Geo-surveying for safe underground mining in gypsum deposit in Monferrato basin (Italy)

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ABSTRACT: Gypsum is an important raw material for constructions and other industrial sectors. In the last few years, gypsum exploitation has been developed, due to the high request on the national and international market. In Piemonte, main gypsum bodies are located in the Monferrato area. In the last centuries, most of them have been exploited and, actually, four quarries are still working. The gypsum bearing formation outcrops show typical geological, structural and hydrogeological features which can influence quarrying exploitation. According to observations and data collected in some gypsum quarries, this paper considers some of these aspects in order to point out the main problems connected to the gypsum quarrying activity and give proper operational advises in quarrying surveying, planning and management of open pit and underground exploitations of gypsum. Due to recent new hypothesis about the geological and structural setting of the gypsum deposits in Monferrato area, particular attention will pay to their consequences on the traditional surveying methods, taking also care to geo-mechanical aspects related to the presence of karst phenomena and stratigraphical or structural marly layers.

1 INTRODUCTION

In the last few years, the gypsum quarrying activity has been increased due to the high request of natural raw material for different industrial sectors. As for every natural resources, a bad management of gypsum exploitations has been frequently responsible of environmental and safety problems connected to the quarry face and drift stability and subsidence hazard on surface. For that reason, both geo-mechanical behaviour and geo-hydrological features of the gypsum deposit have to be precisely defined to program suitable surveys, planning and management of the quarry.

In Piedmont, main exploited gypsum bodies belong to the Messinian “Formazione Gessoso Solfifera” (named “Complesso Caotico di Valle Versa”; Dela Pierre *et al.*, 2003) that are locared along two large belts (from a few hundred meters to two kilometers width), bounding to the N and S the Tertiary Piedmont Basin. The north belt runs in a discontinuous manner for 35 kilometers, from Moncucco to Ottiglio (Monferrato domain), while the south belt (Langhe domain) runs for almost 25 km crossing the whole central area of Piedmont from W to E (Fig. 1).

Figure 1. Geological sketch of the Tertiary Piedmont Basin; outcrops of the Messinian formation are in black.

Many open pit and underground quarries were present in those areas, most of them actually abandoned; at present just four gypsum quarries located in Monferrato domain are still working.

2 GEOLOGICAL AND STRUCTURAL SETTING OF GYPSUM BODIES AND RELIABILITY OF GEO-SURVEYING METHODS IN GYPSUM EXPLOITATION

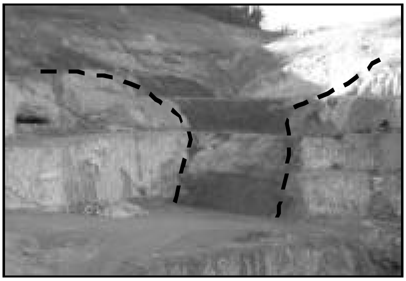
The “Formazione Gessoso Solfifera” (Messinian) can reach a total thickness up to about 400 meters, but the thickness of included gypsum bodies is quite variable and, sometimes, hard to evaluate. They generally seems to exceed 60-70 meters in the north belt, while it rarely exceeds 20-30 meters in the south belt (with values increasing going from West to East).

The messinian succession is characterized by cycles composed of pre-evaporitic deposits - made of thin sands, silts and laminated clays - evaporitic beds - mainly composed of a basal carbonate level and layers of gypsum separated by marls and algal carbonates - and post-evaporitic sediments, consisting of grey marls, needle-shaped gypsum crystals, clays and local conglomerates (Bonsignore et al., 1969; Sturani, 1976). Thickness and presence of the different kinds of deposits depend on deposition areas in the original basin and subsequent tectonic events.

Till now, gypsum deposits have always been interpreted as lenses, with a total length of hundreds of meters, composed of regular gypsum strata - up to 15 meters thick - and interbedded levels of marls, few decimetres up to 2-3 metres thick. Gypsum beds show two facies with different mechanical and commercial characteristics: a coarse-graned selenitic one, with grain size up to tens of centimeters, and a small-grained one, with crystal size ranging from a few millimeters to several centimeters. Gypsum lenses are also locally interested by tectonic discontinuities, sometimes open and refilled of marls and clays.

