

# Subsidence Induced by the Instability of Weak Rock Underground Quarries in Apulia

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**ABSTRACT.** The underground exploitation of calcarenitic rocks, it's not uncommon especially in cases where the calcarenites doesn't outcrop. This activity caused evident phenomena of subsidence in surface with damages to the belongings and people too. In the present note, some Italian cases are outlined, over all for as concerns the geometric characteristics of the mining that strongly influence the stability of single structural elements (pillar, roofs) and of the mine in its whole. Particularly, as regards the shape of the pillars and the excavated tunnels, it is noted that their irregularity facilitates instability, which also increases with the age of the quarry. It's of fundamental importance, an unfavourable orientation of excavation with respect to the structural characteristics of the area, like in Mottola (Italy), where there have also been problems of the decay of the physical and mechanical rock characteristics because of the meteoric water drainage in the quarry.

**Key terms:** Underground quarries, Subsidence, Weak rocks, Geomechanics.

## Introduction

The exploitation of weak rocks, such as calcarenites and second category ones, generally takes place in open quarries. However, underground extraction is not uncommon especially in cases where the calcarenite does not crop out and the removal of surface terrain would be expensive either because of its depth or in order to avoid the resulting loss of the terrain for agricultural production.

In the past, the extraction of calcarenite blocks from underground quarries was carried out using methods that were essentially based on experience. The blocks were therefore extracted so as to leave lines of pillars in a more or less regular form and alignment to support the roof of the cavity created by the extraction.

Examples of analyses of static equilibrium underground cavities, similar to those referred to here, are extensively described in the work of WHITTAKER & REDDISH (1989) and in various scientific papers (BARLA & JARRE, 1990; LEMBO FAZIO & RIBACCHI, 1990; JOSIEN, 1995; BELL & BRUYN, 1999; LAUSDEI *et alii*, 1999; ORESTE *et alii*, 2002) which prevalently concern the underground exploitation of rocks of high economic value and which have, in any case, a geomechanical behavior that is often very different from that of weak rocks. There are relatively few studies and research on underground calcarenite quarries (FORNARO & BOSTICCO, 1998; BRUNO, 1999; PICCINI, 1999). As regards Italy, there may be two explanations for this: the first is that this type of quarrying is rare owing to the limited self-supporting capacity of these soft rocks, which causes a high risk of instability both for the area exploited and those

adjacent to it; the second is linked to stratigraphic factors and thus to the fact that calcarenite rocks were widespread particularly during the Plio-Pleistocene so that they tend to occupy the upper parts of the stratigraphic series, and are found most often on the surface with a limited thickness rather than in depth.

The most significant morphodynamic process associated with the instability of the underground extraction of rocks is that of subsidence. This involves the modifications induced in the surface morphology by the collapses and settlement that take place within the underground cavity, with the considerable damage that results to the infrastructure and housing above, especially in the case of cavities below built-up areas (TONI & QUARTULLI, 1985; CHERUBINI, 1990; BRUNO & CHERUBINI, 2002).

## Petrography and Physical-Mechanical Characteristics of Quarried Rocks

The rocks subject to underground exploitation in Apulia are essentially those belonging to the Plio-Quaternary formation of the "Calcarenite of Gravina".

Petrographically they can be classified as medium to rough and locally ruditic grained calcarenites, with a color that varies from white to light yellow. In detail these are biosparites with a prevalently grainstone and, secondarily, packstone-grainstone texture. The bioclastic granules, that prevail in percentage terms, are due to the fragmentation both of macrofossils (lamellibranches, gastropods, sea urchins, bryoz, algae, etc.) and microfossils (planctonic and benthic foraminifers, etc.). In reverse order of abundance,

the lithic granules are formed by quartz, feldspar, polymineralogical granules, iron oxide and glauconite (COTECCHIA *et alii*, 1985).

From the technical point of view these rocks can be classified as “weak rocks” (DOBEREINER & DE FREITAS, 1986; CALABRESI *et alii*, 1990; EVANGELISTA & PELLEGRINO, 1990), with very limited simple compression strength; the values of the physical-mechanical parameters they present, are rather variable owing to the great lack of compositional and textural homogeneity of the rock (CALÒ *et alii*, 1992).

Previous studies have revealed a significant variability of some physical parameters: degree of compactness, porosity, imbibition coefficient in relation to the depositional environment of the rock (ZEZZA, 1981) and monoaxial compression strength relative to the outcropping or underground sample (SPILOTRO *et alii*, 1993).

