SUBMERSIBLE PUMPS IN MINES DURING EMERGENCY SITUATION

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ABSTRACT

In this paper anomalies of pumping plants with submersible pumps, utilised in underground mines to stand up to emergency situations, are analysed. These emergency situations, especially if unexspected, are sometimes difficult to face effectively by avoiding risks due to their evolution. Some events that can occur, in particular circumstances, during a flood and make dangerous the same emergency interventions are analysed too. The failures of the plants, that in such emergency situations often occur, and these events are imputed to the impossibility of sufficiently exact valuations both of elements for the previsions of the events and of data necessary for correctly choosing the plants and to the fact that the short interventions times often oblige to choose not always fit solutions and to utilize available plants, some times not quite suitable. Such analyses are carried out by examining the results of long lasting trials performed in mines during: one spontaneous flood; one due to the mining; and, above all, one flood, that is still taking place in a mine which has to be abandoned, that is carried out and controlled in order to identify and then to avoid effects which by evolving could cause damages in surface. They lie in identifying deviations of electric, mechanical and hydraulic parameters in order to find their causes and the means for eliminating or making inefficacious of them those that would cause not wanted consequences. The increases of the gas concentrations in one mine and the oscillations of the water level, owing to lanslides, in another, that are occurred during floodings, have been events that have increased the risks in the course of the interventions, events that have been deepened in order to can foresee them.

INTRODUCTION

The cases in which the water pumping from an underground must be without delay for the first time realized or potentiated happen when:

- in consequence of landslides or obstructions in the drainage ways or owing to increases of rate flow of water inflows into mine, the drainage by gravity gets insufficient;

- in consequence of failures or because the water inflows into mine increase, the pumping plant gets insufficient (Singh and Vutukuri, 1995);
- it is necessary to depressurize aquifers by isolated or integrative pumping plants;
- it is necessary to empty a flooded mine or to stop the rise of the water level in a mine that is flooding.

The most efficacious system for intervening in the cited circumstances lies in making use of submersible pumps, over all because these don't require specific mining works. In spite of that at times it is not possible, owing to the short times that one has for the interventions, to face these emergencies with adequate plants, nor it is possible to test their efficiency for sufficiently prolonged times; therefore, according to circumstances, it isn't possible in all occasions to limit or reduce the water level in a mining cavity or the hydrostatic pressure round a mine.

"BAGNI SAN FILIPPO" MINE: SPONTANEOUS UNCONTROLLED FLOODING AN CONSEQUENT INCREASE OF GAS INFLOW IN NON FLOODED GALLERIES

Before 1965, when excavation works started and were completed 2 years later, reaching a depth of 155 m, the mine had never been flooded. The water would gush out from the slits in the Rhaetian limestone (Upper Tias) and from points where the latter would come into contact with the upper clay layer, with a total flow which was never greater than 35 l/s and never below 12 l/s. Since 10 March 1997 new underground water flows were recorded, as well as ground settlings with the formation of chasms, increasing the flow of already existing water. Two days later the total flow exceeded the amount that could be drained out by centrifugal and non submersible pumps installed underground, and because of which the two deepest levels had to be flooded.

In order to empty the underground area submersible pumps were used, driven by asynchronous watertight squirrel-cage shaped motors (Liwschitz, 1957), which were available from a nearby mine and introduced into S. Luigi's well. However, such pumps had to be substituted due to their frequent failures probably caused by:

- the temperature of the drained water was higher than the specified temperature for those types of pumps;
- the casing had not been arranged around the motor-pump unit, therefore the absorbed water couldn't cool the motor since it was not flowing on it;
- the sediment which was expelled with the water, thus slowing and hampering the impellers, would overstress the motor thus overheating the winding, reduce the electric resistance of its insulation and short-circuit.

In similar circumstances more appropriate pumps should be used, considering the temperature and the turbidity of the water to be drained as well as enclosed plants.

If we wanted to reduce the period of pump substitution due to faults, flexible instead of hard piping could be used.

Picture 1 indicates the changing of the water level in the mine through time during the first flooding stage. The minimum and maximum levels, with the exception of those of the 16, 22, 26 and 29 March and the 23 and 25 April, which indicate a reversal of the direction of the water level determined by rain, correspond respectively to pump failures due to faults and repairs.

After the flooding, CO_2 and H_2S gas flows increased notably due to their continuous inflow into the mine (picture 1). Such increases, which had enabled floods to be predicted, had been explained by linking them to hydrodynamic evolutions that used to happen frequently in that underground area after the first episode but had been stopped thanks to their timely forecast

(Sammarco, 1976 and 1982). On the other hand, whenever the gas flows were not regularly sampled by measuring their concentration in the ventilation air, their increases were indicated by the increase of the pumped out water, which had to be done in order to keep the water in the mine at a constant level. However, concentrations and increases of the gases would happen whenever the pumping capacity was insufficient.

"MERSE" AND "CAMPIANO" MINES: FLOODINGS CAUSED BY UNCONTROLLED MINING

In the Campiano mine the Boccheggiano vein has been cultivated up until 1994. It was mainly formed by pyrite and its top section was cultivated in the past together with the Merse mine. In both above mentioned mines hot and cold water bodies had been found in the points indicated in picture 2, which originated water inflows. The most important ones were those originated on 15 April 1901 and 26 January 1977 in the Merse mine and in the Campiano mine respectively.

In the former during the excavation of a gallery at 320 m below the sea level and about 70 m away from the vein, a fracture was detected from which water gushed through, at 43°C and with an initial flow of 20 l/s, which flooded the mine due to the insufficient pumping capacity of the steam pumps, which were installed in the bottom level (Corpo 0delle Miniere, 1901-1908).

In the second mine, at 38 m above the sea level, water gushed out from the advancing front of the main ramp which had just penetrated the phyllites bed, next to a mining hole which was being excavated. Its temperature was 52°C , its initial flow 150 l/s and it flooded the entire mine. The water flow found during the above mentioned excavation was contained in the vein sections, in the evaporites, in the phyllites as well as in the voids obtained from the cultivation of the overhanging Merse mine, which was drained during the emptying of the Campiano mine. However, the likelyhood of finding such a water body was underestimated, since it had not been taken into consideration that these formations could permeate through the fractures, although previous borings carried out in the undergroung had not detected any water flows. These could be intercepted by the mine network itself during its development and the phyllites, although usually dry, could have contained large water bodies (Sammarco, 1988).

