Underground Quarrying and Water Control: Some Cases from Northern Italy

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Abstract

The geological and hydrogeological settings of deposits have a considerable influence on mining operations, and the mines can have a strong impact on natural systems. In particular, specific cases of interaction between exploitation activity and natural water circulation have been observed in the Monferrato area (Piemonte) and in the Prealps (Lombardia). Three underground quarries (two of gypsum and one of marls) have been geologically, hydrogeologically, and structurally investigated to plan future mining activities or mine void reclamation and thereby enhance sustainability criteria: environment, society, and the economy.

Key words: underground quarry**;** industrial materials**,** water control**;** Italy

Introduction

National regulations in Italy distinguish quarries from mines solely on the basis of the exploited materials. Both provide for underground exploitation and the need for land conservation, low environmental impact, and good quality of natural raw materials. According to mining techniques, underground quarries and mines are built on one or several superimposed levels by creating drifts, rooms and pillars, or rooms and rib pillars. There is considerable interaction between underground exploitation activities and natural phenomena, human activities, and land uses, in particular with regard to to distribution of stresses, water circulation, void stability, and safety.

This paper explores water interaction with mining activity in three specific cases located in the northwest of Italy, two gypsum underground quarries in Piemonte (Moncalvo and Montiglio Municipalities), and a mine of marls for cement in Lombardia (Olgiate Municipality). Only one of them is still working (the Moncalvo gypsum quarry); the other two are abandoned.

The Moncalvo gypsum quarry

The Moncalvo gypsum quarry has been worked since 1993 and consists of 12 km of drifts, which are settled on three regular superimposed levels connected by a helical ramp, between 170 and 113 m above sea level (a.s.l.). The ore body is made on regular coarse- and thin-grained gypsum strata, 10-15 m thick, separated from marly layers, from a few decimeters to 2 m thick. In particular, four gypsum strata have been recognized: one of thin-grained and three of coarse-grained gypsum. Burdens are represented by a succession of marls with thin interbedded layers of gypsum and clay-marly loose deposit.

Because of the low mechanical resistance of the gypsum and the regularity of the ore body, the quarry is mined using continuous mining machinery, i.e., a "roadheader," in a room-and-rib-pillar lozenge pattern; the mined walls have a smooth and regular profile.

The gypsum body is relatively massive; only a few discontinuities and dry relict karst morphology of short development have been intercepted. Local water inflows with a limited and constant discharge (< 1 l/s) were found at some discontinuities, mainly in the SE area of the quarry.

In February 2005, the roadheader intercepted a fracture at the mine face, with a water inflow of low discharge, but high hydraulic pressure. Due to the cut-off of a karst conduit, an inrush event suddenly took place and a large amount of water (about 60,000 m^3 with discharge of some m^3/s) and terrigenous marly sediments came into the quarrying drift (Amalberto et al., 2006). As a consequence of the inrush event, near the NE border of the quarry area, a funnel-shape sinkhole originated at the surface, with a minimum depth of 10 m and a maximum diameter of about 20 m (Fig.1). Pumping, which started the day after the event, continues, and the water level, which was originally at 170 m a.s.l., has stabilized at 134.7 m a.s.l.

To identify the presence of karst empty caves and active karst circuits, a surveying campaign was carried out by means of drilling, piezometric monitoring, geophysical methods (electrical method and seismic refraction tomography), speleological activity, census and monitoring of water inflows, and chemical-physical laboratory tests. An automatic rain gauge (with hourly measurements) was installed