## Natural and Artificial Cavities

### Cutrofiano quarry

The town of Cutrofiano lies in Salento, to the south of Lecce at an average altitude of around 100 m above sea level. The southern part of the town is characterized by a stratigraphic succession (FIG.1), formed by sedimentary rocks of the Plio-Pleistocene, transgressive on a substrate prevalently formed by marly calcarenites of the Upper Miocene “Pietra Leccese” which, locally, can be represented by the Miocene “Calcareniti di Andrano” or by calcareous-dolomitic rocks of the Cretaceous.

The overall thickness of the Plio-Pleistocene layer is not constant and, though it remains within 30-40 m, it tends to increase to the south. In particular, the calcarenites, known locally by the term “tufo”, and ascribable to the Formation of “Calcareniti di Gravina”, have been widely exploited since the beginning of the last century as building Material (TAB. 1).

Table 1. Physical-mechanical parameters of the calcarenites of the Cutrofiano Quarry.

|        | Specific weight of grains ( $\gamma_s$ ) KN/m <sup>3</sup> | Unit weight of volume ( $\gamma_a$ ) KN/m <sup>3</sup> | Imbibition coefficient % wt | Porosity %  | Degree of compactness | Compression strength MPa |
|--------|--|--|-----------------------------|-------------|-----------------------|--------------------------|
|        | 25÷27.40   | 13.40÷18.50  | 20.00÷30.00                 | 28.00÷51.00 | 0.52÷0.70             | 1.00÷13.76               |
| s.q.m. | 0.80   | 2.00   | -                           | 8.20        | -                     | 0.35                     |

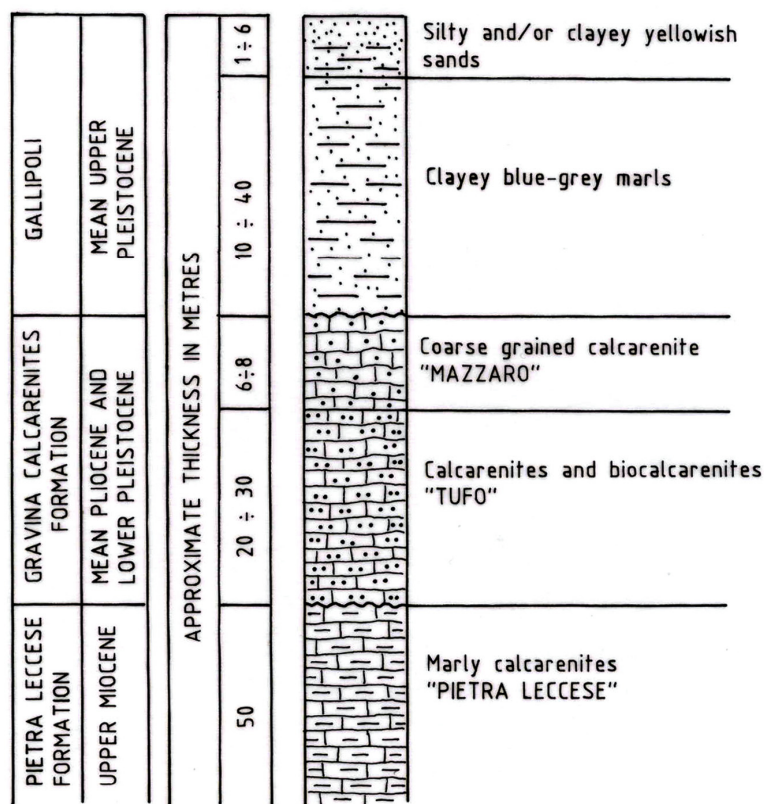


FIG. 1 - Typical stratigraphy in the area of the Cutrofiano quarries (Italy).

Extraction has been carried out underground, employing manual tools in the past and mechanical tools in more recent times. Some of the oldest quarries reveal areas quarried both by hand and mechanically (FIG. 2).

The underground extraction of calcarenites in this area employs the technique of tunnels and pillars abandoned on a single level, and it is technically and economically favored by the presence of very strong and coarse grained calcarenite horizon, with thickness of around  $6 \div 8$  m, known as “mazzaro”.