When the attempt to stop the flooding failed, the emptying of the underground gallery had to be accelerated, mostly to reduce possible water penetration in permeable formations which could have caused cave-ins.

The Campiano mine was emptied by pumping out the surface water or solely by submersible pumps put into the wells, or by the latter and others placed in a series on floating platforms, which were following the water level in its descent and in already drained areas of the ramp. When pumps could not be further lowered into the wells, due to cave-ins caused by the flooding or preexisting obstructions, the floating platforms equipped with submersible pumps favoured the emtying of the deepest part of the mine.

At the beginning the draining was not performed on a regular basis: the flow of the extracted water was irregular and sometimes the water level on the ramp would start rising instead of falling. This used to happen because the submersible pumps of the pumping stations set up in the wells in order to handle emergencies, would fail frequently for the following reasons:

- high temperature of the pumped water which was initially 52°C, fell only to 45°C during the emptying stage which lasted about 7 months;
- incrustation formations on the engines surfaces;
- presence of slime in the sucked water , although the pumps had been kept below a certain water level in order to avoid cavitations;

- penetration of mine water in the motors;
- excessive acidity (PH < 2) of the waters pumped out from the Serpieri well of Merse mine.

The first two listed factors were causing the deterioration of the stator winding insulation of the electric motors, while the third and fourth factors would have damaged mechanical parts and therefore overheating due to overcurrents and short circuits. The excessively acidic water then corroded the pump installed in the Serpieri well of the Merse mine to such an extent that it was beyond repair.

The faults were avoided and the regular drainings were guaranteed by adopting the following measures (picture 2), which eliminated or disabled the causes of the above mentioned faults.

Around every single submersible pump a casing was placed, thus obtaining a greater heat dissipation between the motor and the mine water: before the casing,the pump was placed and in a watertight substance, the water would flow towards the aspiration grid of the pump and it was forced to pass between the outer surface of the motor and the inside surface of the casing at a sufficient speed in order to avoid a temperature increase that could have hampered the necessary cooling of the motor. With such a system another aim had been reached, namely that of reducing the formation of incrustations on the motor's body which were hampered by the water flow.

Each casing base was provided with a thick grid that reduced notably the pumping out of silts.

Through two flexible pipes of reduced diameter, one for the inflow and one for the outflow, which would serve as a link between the surface and the inside of each electric motor - which squirrel cage-like rotor was completely immersed into the water - the inside of the motor could be kept at sufficient pressure to avoid the penetration of mine waters.

Once the draining was completed and in order to avoid the elimination of water accumulations in the old Merse mine through submersible pumps which would soon undergo corrosion, drainage holes were made from deliberately dug galleries, starting from the Campiano mine, at 300 m a.s.l. (picture 2). The extremely acidic water encountered through the holes was expelled through PVC pipes and pumping it directly up to the surface with stainess steel non submersible pumps.

GAVORRANO MINE: CONTROLLED FLOODING

Necessary controlled flooding and adopted criteria

The Gavorrano mine is located in a area that is characterised by hydrothermalism and where a Plio-Pleistocene granitic intrusion caused the fracture and the folding of the sedimentary formation, mostly made by Lias and Trias limestones as well as Neogene sediments, causing fractures and faults: between 1898 and 1981, in order to cultivate pyrite heaps arranged along one of those faults called Gavorrano, mines developed which were gradually linked to galleries thus forming a mining network, which is developing in a horizontal projection for over 4 km and down to a depth of 500 m (Sammarco, 1993).

Although this mine was cultivated entirely with backfilling methods, the total theoretical volume of the residual voids produced throughout the entire period of mining activity was 3.620.000 m3.

The detection, by means of excavation, of both hot and cold waters, the fractures and cavities around the cultivated body as well as preexisting cavities and cavities induced by the mining activity, the voids left due to the incomplete substitution of the excavated minerals, had deep consequences on the hydrodynamics of the territory, causing the disappearance of hot and cold springs, indicated in picture 3 with black and white circles respectively, and reducing superficial water ways due to the penetration in the mine of waters that would earlier flow into them. Such repercussions become clear when comparing the trends of the most intense hot spring flow, s, the flow of the water extracted from the mine, u, and the height of the water table in the proximity of the aforementioned spring, p.

If after the cultivation works this mine had been widened by stopping the pumping altogether, whilst flooding the old springs would have reappeared in the same spots or in different ones, the aquifers would have swollen and the superficial water ways would have intensified.

Since, in the meantime, the situation in the territory had changed, risky circumstances would have appeared. In fact, in the vicinity and around the most intense disappeared spring, which flow before the mining activity was of 80 l/s, a settlement was built. The buildings could have given way as a consequence of the rising of the water level. Besides, above a second spring and in the proximity of other disappeared springs, mud setting lagoons have been built, containing 1.5×10^6 m3 of material, which stability after the flooding of the mine, could have been strongly compromised by the water, which rise would have resulted in its penetration into the basins and the increase of the superficial water flows if they had not been able to flow into the basins themselves (picture 3) due to an inadequate and inconsistent embankment.

Given the nature and the special structural and morphologic situation of the formations above the mine and the aquifers detected by it, strongly disjointed, fractured and karstified formations almost everywhere, the unruly enlargment of the mine cavity could have uncontrollably potentiated fractures and created chasms.

Apart from such surface repercussions the flooding could have resulted also in underground cave-ins, which had happened also before the flooding, thus causing violent water rising in wells with great danger for the workers inside. The quicker the water had risen, the more frequent and consistent the cave-ins would have been.

Bearing this in mind it is necessary to flood the mine in such a way to be able to determine the rise of the water by monitoring its effects in order to:

- block it below the allowed piezometric surfaces - such blockage could be permanent if a reduced power were used for pumping with respect to the necessary power in order to keep the mine dry; or it should last until the interventions have been carried out in order to prevent the water, once the flooding is resumed, from penetrating into the underground areas in which its presence could undermine the stability of the works carried out on the surface.-;
- slow it down as much as possible in order to reduce the risk of cave-ins - thus gaining the advantage of completing, while the water level in the mine is rising, the flooding of the underground cavities which have been emptied because of the mining activity; this would also avoid the underestimating, during forecasts, of the quantity of water to be pumped permanently if we were to chose the solution of maintaining the piezometric surfaces around the mine permanently depressed-;
- prevent workers from being in the underground cavities in case the fluctuation of the water level induced by the detachment of rocks sholud cause cave-ins, which are preceeded by such activity.