On the base of the field data collected, in some areas, this geological model is not fit to explain local setting. As a matter of fact, somewhere (as for exemple in the Montiglio and Moncucco area), gypsum bodies seem to belong to a chaotic deposit resting unconformably on the older geological formations and interpreted as a melange of different blocks (made of bioclastic rudstones, coquinoid grainstones, limestone, dolomite, carbonate monogenic breccias, conglomerates, marls and gypsum) floating in a matrix of weakly consolidated “mud breccias”. In particular, matrix consists of brownish silty-marly deposits, containing small clasts of grey marl from some few millimetres up to several centimetres size. Probably, the “melange” comes from gravity-driven processes and mud diapirism phenomena (suggested by methane-derived carbonate), related to tectonic events that affected and dismember the original evaporitic succession after its deposition (Dela Pierre et al., 2003).

According to this hypothesis, gypsum bodies represent irregular blocks of various size, ranging from some meters up to several hundred meters of extension and dozen of meters of thickness. They mainly conserve typical depositional succession of alternating marly layers and gypsum beds (coarse and small-grained), but clastic gypsum facies and tectonic structures with marly-clay refilling are more abundant. Transpressive tectonic structures are also been observed (Fig.2).


a)


b)

Figure 2. a)Transpressive structure observed in the Moncucco quarry (Asti), probably related to diapirism phenomena. b) Karst void in a mining drift excavated by roadheader.

Due to mechanisms of genesis, the shape of gypsum bodies and original stratigraphic relationships with surrounding deposits are uncertain from time to time. Each block is completely bounded by tectonic contacts and lateral continuity is not assured. For that reason, more attention has to be paid to the choice and reliability of surveying methods in order to define both shape, dimension, orientation, structure of gypsum bodies and thickness of the overburden deposits. All this parameters need to be clearly identify to succeed in the exploitation activity, due to their influence in the quarrying management since the planning stage.

Usually, besides field observations, the reconstruction of geological setting can be accomplished with the help of drillings and, eventually, geophysical surveys using electrical methods (SEV or electric tomography) and seismic refraction methodology. Considering the possible chaotic set up of the deposits, drillings need to be step up and geophysical surveys become necessary. Isolated drillings in fact are not exhaustive: because of the extremely variability of the geological setting, they just give punctual information and simple correlations between them are not reliable.

Moreover, drillings allow to carry out in situ tests and collect samples for analysis and laboratory tests in order to define the gypsum quality and geotechnical parameters of exploited deposits and overburdens (cohesion, angle of repose, specific weight, deformation modulus, elasticity modulus, section modulus, compressive strength, shear strength).

Due to the short number and limited size of outcropping areas, when open pit or underground quarries are already present, structural setting as well as physical, mechanical and hydraulic features of discontinuities can be appropriately investigated by means of detailed structural surveys in correspondence of existing quarry faces and drifts.

3 HYDROGEOLOGICAL ASPECTS CONDITIONNING EXPLOITATION ACTIVITY AND QUARRYING MANAGEMENT

Considering the low primary permeability and the geo-structural features of gypsum bodies, they can be considered like a bedrock aquifer systems due to the presence of faults, open fractures and karst voids. Infiltration and diffusion phenomena through the overburden represent a way of inflow for water from surface, whereas open discontinuities are not only the way of leakage for this water, but also a passage for water eventually flowing from the bottom.

Because of the high solubility, one of the main problem in gypsum exploitation is represented by active karst or presence of abandoned karst voids refilled by residual deposits (usually clay and marls). Gypsum karst has a considerable influence on quarrying activities, as well as quarrying activities can produce strong impact on gypsum karst, particularly when changes in groundwater circulation are induced and quarry interferes with the local hydrogeological setting. Without a steady geo-survey and a correct quarrying management, exploitation activity can be responsible for dangerous water inrushes, impoverishment of natural water resources, lowering of the water table in communicating surface aquifers, increase in water flow velocity and gypsum dissolution rate, collapses and drawdown cones extension. Gravitational breakdowns can initially develop in the karst unit and, in some cases, successively propagate upward through the overlying beds, reaching the surface and producing subsidence phenomena (Fig.3).

Figure 3. Sinkhole developed in the gypsum quarry area of Moncalvo (Asti).