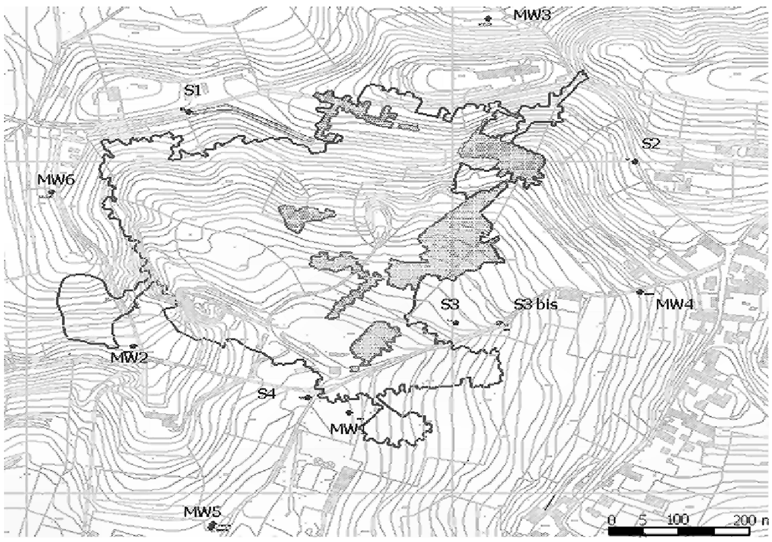
Figure 1 *This sinkhole originated at the surface in connection to the inrush events in the quarry drifts.*

to analyze groundwater table variations relative to rainfall. Finally, a weir equipped with a digital data logger placed close to the point of the inrush continuously measured the level, the temperature, and the electrical conductivity of the water coming from the karst system (Bonetto et al., 2007). At present, water is collected in basins and pumped outside the quarry to stabilize the groundwater table and carry on mining operations in the higher quarry panels. Unfortunately, due to the high values of TDS, electrical conductivity, and sulphates, the water is not suitable for irrigation and so is reintroduced into the surface drainage pattern.

The Montiglio Gypsum Quarry

The abandoned quarry of Montiglio is set up on more than 52 km of drifts, displaced on seven superimposed levels reaching an average depth of 100 m from the surface. The exploitation developed traditionally with drill and blasting techniques, by creating rooms and abandoned pillars, arranged as a "chessboard." Exploitation started in the 1940s and carried on until 1990. Since 1974 and until 1985, industrial sludge was stored in the three upper quarry levels where exploitation had already stopped.
Since the quarry was abandoned, the seventh level has progressively flooded and local water inflows have been observed in the upper levels. Due to the presence of industrial sludge storage, a surveying program, including a drilling campaign and detailed geostructural and hydrogeological surveys, were carried out to identify the possible flow patterns of the water and sludge leachate (Fig. 2).

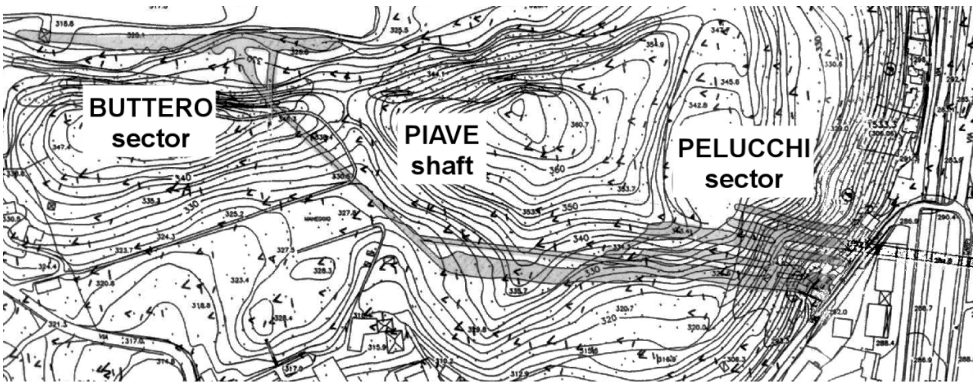
Figure 2 *Sketch of the quarry area with the location of sludge storages and drillholes(MW and S series).*



According to the data collected, the exploited gypsum body represents a block up to 100 m thick and several hundred meters across, floating in marls sediment. The permeability of the deposit has been assessed by both Lugeon and tracer tests to verify a possible connection between the water inside the quarry, the outside groundwater table, and the hydrographic network. On the basis of the obtained permeability values (< 1 UL), the gypsum body can be considered a virtually impermeable system. Its very low permeability is principally due to few open fractures and karst processes (Bonetto et al., 2005).
Drifts represent a system of drainage for water: in particular, two karst springs were observed in addition to the contribution of infiltration and leakage of water from the surface during rainfall events. The marly sediments, which include the ore deposit, prevent a connection between water inside and outside of the quarry. In the exploited voids, water is collected in a properly built basin in level I and is successively pumped to the surface into the artificial "Codana Lake," located close to the quarry.