In order for the Gavorrano mine to be flooded according to the above mentioned criteria, a project has been devised; it includes specific works and interventions, to be ordered and coordinated by its author (Sammarco, 1987). It consists of the substitution of an old plant of non submersible pumps used during the works, with another pumping plant that can be controlled and driven also

from the surface and which is able to increase, stop and decrease the water level to our requirements. In order to obtain the controlled flooding down to the mine level of
-140 m, submersible pumps have been used, which have been placed in a well (Impero Well), at a depth of -200 m, at the base of the piping. The flooding then proceeds by using additional submersible pumps placed in another well (Roma Well), close to the first one at a depth of -155 m. In order to face unusual rises of the forecast water flow, which had already happened during the first stage of the flooding, to each pump a second pump has been added in series as a booster.

In this way the control of the effects of flooding, necessary to be able to discipline the flooding itself thus avoiding the aforementioned risks both on the surface and inside the mine, has been completed.

- During the rising stages as well as during the blocking and decreasing stages of the mine water - the latter necessary for various reasons - the water level in the piezometric wells, as shown on top in picture 3, is frequently measured;
- the water level in the mine and its possible fluctuation is constantly recorded by digital and analogue systems.

In the setting up of the plant other improvements gained during previous emergency experiences were adopted; each pump, driven by a squirrel cage-like induction motor, has been provided with a casing, using pumps with a diaphragm in order to preserve the overpressure in the motor space and installing automatic systems and signalling and remote devices which provide early detection of faults and their immediate repair.

Emergency situations during controlled flooding and their management

Extreme care has been taken in order to guarantee the constant availability of the plant, since uncontrolled water rises were not allowed. All forseeable situations that would have not allowed to keep the flooding under control, have been considered and alternatives found in order to disable it or make it ineffective. Such alternatives have been adopted not only by redundant elements and systems which are part of the plant but also by adding intervention scenarios in case of faults. The extremely high level of reliability of the hydraulic circuit during the first and most critical flooding stage, clearly emerges; in fact, there are two emergency pumps and pipes that can be enabled immediately in case the operating pump or piping should fail. Any of the three pipes can be used. There are also at least two possibilities to access pumps and pipings in order to repair or substitute them.

This contributed to the succesful reaction in emergency situations which appeared mostly because the new plant has not been tested before the flooding. In order to test it, water had to be introduced in the 'puisards' of the wells, where the new pumps were located, and after sealing the fractures thus making them watertight. The more and more frequent faults of the old plant and the danger faced in repairing them, since they could be accessed only through the galleries which static situation had been compromised, led to the disabling of the old plant, because it could not operate long enough to carry out impermeabilisation works for that test and the test itself; the plant was only used in emergency situations. In other words, these situations, caused by the precariousness of the old plant, have been faced with the activation of the new plant; however, other emergencies have arisen due to the unsufficient testing which could have detected and eliminated the faults thus check-spelling the continuity of its operation, badly needed for its safety.

Since the testing has to be done during its operation and for this purpose the plant has to be sound, the following is caried out:

- Constant logging of electric, mechanical and hydraulic parameters (Kemp, 1963) to detect deviations caused by incipient faults before their progression can lead to unwelcome events.
- Extremely detailed analysis of each fault, to detect and eliminate the causes as well as determination of its frequency of occurrence.
- Operational analysis (Messina and Chiesa, 1986), especially after each improved modification, in order to further increase the reliability of elements and systems which are part of the plant and the plant in its complex.

Analysis of faults and measures adopted to avoid them

Picture 4 shows the operation periods of the old plant and of the pumps of the new one over the past two years. During this period the water level has been forced up to 143 m below the sea level, while the new plant was being tested and faults and anomalies thoroughly scrutinised in order to improve its reliability. The arrows indicate failure induced pumping stops. The faults, which have been numbered according to their occurrance, have been summarised indicating, in the most significative cases, the intervention methods and measures adopted to avoid them.

1. Leak in the supply duct at the level of a flange coupling.

2. and 3. Pumps failure due to badly insulated relay switches, set at 50 kohm.

4. Pipe bursts in 4 points, detected when old plant had been reactivated, after the failure of the new pumps which had operated for less than an hour. A watertight door had been immediately closed to avoid, in absence of pumping, the flooding of the control level situated at 200 m below the sea level; by-passes had been applied to use less corroded piping sections and delay the closure of automatic valves to reduce hydraulic shocks.

5. Pump failure caused by an isolation switch on a 6kV line upstream of the transformer. Old electric cables have been replaced and the overloading of the pumping lines with other users has been avoided.

6. and 7. Pipe bursts.

8. Spontaneous failure due to short-circuit of the statoric winding caused by excessive absorption, caused in turn by the heavy wearing of the thrust bearing.

9. Failure due to badly insulated relay, which intervention current together with that of other pumps relays has been reduced from 50 to10 k ohm to extend the operation of the same pumps by tolerating lower insulations.

10. Manual stop, having realised that the absorption was excessive. An unusual wear of the thrust bearing has been noted.

11. Failure caused by badly insulated relays; the insulation of the statoric winding has been damaged by excessive absorption current caused by the unusual wearing of the bearing-bush, the latter caused in turn by the rotor jumping out of its axis.

12. Failures induced after detection of scarcely insulated statoric windings. Both pumps' windings have been reconstructed and subsequently those of all other pumps, insulating them with a double layer of polyethylene instead of a single layer of PVC.

13. and 14. Failures due to anomalous wear of thrust bearings, wearing caused by excessive vibration of the supply ducts.

15. Failure due to the breaking of the diaphragm which determined great mechanical damage and the increase of the absorption until the activation of the maximum current relay. The motor has been repaired by substituting the diaphragm, the stator and its winding, the

rotor, the bearing-bushes and the thrust-bearing. It has then been mounted and extreme care has been taken in activation of the system and the diaphragm.

16. and 17. Gasket break between the flanges of a coupling. Once the cause has been detected all other couplings have been checked in order to avoid other similar cases.

18. Pump failure due to short-circuit of the statoric winding, probably caused by the abrupt deterioration of the insulation and not by motor overloads, since only the badly insulated relay has tripped and not the maximum current relays; no insulation reduction has been noticed an hour before the failure. At present it is not possible to celarly determine the circumstances and the causes of the fault, since the pump has not been recovered yet because access to the mine has been banned, due to recently detected high water level fluctuation.