From a static point of view the “mazzaro” behaves as a slab which has the double task of spreading the loads better on the pillars and contributing with the pillars to support the lithostatic load above. The initial geometry of the extraction was a chessboard with tunnels and lines of pillars arranged orthogonally to each other; subsequently, after the first cases of subsidence, the Mining Office of the Region of Apulia advised the development of extraction according to a plan with staggered pillars. While on one hand this

arrangement of the supporting structure makes the operations of hauling the quarried material slower and more difficult, on the other hand it gives greater stability to the roof of the tunnels where there are widespread tectonic discontinuities whose orientation happens to coincide with that of some tunnels.

In the two quarries studied (FIG. 2), a static study was carried out on two of the geometrical characteristics of the pillars and therefore the area (A) and the perimeter (P); the (A/P) ratio represents a parameter known as “characteristic dimension of the pillar” (W). This is a necessary and discriminating factor for the calculation of their stability and also enables significant statistical comparisons to be made between different quarries.

In particular, evaluation was made of the variation of the ratio (W) between the two quarries and, in the case of the “Rene” quarry, within the same quarry in relation to different methods of extraction.

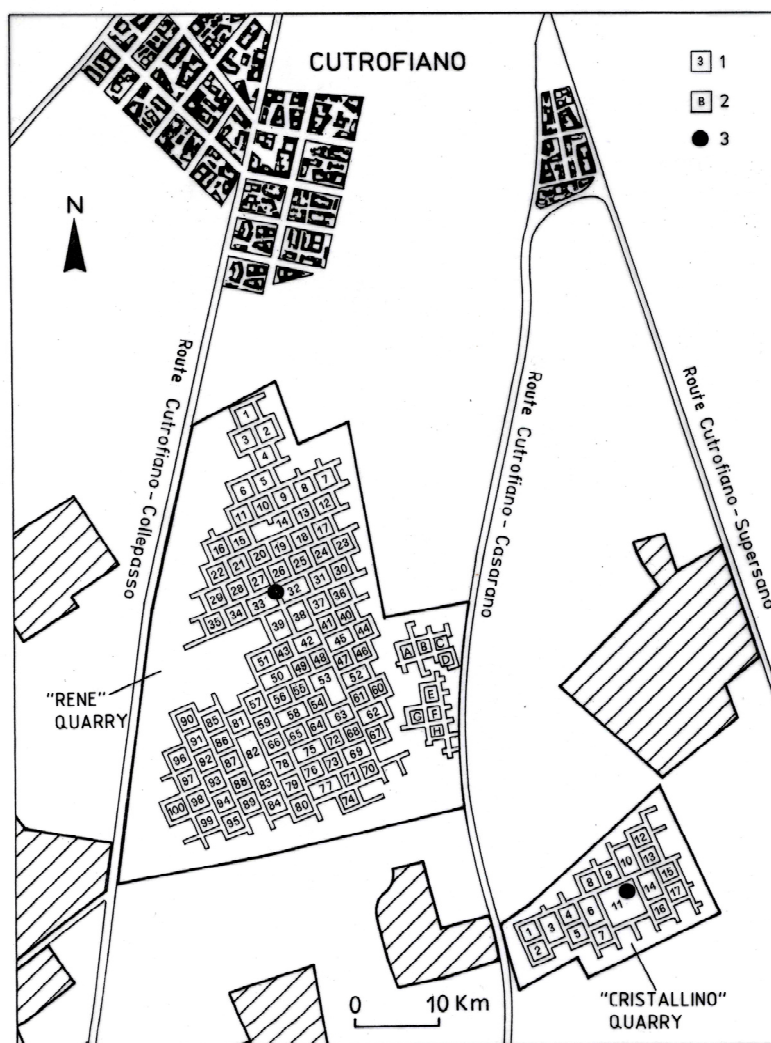


FIG. 2 - Plan of the pillars of the Cutrofiano quarries (Italy) studied: 1) Mechanically excavated pillars; 2) Hand excavated pillars; 3) Entrance to the quarry.

The results obtained for the “Cristallino” quarry, where extraction terminated in 1995, indicate a substantially bimodal distribution of the ratio with an average value of  $A/P = 6.20$  m.

The western part of the “Rene” quarry, worked with mechanical tools, reveals a more or less unimodal distribution of the ratio with an average value of  $W = 5.73$  m. The eastern part of the quarry, which is older and worked manually, reveals a considerably more uniform distribution of the ratio in question, with an average value of  $W = 3.64$  m that is much lower than that calculated for the rest of the quarry.

The highest values of ( $W$ ) found both in the “Cristallino” and, to a greater extent, in the “Rene” quarries is due to the presence of a limited number of pillars of large surface dimensions which may be explained by the safety

technique employed by the quarrymen of creating a clerestory (a shaft for the passage of workmen) in correspondence with the large pillars (FIG. 2). Another reason might be linked to technical decisions to guarantee greater stability in areas where the characteristics of the rocks are inferior and/or where there are significant breaks in the rock.