Gypsum karsts begin to develop in deep-seated conditions and continue to evolve during the uplift of gypsum layers into shallower positions due to tectonic events and contribution of the erosional activity. Such development commonly occurs under confined hydrogeological conditions, evolving subsequently to phreatic and vadose conditions. Depending on initial discontinuities pattern, in confined conditions, active groundwater circulation favours the development of uniform maze conduit systems or isolated large voids; on the contrary phreatic and vadose conditions favour the development of linear or dendritic cave systems. Actually, evidences of dissolution processes and karst activity in gypsum deposits have been principally observed in the upper part of the gypsum body, particularly up to the talweg of the main local river (Fioraso & Boano, 2002).

Since water circulation in gypsum bodies is directly connected to discontinuities and karst system features, structural setting of the deposits and voids distribution have to be defined, as precisely as possible, by means of geo-mechanic surveys and geophysical methods.

Data collected during geo-mechanic surveys display orientation and extension of main discontinuity systems and, consequently, hypothetical water flow directions; besides, opening and frequency features of discontinuities furnish average permeability values for gypsum body, for example using Snow (1969) or Kiraly-Louis (1969) equations. Permeability conditions can also be studied by means of Lugeon Tests, but their reliability is strongly conditioned both by the way of carrying out the test and the punctual geo-structural setting. Results coming from geo-mechanic surveys and Lugeon Tests can be finally compared.

According to the hydrogeological behaviour of gypsum bodies, some piezometers have to be planned to investigate the presence of water in the different sectors of the exploited area. Furthermore, in order to verify the presence of connections between water inside and water outside the quarry, tracer tests can be made by means of fluorescent tracer introduced in proper drilled boreholes, monitoring its presence in piezometers located out of the exploited area.

Concerning geophysical surveys, main results have been obtained by using electrical and seismic refraction methodology, integrated with properly located drillings to set geophysical data obtained. In that way it is possible to clarify the structure of the gypsum body as for example to point out the presence of faults, shear zones, karst caves and burden thickness (Ferrero et al, 1990).

Reliability of the data processed can be increased by testing time to time small parts of the deposit or even singular exploiting panels; nevertheless this solution requires time and considerable liquid assets.

In order to take precautionary measures and prevent water inrushes due to the unexpected presence of active karst circuits, horizontal drillings can be periodically renew during exploitation in correspondence of the quarry face. That will also allow to update and eventually revise geological knowledge and project data. In case of water inflow through the drillings, it is recommended to install a proper drain cock with manometer in order to monitor the water pressure behind the quarry face and avoid an uncontrolled water inrush.

In underground quarries, inflowing water is collected in proper basins and rejected outside by means of pumps. Systematic pumping could be accepted during quarrying activity, but it can’t be protracted in the rehabilitation stage. For that reason, where possible, it is necessary to create a new way of flowing to reinsert water in natural circuits for example by means of gravity drains or pipes.

4 GEOMECHANICAL AND MINING FEATURES

As previously described, the layout of the gypsum deposits, at least in the geographical ared here taken into account, are related to the original sedimentary processes followed by subsequent gravitative phenomena which involved the sufficient energy to fracture and displace large blocks and platforms gypsum strata bearing and to remold them inside a caotic external formation; eventual and local gas eruption phenomema possibly occurred, but not so extended to induce the present geostructural setting.

In any case, the deposits occur with regular subhorizontal strata, or with large disturbed massive bodies or, locally, with inclined seams. Rarely these structures are not interested by intercalations or laterally displaced heterogeneities. These events have to be taken into account as they have different consequences: for example on the regularity and repeatability of the mining schemes, on the stability nearby the borders of the deposits and also on the quality of the exploited materials.

The geomechanical parameters for the gypsum are those typical of a weak material but some differences arise when considering for example a realtive stiff behaviour while in failure. The range of the experimental values are also influenced by the crystallinic structure (small or large sized crystalls). One should be aware that due to typical anisotropy of the materials and to the weakness of the gypsum it is not wise to simply adopt the literature values, because the risk of false assumption is very high. Moreover it should be of great help for understanding the rock pillar behaviour to carry out also triaxial compressive tests. Few data can be found in the literature as far as creep deformation in gypsum is concerned.

Table 1. Range of geomechanical parameters for gypsum.