19. During the testing, the probe which activates one of the two pumps placed in a booster in the Roma well has failed due to the presence of an air bubble between its electrodes. In both boosters, appropriate vents have been made to let water in homogenously after the sump pumps have been started.

20. and 21. Overheating, melting and arcs for defective solderings damage the couplings in such a way that they interrupt the feed at the level of the starting inductances which are damaged by the pump in the booster and by the sump pump of a same pumping line in the Roma well.

21. Manual stop of a base pump in a pumping line of the Roma well due to excessive absorption. Mud depostis have been located in the two pumps in sequence and along the pipe-work as well as the wearing of a bearing-bush which has been replaced together with the broken diaphragm. On the water surface and slightly above the aspiration area of the sump pumps, thin floating particles have been detected. It is thought that such an inconvenience will stop as soon as the head on the pumps is increased.

Of all the faults and carried out interventions, those concerning the piping and the statoric windings of the motors which operate the submersible pumps for controlled flooding, are being currently analised.

Faulty pipe-work

Leaks or interruption of the supply ducts have happened due to:

1. pipe bursts due to their progressive thinning, at times even perforation because of corrosion;
2. in one single case during the mounting, detachment of a sleeve from the back end of the pipe due to defective soldering ;
3. damaged gaskets in correspondence with the Victaulic couplings and a flanged coupling.

The faults described in point 1 concern the piping of the old system and partly that used for the new system, mainly in sections adjacent to pumps and during their failure. In order to reduce their occurrence, the most corroded sections of the pipes have been replaced and the closing time of the valves at the head of the pumps have been increased to reduce hydraulic shocks at pump failure.

The unusual bursts under point 2 consisted in the severance of a double soldered coupling linking the pipe to its sleeve. The detachment was caused by an excessive percentage of Carbon found in the sleeve by spectrometric tests. In order to completely avoid such bursts, all sleeves have been replaced with others more suitable for solderings; the dimensions of the latter have been increased; a tooth has been obtained round the inside circumference of the sleeves; once pushed into the soldering it strengthens considerably the sleeve-pipe coupling; a check of all solderings has been ordered (Sammarco et al., 290-95).

Damage to gaskets for Victaulic couplings, successfully used for several decades in mining, were detected when a faulty supply of gaskets was used: after an operation period varying from a few days to a few months, for 10% of such couplings, initially faint water leaks occured, which grew stronger if the gaskets were not immediately replaced. Such inconvenience has been removed after substituting the faulty gaskets.

Some gaskets, placed on a flanged coupling at the base of a connector, have also been severely damaged. The latter appeared to be necessary to avoid cavitation of a pump, which was shorter than the one it was replacing. In picture 5, top, the trend of the flow of the water extracted by the mentioned pump can be seen:

- as soon as it starts operating, a;
- after an initial replacement of the gasket, as soon as an abrupt flow reduction had been detected and found completely severed in the intermediate point between two flange connection bolts, b;
- after a second replacement of the gasket, which hasn't been examined since the pump has not been recovered, carried out after a 10,3% flow reduction, c.

In the same picture, the periods in which the speed of the flow reduction increases correspond to the operation of the pump: clearly the pressure impulses obtained with the setting into motion, would determine abrupt deterioration of the state of the gaskets; the periods of the flow increase correspond to leaks due to gaskets for Victaulic coupling downstream of the measuring section of the flow. However, flow reductions similar to those visible in the picture can indicate, in similar cases, deteriorations and complete severance of the gaskets.

The gaskets would break because the surfaces of the defective flange were not parallel to one another. Therefore, the gaskets not being evenly compressed, would allow water leaks under pressure that would damage both gaskets and flange. In order to prevent this from happening again the surfaces of all the flanges have been thoroughly smoothed with a lathe, some silicon has been applied between the gaskets and the flanges and extreme care has been taken in obtaining an even locking.

Insulation thinning and short-circuit of the statoric windings

From the beginning of the testing it appeared that the values of the PVC insulation resistances of the statoric windings of the motors of the submersible pumps in the Impero well would rapidly reduce after start-up down to 50 k ohm; the safety relay had also been set to this value.

Subsequently, after the activation threshold of such relays had been dropped to 10 k ohm, the following conclusions were drawn:
the values of those resistances would reduce during the operation of the pumps, as shown in picture 5, below; with the increase of the number of start-ups the decreasing speed of the values would increase (picture 5); even in such a precarious situation pump B would fail after 750 hours and pump C after 410 hours.

After the windings of all motors have been reconstructed by using for insulation not one single PVC layer but a double layer of polyethylene (Hellman and Tams, 1986), the mentioned inconvenience reappeared only on one other occasion, where a short-circuit of the statoric winding occured without notice; the contrary would apply in the case of PVC insulated windings through the reduction of the insulation resistance values. This reduction was rapid at first then slower and slower before the motor would stop (Sammarco et al., 47-95).

Level logs to anticipate risky cave ins -induced water rises

Massive cave-ins in the mine being flooded have already occured. They could happen again because the deterioration of the mechanical characteristics of the backfillings and some diaphragms, when the water level is rising, could undermine the support of the formations around the mine cavity. Since such cave-ins could determine such aggressive and high water rises through the wells, it is necessary to timely anticipate them during the management from the underground controlled flooding.

Since usually consistent cave-ins are preceded by the detachment of rocks, which fall into the water determining a fluctuation of its level, the latter is logged in order to identify the movements that anticipate massive landslides and to avoid consequent risks.

Such logs are carried out using strain gauges with electric resistors as sensors, kept a few meters below the water level. In the near future also sensors made of conductors will be employed. They are partially immersed and inserted into an electric circuit which closes through the water and are crossed by current which varies according to the water level (Sammarco, 29-97). Picture 6 shows the mine's Impero well; the uninterrupted line, perpendicularly intercepted by brief sections, indicates the cable bearing the sensor and through which the water level, regularly sampled by the sensor, is sent to the surface.

The same picture shows the movement of the water level in the well, occured after a collapse in the mine cavity during the flooding.

CONCLUSIONS

Floodings and emptying of the mines usually indicate events that are characterised by complex dynamics difficult to anticipate. Therefore, emergencies have to be faced, both linked to events to be controlled and the means of control, since the latter are not always suitable for all scenarios, which are difficult to anticipate.

This is the reason why the pumping stations which should activate in emergency cases will have to be adequately overdimensioned (upgraded), with high redundancy level and able to operate in difficult conditions. They will be equipped with signalling devices, remote and automatic control, able to identify and log the causes as well as to eliminate or fight them to avoid undesired events, but most of all specific experiences will have to be considered.