The Marl Mine of Olgiate Molgora
The Olgiate Molgora mine site is located in the north of Lombardia (Italy); it was exploited as for cement industry marl. Exploitation was carried out from 1906 to 1955. The abandoned drifts are characterized by two main areas: the first (named Pelucchi) is set up on five levels with single drifts 170-280 m long, connected by a skip that covered a drop of 56 m; in the second (named Buttero) there are three main mining levels, with single drifts 260 m long, connected by a vertical 28 m shaft. These two main sectors are connected by a 320 m drainage shaft (named Piave), located nearby the upper drift (Fig. 3).

Figure 3 *plan of the Olgiate Molgora mine sectors*



Tunnels have been involved in water infiltration processes and the four deepest levels have entirely filled with water after mining ceased, containing an estimated water volume of about 150,000 m^3. During large rainfall events, the water level rises to the upper drift to the road near the main entrance of the mine. Underground water circulation is also responsible for serious damage to nearby buildings. By means of monitoring activity, a hydrogeological model of groundwater and tunnels has been completed with the aim of assessing the risk of flooding of the town of Olgiate Molgora and providing civil protection (De Luca et al., 2007).
Two pressure transducers were installed in the drifts to correlate the water table and rainfalls. In the Pelucchi area, the piezometric level is strictly related to atmospheric precipitation: water level variations recorded a delay of less than 24 hours. Water sampling and chemical analysis were used to study the hydrochemical features of the mine water and multi-parameter log analysis allowed the evaluation of the chemical vertical distribution. Anions and cations do not vary considerably in vertical profiles, highlighting a general lack of stratification. The uniform ion distributions and the constant water temperature at various depths indicate a common origin.
Groundwater sampled in wells and piezometers outside of the mine has the same chemical features as the mine water, suggesting an interconnection between the groundwater and the water in the mine. Both are characterized by Ca-Na bicarbonate profile, according to the Piper and Shoeller diagrams where the major-ion data were plotted. The use of a fluorescent dyes (Na-fluorescine) in the mine allowed the evaluation of groundwater flow direction and rate.

Remarks

Inadequate management of the exploitation of natural resources has frequently been responsible for safety and environmental problems. Appropriate planning schemes based on the geo-mechanical behaviour of the material, the hydrogeological features of the deposits, and the relative vulnerability of the sites, are necessary to assure the proper use of raw materials and to assure that quarries achieve environmental sustainability and operate safely.

The stability of the quarry structures and the geometrical parameters of sill, crown, and rib pillars are strictly connected with drifting depth, thickness, and the kind of cappings and geo-structural setting of the ore body. With regard to soluble rocks, risks are particularly associated with the presence of large empty karst caves or caves filled with marly-clay deposits or water that exert dangerous pressure on the mining face. Therefore, advance exploratory drilling in different directions is recommended to prevent unexpected mine face instability and interference with mining operations as caused by dangerous inrush events in local hydrogeological settings.

Safe restoration of abandoned drifts filled with water may involve reducing water infiltration and the dewatering of mine voids. Changes of stress distribution on the rib wall and a worsening of geotechnical rock features should be considered where continuous water filling and emptying may occur. Lowering of the water table, drainage of surface flows, and drawdown cone extension should be taken into account when planning quarrying and the future rehabilitation of abandoned voids. In addition, the potential sustainable exploitation of underground water storage in mine void space should be considered as a future resource.

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