### Mottola quarry

The quarry studied is located in the southeastern part of the town of Mottola (TA), and more precisely in the area overlooking the town slaughterhouse. From a geological point of view the area is characterized by a litho-stratigraphic sequence (FIG. 3) which has some similarities with Cutrofiano (CHERUBINI *et alii*, 1990).

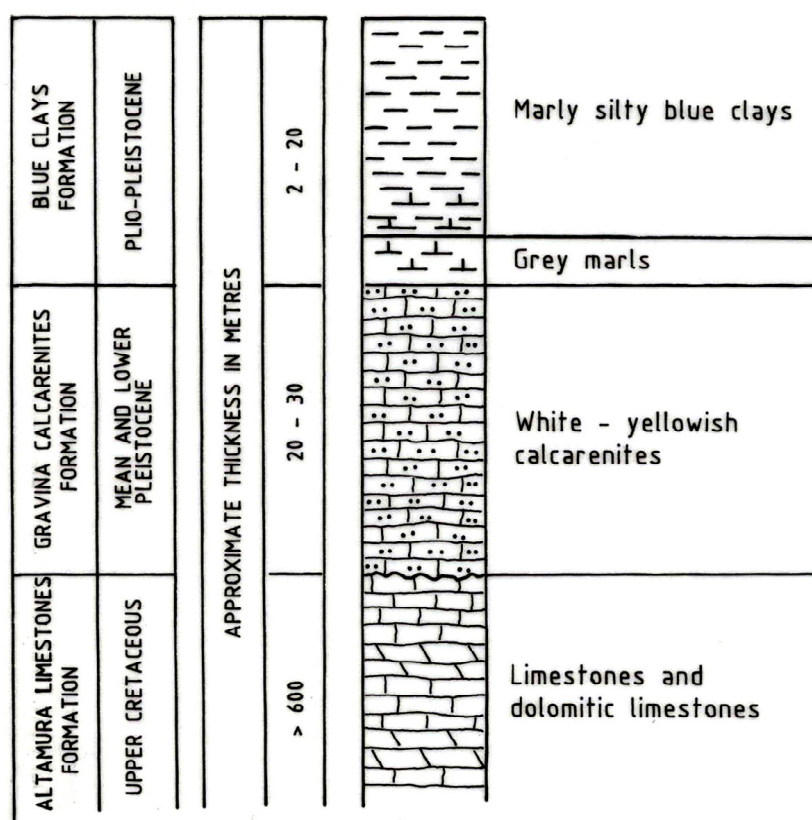


FIG. 3 - Typical stratigraphy in the area of the Mottola quarry (Italy).

The calcarenites extracted underground, belong to the Formation of the “Calcariniti di Gravina” which, transgressive on the calcareous-dolomitic substrate of the Cretaceous, lie below a sedimentary covering around 20 m thick formed by a thin level (20-30 cm) of compact grey and brown colored marl above which lie sub-Apennine marly-silty clays of the Plio-Pleistocene. It is worth noting that in this area, unlike in Cutrofiano, in the upper part of the bank exploited, the layer of tenacious calcarenites known as “mazzaro” is absent. The working of the quarry,

which probably began at the end of the 19<sup>th</sup> century, was carried out with the classical system of excavated tunnels supported by lines of pillars; the excavation plan (FIG. 4) shows great irregularities of form and dimensions in the pillars, which also reveal variations in height.

The physical and mechanical characteristics of the calcarenites have been deduced from many laboratory tests (CHERUBINI & GIASI, 1993); the average values obtained, listed below in Table 2, allow the classification of this lithotype as “weak rock”.