The positive result of the controlled flooding of the Gavorrano mine, carried out according to plans, is to be attributed mainly to the acquisition of knowledge about floodings in difficult situations, learnt during the course of their occurrence and during the application of methods adopted to fight them. These elements reveal the importance of studying events in their evolution in order to constantly improve the efficiency of the plant by adapting it to the new reality. The analysis of the faults, carried out during the flooding through the regular logging activity of relevant electric, mechanical, hydraulic parameters, allows to improve the reliability of the plant through successive innovations and to obtain quantitative data on faults themselves. In this way critical situations can be anticipated and risks reduced.

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Some floods of mines for which submersible pumps have been utilized are mentioned and causes and behaviours of events that at times have not made it possible the control of the flood are analysed. On the other hand it is demonstrated that the rise of the water level in a mining cavity can be quite controlled if redundant pumping plants are utilised and it is avoided that failures are repeated by analysing these last as soon as they occurred in order to find their causes and to eliminate them.

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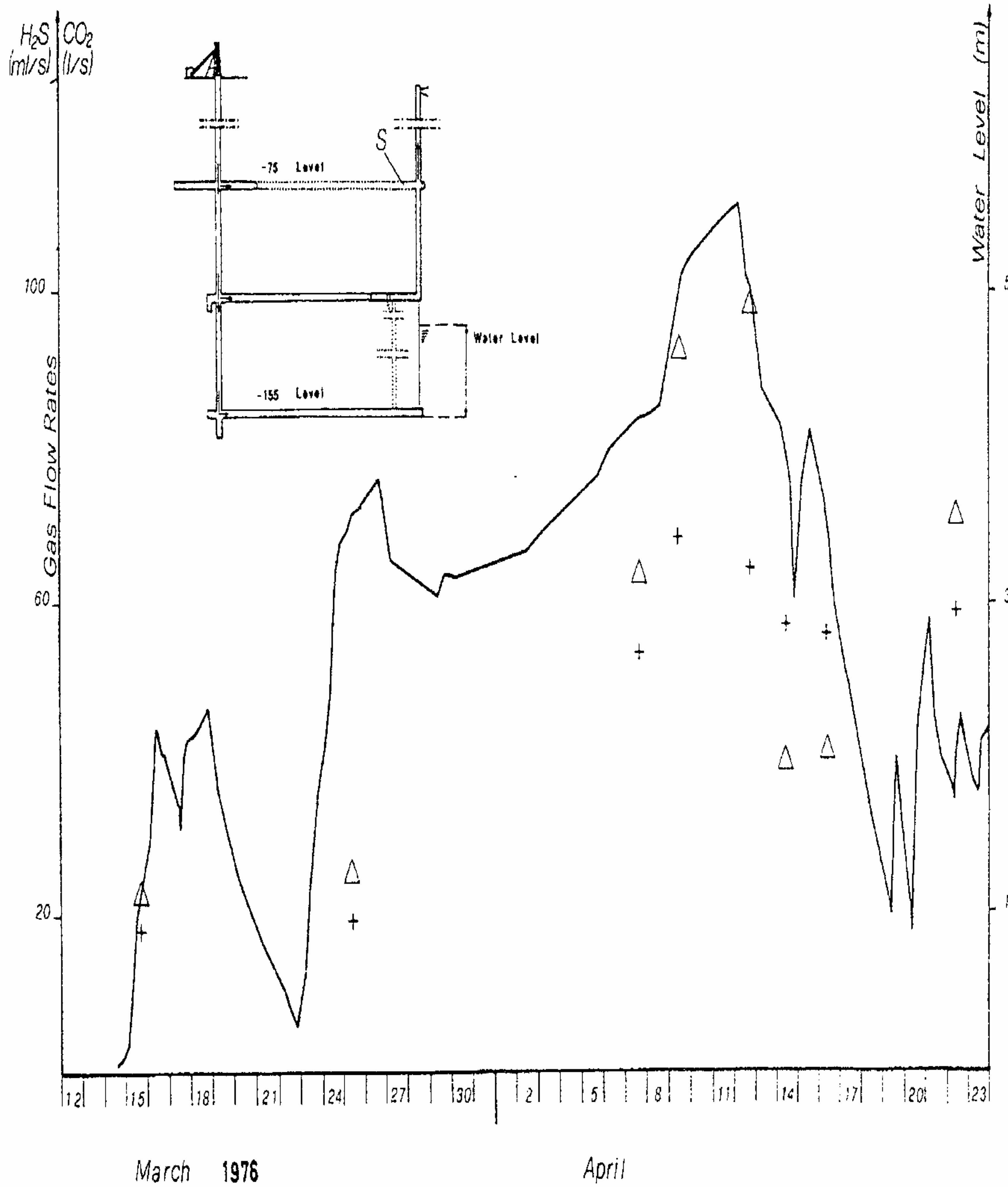

Figure 1. Bagni San Filippo Mine. Water level in mine and flow rates of the gases CO_2 (triangles) and H_2S (crosses) obtained by taking in the cross section S air flow rates and gases concentrations.