Geomechanical parameters on intact rocks	Fine grained gypsum	Coarse grained gypsum
ã - unit weigth (g/cm^3)	2.07-2.23	2.10-2.32
C_0 - uniaxial compressive strenght (MPa)	11.1-15.5	5.7-11.7
E_s - secant modulus (MPa)	10100-15700	1700-4500
E_t - tangent modulus (MPa)	6100-14400	1900-4900
ν_t - tangent Poisson coefficient	0.40	
T_0 - tensile resistance (MPa)	1.16-1.79	0.34-0.75
c_p – peak cohesion (MPa)	2.9-5.0	1.1-4.2
ö$_p$ - peak friction angle (°)	39-48	38-57
ö$_r$ - residual friction angle (°)	32-35	31-40

At a larger scale, that of the geological formation, the most relevant characteristics of the rock mass are:

- the limited but meaningful occurrance of fractures in the gypsum, due to the long term viscosity of the gypsum and to the sedimentary process; the origin of these discontinuities is linked to regional tectonics and to the contact between different rock types (Fig.4);
- the presence of both false roofs and thin or thick inclusions of other soil/rock veins. These last elements should be detected during the geological survey in order to depict a possible scenary of separation of gypsum blocks while mining. The problem of subhorizontal slabs is relevant only the upper part of the body, where there is the transition to marl, argillites, soft sandstones etc.

Due to all these reasons, the gypsum can be reasonably modelled by means of continuous models, only assessing local stability problems by means of limit equilibrium method.

The mining methods are mainly those of room and pillar explotation, sometimes with local filling by waste rock, but due to secondary purposes. The bodies, apart the open pit excavation, are exploited on different levels, connected each others through elicoidal ramps. The approximative width of square pillars is of about 6-8 m and the rooms are similarly 7-8 m large. The heigth of the level is usually about 6-7 m and the horizontal barriers between levels is at least 3.5-4.0 m. On this base one should assess the recovery factor and compare it with the increasing stress on the pillars, by adopting for example the tributary area method for stress calculation and by arranging the pillar strength reduction following the literature approaches. It should be emphasized that for the roof stability both the hypothesis of thin layer loaded by the superimposed rock and the case of thick beam (arch effect) should be adopted for a reliable and complete stability assessment.

The exploitation is usually done by means of blasting (Fig.4), creating a main drift and then creating transversal adits to contour progressively the new pillars. Another suitable technique is the use of road header with truck mucking.

Finally, considering the monitoring it should be always arranged a system of pillar and roof monitoring, and wall contact as well. The pillar and the roofs can be equipped with optical targets and crackmeters, for the pillar also crossing extensometers can be useful if well installed and in a preliminary excavation phase. Some devices for stress recovery (flat jacks or borehole stressmeters) can be occasionally installed. For the wall control (subsidence, roof detachment) long base extensometers are suitable for the purpose.

5 CONCLUSIONS

Gypsum is an important raw material for building constructions and many other industrial sectors.

In Piedmont, main exploited gypsum bodies belong to the Messinian “Formazione Gessoso Solfifera” (recently named “Complesso Caotico di Valle Versa”; Dela Pierre et al., 2003) which principally outcrops in the Langhe and Monferrato domains (Tertiary Piedmont Basin). Many open pit or underground gypsum quarries were opened in that areas, but most of them are actually abandoned: at present, the only active ones are located in Monferrato.

Figure 4. On the left, a room and pillar mine, excavated by blasting. On the right, a main transerval joint in a pillar.

Due to its geo-structural setting and hydrological features, gypsum exploitation has been frequently responsible of environmental and safety problems connected to the quarry face and drift stability and surface subsidence hazard. Stratigraphical or structural marly layers, active karst circuits and abandoned karst voids refilled of water or terrigenous deposits are main critical aspects to pay attention in planning and management of quarrying activity.

Methodological approaches to assure a right risk management and suitable land planning consist in geological, structural and hydrogeological studies, supported by geophysical surveys and hydrological monitoring.

First, reliability of surveying program depends on geological asset of the deposit: the presence of regular gypsum lenses or chaotic melange (irregular gypsum blocks included in a matrix of weakly consolidated "mud breccias") influences correlation, number and distributions of mechanical and geophysical surveys.

Furthermore, both geotechnical and geo-mechanical behaviour of the gypsum deposit and marly levels have to be precisely defined by means of suitable laboratory tests and in situ monitoring activities in order to verify face and drifts stability and reconstruct tensional stresses distribution in the ore body.

Finally, attention have to be focused on water resource protection and hazard assessment connected to the presence of karst activity in order to prevent environmental impacts and guarantee a correct exploitation of gypsum resource in safety conditions.

For a safe design the steps regarding local geostructural survey, the geomechanical characterization and the stope monitoring, mainly for deformation, should always be foreseen.

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