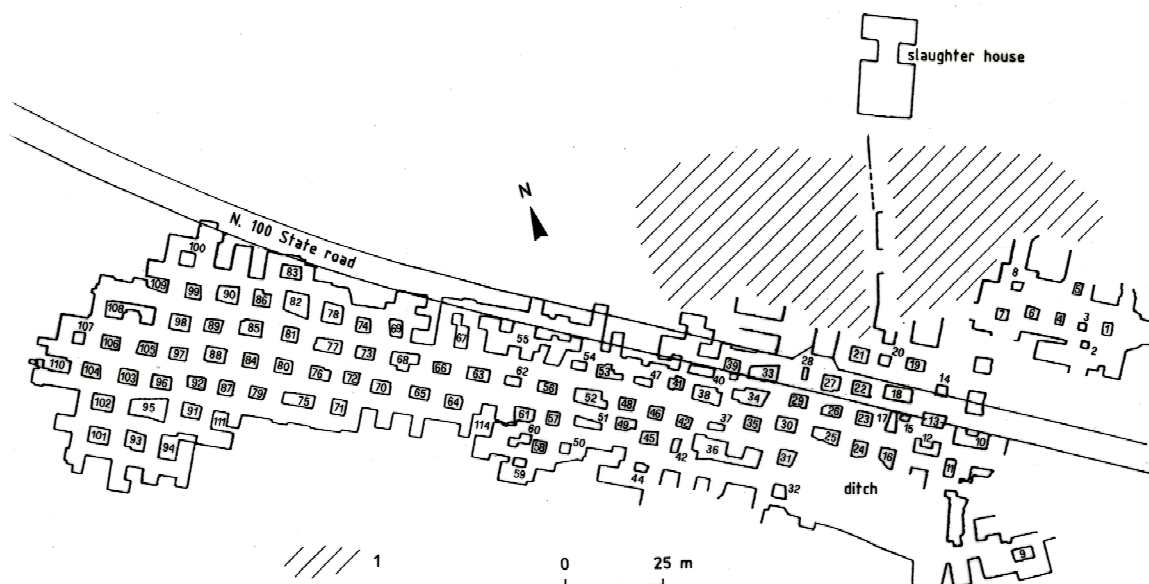


FIG. 4 - Plan of the pillars of the Mottola quarry (Italy): 1) Possible extension area of the quarry (from CHERUBINI *et alii.*, 1990 - modified).

The study of the statistical distribution of the area/perimeter ratio of the pillars indicates a roughly Gaussian distribution, with an average ratio of  $A/P = 0.93$  m, which is considerably lower than the values obtained for the same lithotype in the Cutrofiano quarries.

The slight tendency towards high A/P values, obtained in a more marked way also in the Salento quarries, in this case is not explained by safety measures linked to the access

route to the quarry (lanternino) which was by a descending ramp that allowed direct access from a previously excavated ditch to the tunnels where work was carried out; it is therefore more likely to be due to rougher methods of excavation and/or the necessity of leaving pillars at higher sections in correspondence with points critical for the stability of the quarry.

Table 2. Physical-mechanical parameters of the calcarenites of the Mottola Quarry.

|        | Specific weight of grains ( $\gamma_s$ ) KN/m <sup>3</sup> | Unit weight of volume ( $\gamma_a$ ) KN/m <sup>3</sup> | Imbibition coefficient % wt | Porosity %  | Degree of compactness | Compression strength MPa |
|--------|--|--|-----------------------------|-------------|-----------------------|--------------------------|
|        | 14.06÷18.35  | 17.60  | 21.00                       | 33.60÷49.10 | 0.51÷0.67             | 0.42÷1.20                |
| s.q.m. | -  | 1.60   | -                           | -           | -                     | 0.26                     |

The survey of the geometry of the quarry, carried out in 1988 (CHERUBINI *et alii.*, 1990), has recently been repeated with the following objectives:

- a) to perfect and, in some areas, complete the previous survey;
- b) to control the condition of the cavity comparing it with that at the time of the previous survey;
- c) to carry out the systematic geo-mechanical study of the calcarenitic rock mass.

This last aspect is especially important in view of the fact that, following the discovery of a series of underground cavities of which historical recollection had evidently been lost, some interventions were made from the surface, such as jets of cement and/or drilled poles (FIG. 5), in order to

improve the overall stability of the roads above the quarry, destroying, in part, the structure of the cavity and reducing its stability.

As regards the problems of stability, it should be emphasized that there are numerous and widespread breaks both in the pillars and in the roof of the tunnels; some of these are of tectonic origin, others are neoformation due to the static collapse of rock mass.

In particular, it should be said with regard to the roof of the tunnels that the central part of the quarry is without doubt that which is most fractured and damaged, with breaks up to 50 m long. However, there are also roof collapse phenomena along the southern border of the western part of the quarry.

Following the geomechanical survey, it has been possible to classify the pillars of the quarry according to BEKENDAM & DIRKS (1990). Using this classification, which does present some problems but is, at the present time, the only one available in the literature, we can note that the most widespread class of pillar is the fourth, which

refers to pillars with cracks that run from the base to the roof. These pillars are prevalently located in the western and central parts of the quarry (FIG. 5), while the undamaged columns, those belonging to the first class, are located in limited areas along the perimeter of the quarry.