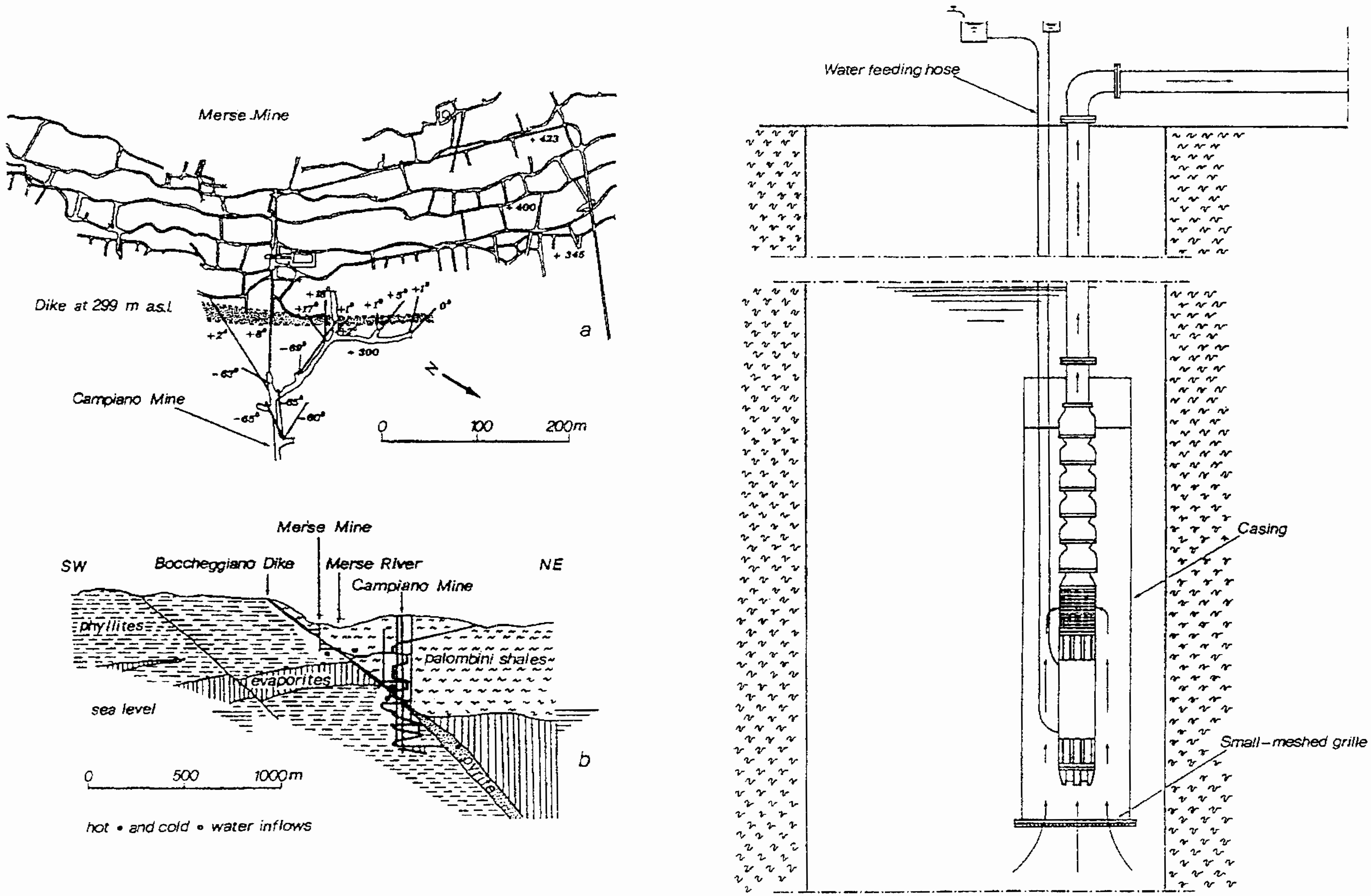

Figure 2. On the left: the Merse Mine and the Campiano Mine, flooded in 1901 and in 1977 respectively. On the right: devices for avoiding breakdowns of the submersible pumps used for dewatering the Campiano mine.

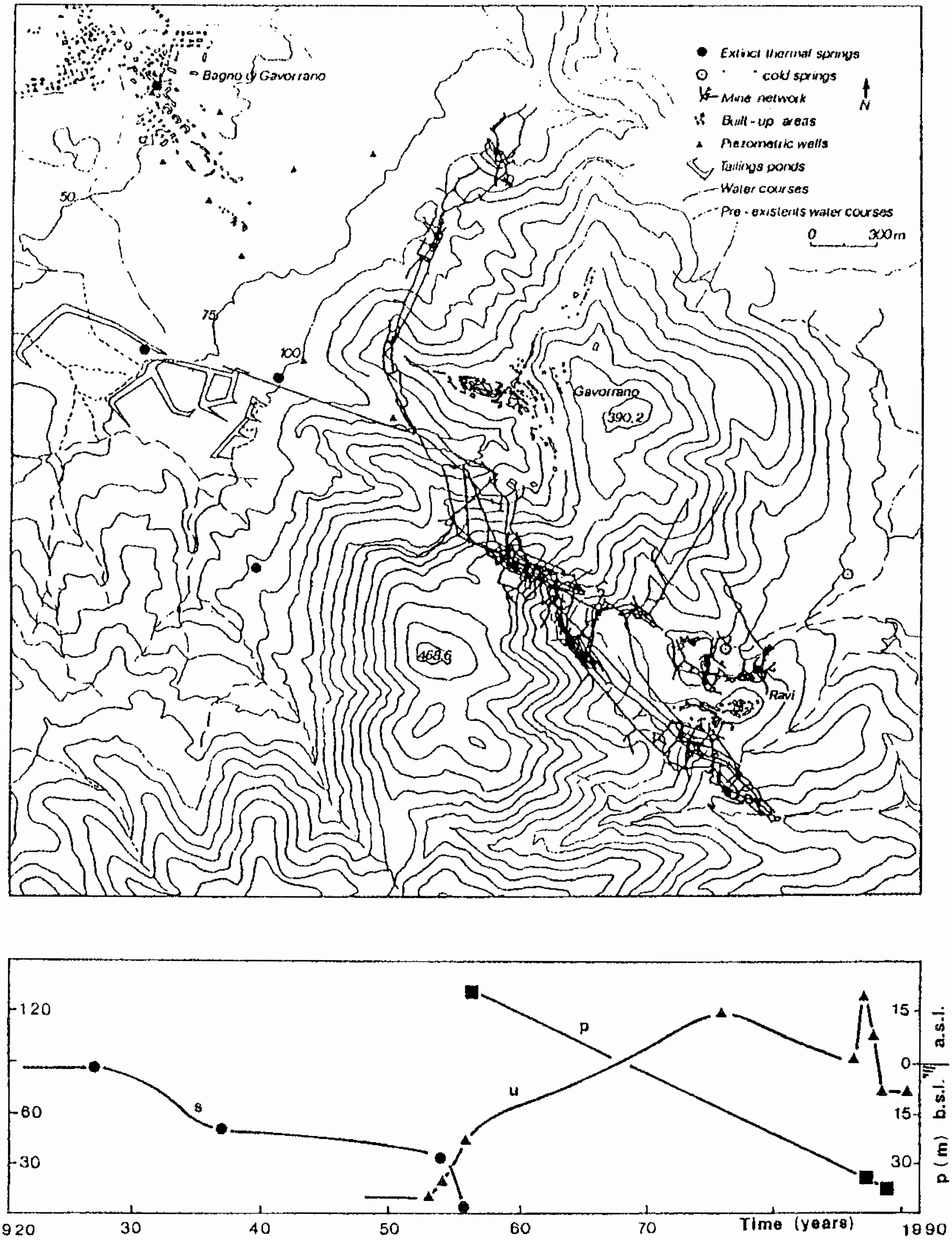

Figure 3. Gavorrano Mine. Above: mine network, morphology of the surface over and round the mine, pre-existent and actual situations. Below: correlation between the water flow-rate pumped out, u, and the hydrodynamics of surface, s and p.

