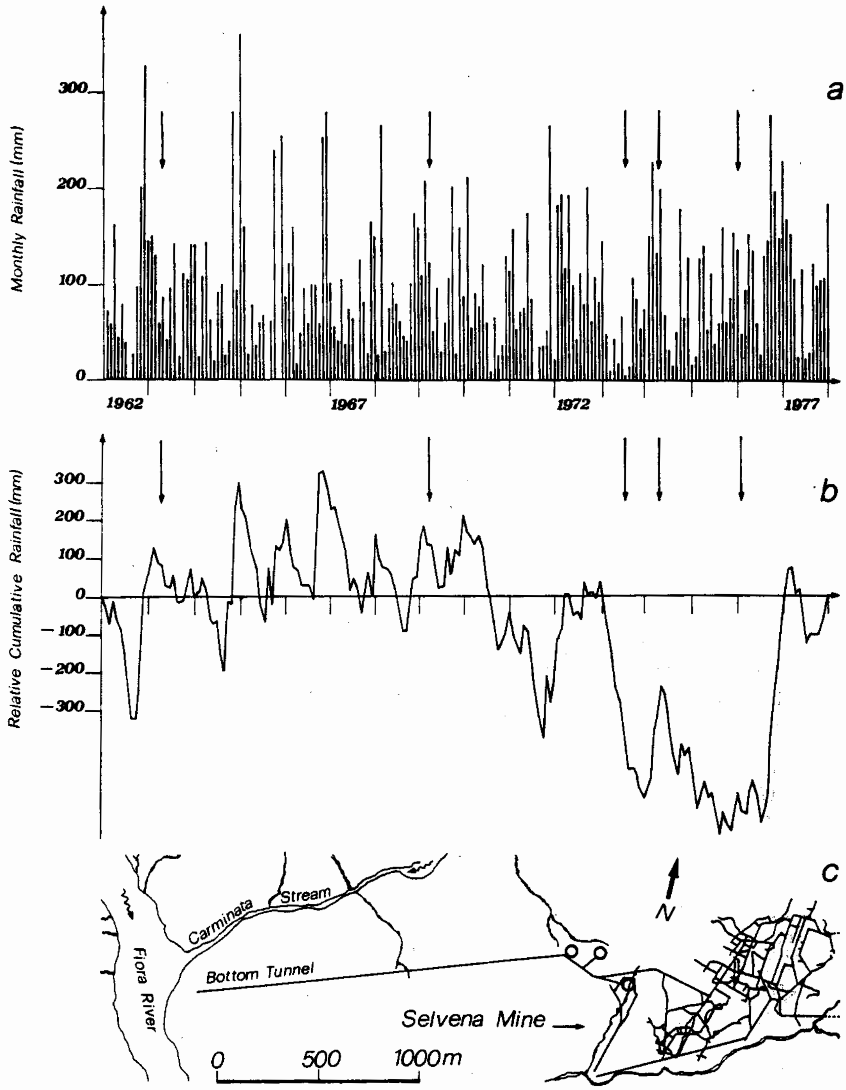


Figure 3. Selvena Mine.
Temporal position of the inrushes with respect to the trends of the monthly rainfall (a); and the relative cumulative rainfall (b).
Mine network: the circles indicate the points of the bottom tunnel where the water inrushes occurred (c).

exploiting the lowered part of a lignite seam included in a clayey-marly formation, the raised part of which, separated from the first by a fault zone was already exploited, and had been abandoned for ten years, Pintus and others, 1935 [4]. It was in consequence of the blasting at the face of a gallery which had reached the fault zone and was 8 m distant from a slope of the old workings, there was a water inflow coming from the slope and, 10 - 15 minutes after the blast, a devastating eruption of clayey material and water occurred. The water would have crossed, at the outset infiltrating only, the pillar between the old and new workings which had been made thinner, fast increasing the hydraulic conductivity and at the same time decreasing the resistance of the pillar so much that it collapsed. This happened since the extent of the old workings was not known in detail. It can be seen that water seepages, which today would have been identified were at the time ignored, Sammarco, 1991 [9]. Swelling in correspondence to the eruption face, which probably occurred before the blasting, would have been noted but undervalued at the time.

In March 1976, the Bagni S. Filippo mercury mine was unexpectedly flooded as a result of the spontaneous appearance of water inflows and of the intensification of pre-existing inflows, Sammarco, 1981 [5]. This occurred owing to expulsions of occludent materials at their turn due to hydrostatic pressure increases in consequence of intense rainfall and/or of obstructions in the inflow paths. Variations, too in decrease, of the water inflow rates and simultaneous settlements and sinkings of galleries occurrred, this emphasised the reciprocal influence between the hydrodynamics round that mine and the prevalently clayey formations involved by the water circulation.

CONCLUSIONS

The motion of the waters which, inflowing or downflowing, involve mining voids, is never rigorously regular, nor is it possible on all occasions to foresee its inadmissible variations, on account of the same nature of the factors which influence the water flows and the ways with which such factors act and interact. This paper offers a contribution to the provision for and/or prevention of inundations and water inrushes in mines, which in any case depends on quite intolerable irregularities. By analysing the factors that regulate the inflows and downflows and emphasising their mechanisms of action and interaction and above all through the description of episodes that have occured in past times, but made clear on the basis of results of recent experiences. It is by interpreting present events with current methodologies that the dynamics of hazardous analogous events that occurred in past times can be explained so much as to prevent that these events are repeated.

What has been expounded, even if cannot be unconditionally generalised by reason of the substantial and at times unknown differences between one case and another, can supply essential information for deepening specific understanding of cases in order to avoid future floodings and inrushes occurring causing dangerous situations.

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