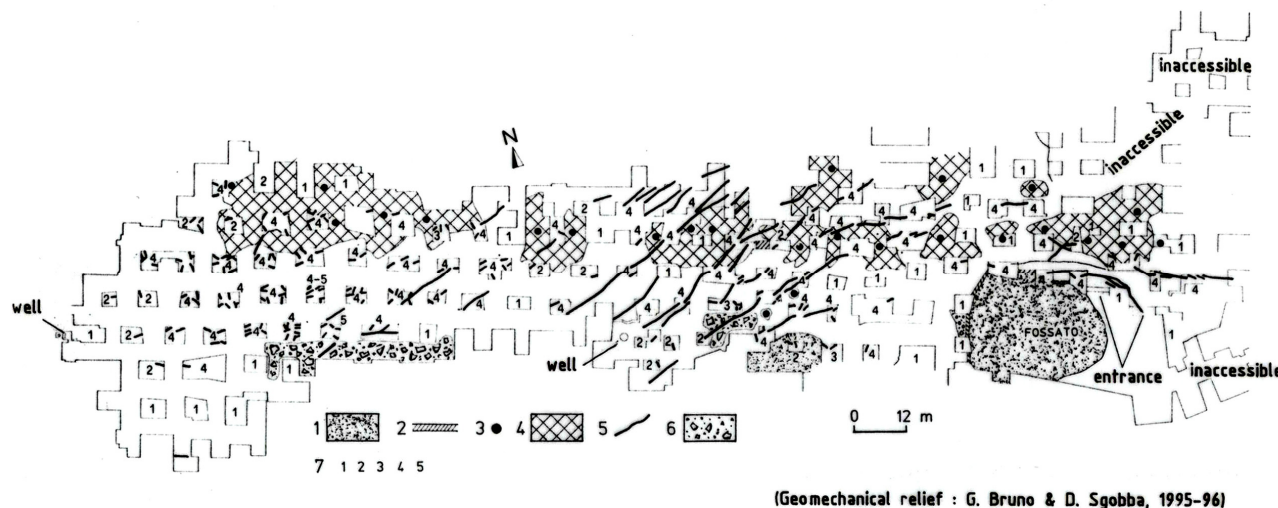


FIG. 5 - Geostuctural setting, geomechanical classification of the pillars, location and typology of rock improvement interventions (Mottola quarry - Italy): 1) Waste materials; 2) Concrete walls; 3) Injected iron coated concrete piles ( $\Phi \cong 500$  mm); 4) Concrete grouting; 5) Traces of fractures; 6) Rock falls from the roof; 7) Classes of pillars (according to BEKENDAM & DIRKS, 1990).

## Conclusion

Various studies have been carried out in recent years of underground quarries worked in various parts of Europe since the 1<sup>st</sup> century A.D., for reasons of the stability of the territory above the cavities and to evaluate the eventual possibility to recover and rework them. There are many cases of the underground exploitation of calcarenitic rocks, which can be defined as “weak rocks”, employed as building blocks.

An examination of the proposals advanced by various Authors for the study of stability problems has made it possible to concentrate on some geometric parameters of the pillar columns that safeguard their stability i.e. their area (A) and perimeter (P) or better their A/P ratio, as well as the ratio between empty and filled spaces.

It has, in fact, been seen that an increase from 16 m<sup>2</sup> to 20-25 m<sup>2</sup> of the section of pillars, imposed in the Cutrofiano quarry by the Mining Office of the Apulia Region has determined an improvement in the stability of the quarry. The same result has been obtained with the adoption of a

staggered pattern of columns as opposed to a chessboard pattern.

The presence of damage to the territory above (induce subsidence) and, in some cases, within the quarry is sometimes due to factors specific to the quarry studied.

As regards the shape of the columns and the excavated tunnels, it is noted that their irregularity facilitates instability, which in general increases with the age of the quarry; also of fundamental importance is an unfavorable excavation orientation with respect to the tectonic and structural characteristics of the area, as is the case of Mottola (Italy), where there have also been problems of the decay of the physical and mechanical characteristics of the calcarenites following the drainage of meteoric water in the quarry.

From the statistical analysis of the area/perimeter ratio of the columns it emerges that, in the quarries studied, the reduction of the A/P tends to be accompanied by an increase in the damage found both between different quarries and within the same quarry.

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