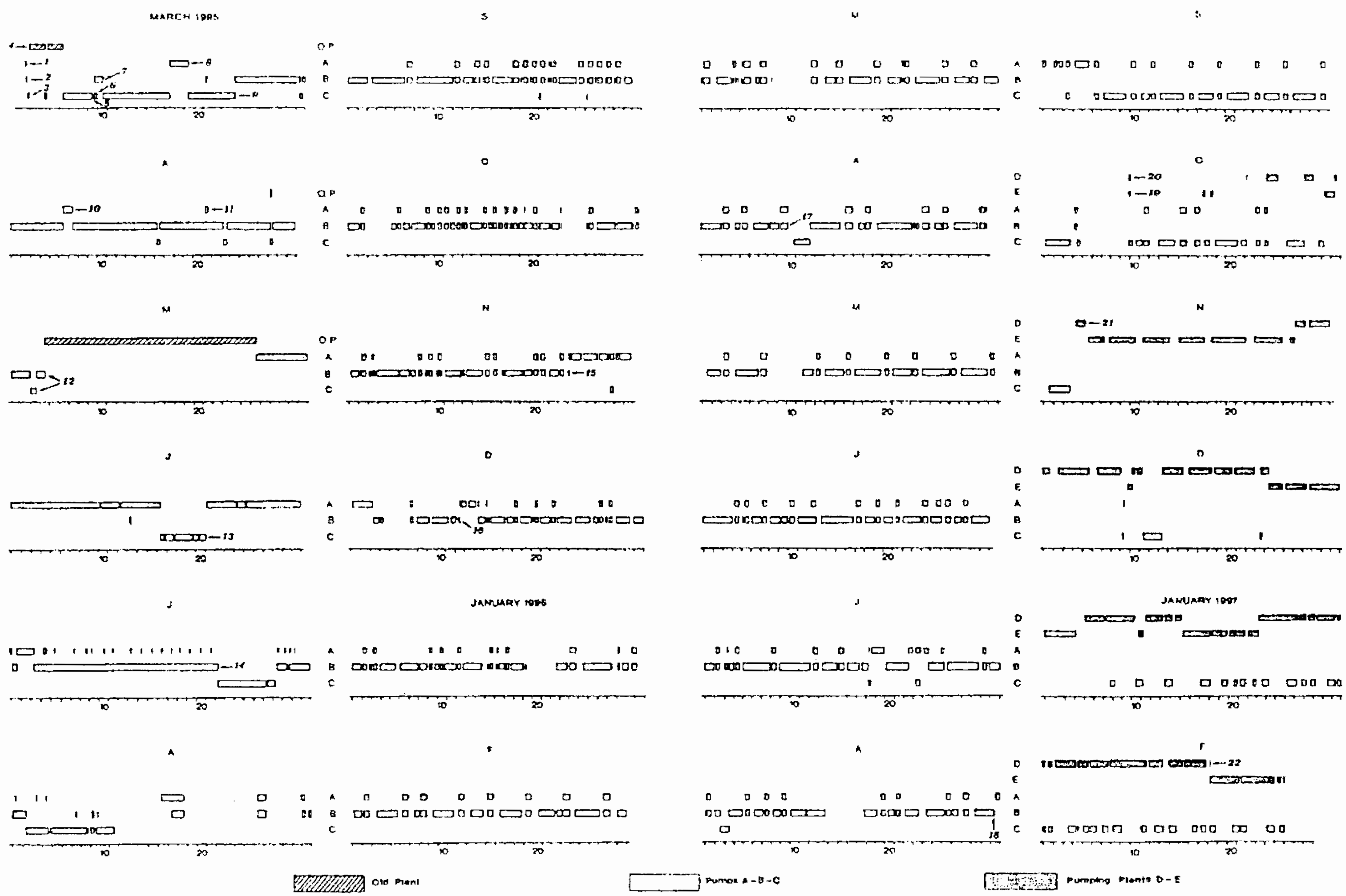

Figure 4. Gavorrano Mine. Working periods of the old pumping plant and of the new pumps: the arrows show pumping stoppings due to failures that hav'nt, however, absolutely prevented the continuous control of the water level in mine, owing to the highlevel of reliability of the system adopted for realizing that control (fail-safe).

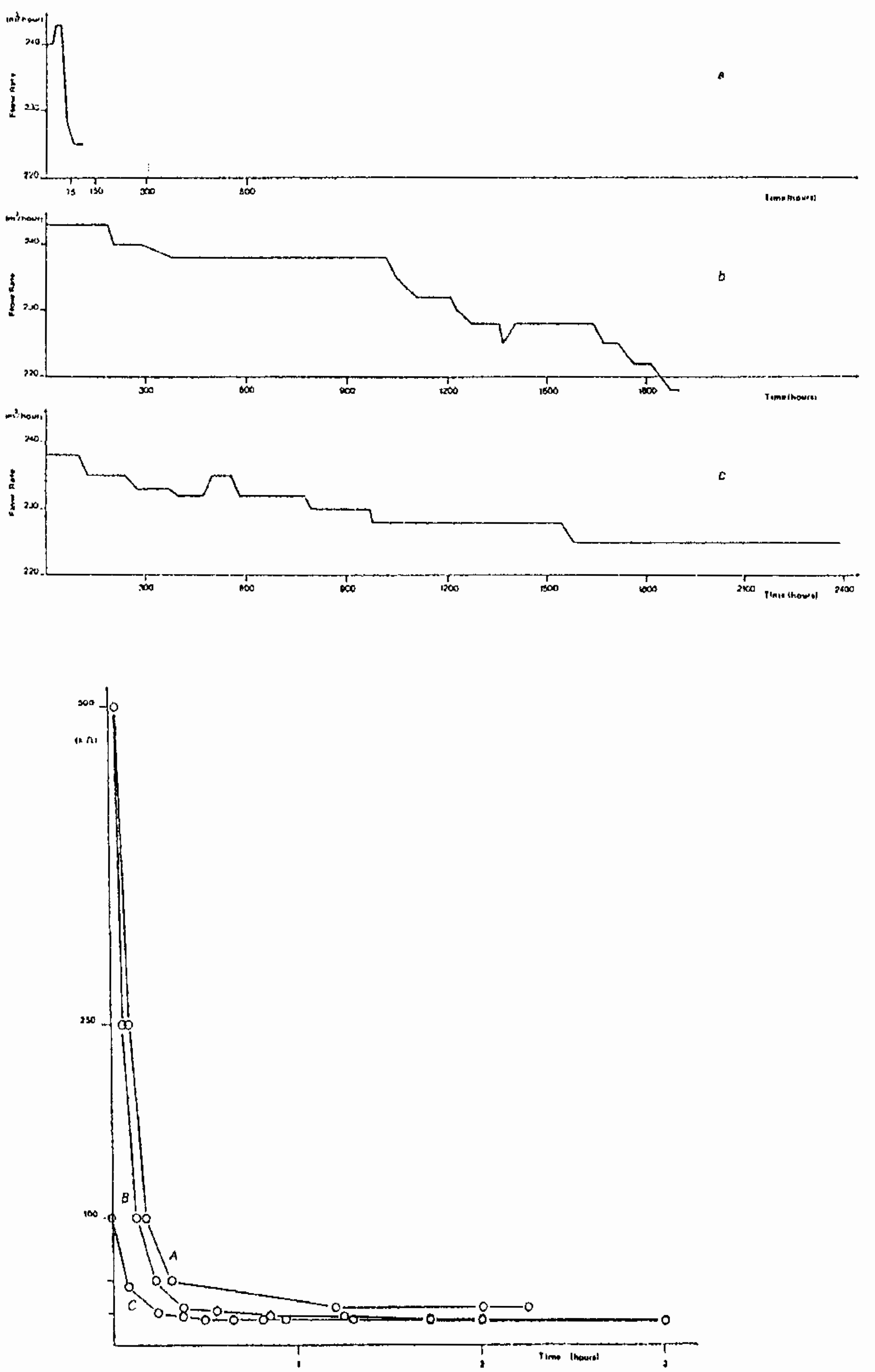

Figure 5. Gavorrano Mine. Above: typical decreases of submersible pumps flow rates owing to breakings of gaskets of flange joints. Below: decreases of the PVC insulation resistance of the stator winding after a first starting, A, and after following statings, B and C; for the gradual deterioration of the insulation materials PVC that are subjected to high temperatures it is possible, by recording the values of their resistances, to foresee and avoid short circuits.

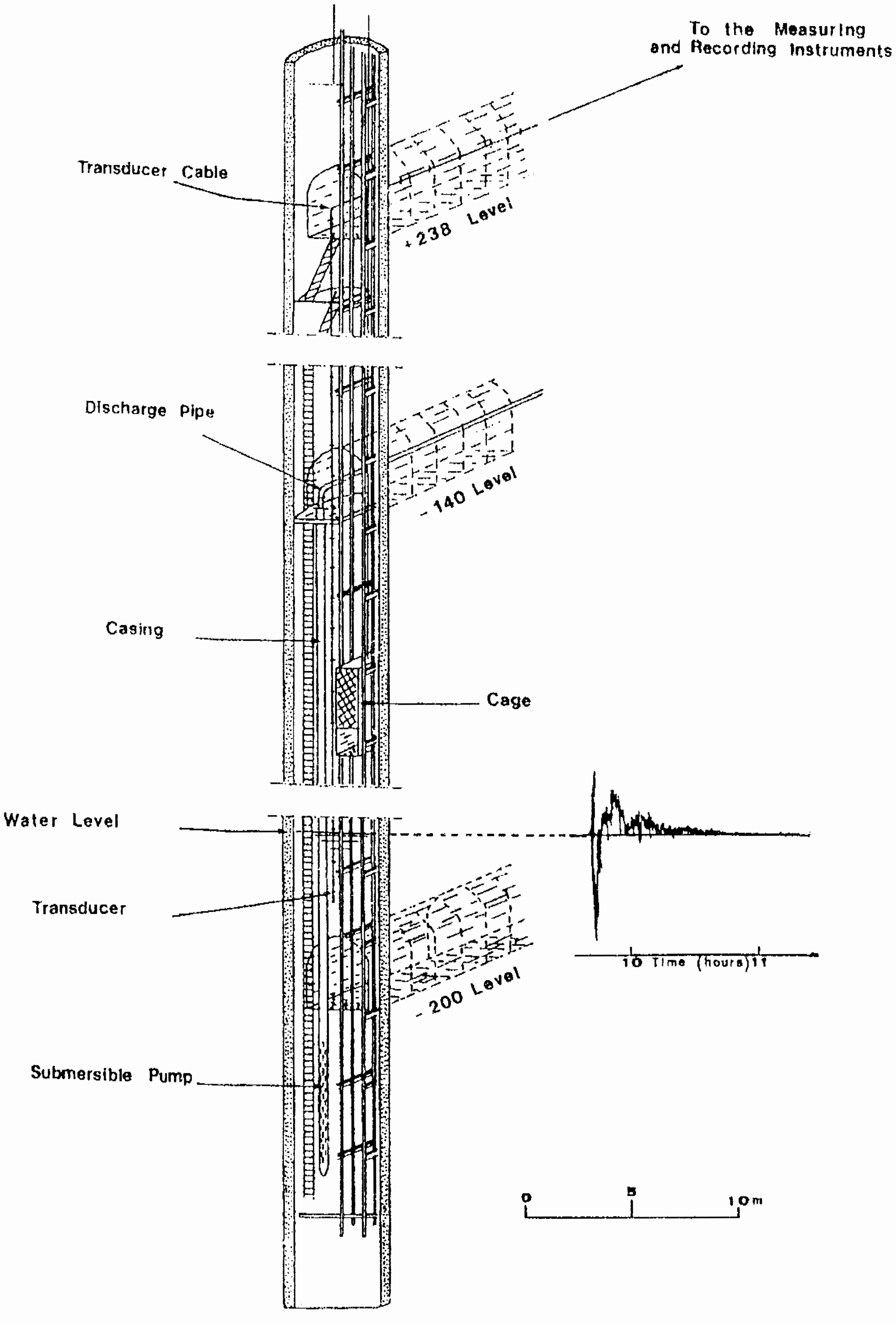

Figure 6. Transducer in a shaft of the Gavorrano Mine for recording oscillations of the water level, in correspondence to this level the oscillations that occurred on the eleventh of June 1996 in consequence of a landslide have been drawn.