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Dimension stone exploitation in the Ossola Basin, Italy

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ABSTRACT

Dimension stone exploitation in the Ossola Basin, one of the biggest in Italy, is strongly influenced by the orientation and spacing of discontinuities as well as the topography of the quarry site. Exploitation techniques too are often affected by these critical conditions. In the paper, the rock properties affecting the exploitation and the most useful splitting techniques are discussed. An example of the application of the exploitation method is also given.

INTRODUCTION

Italian mining is negligible on a worldwide scale, except for dimension stones, where Italy is an important producer, transformer, and trader. The share of Italy in the production of commercial blocks is shown in Fig. 1. Virtually, all Italian regions contribute significantly, though some regions hosting the larger basins are favoured (Fig. 2).

Dimension stones represent a typical "small mining" sector, where large and small basins can profitably feed medium to small enterprises with the annual production down to 500 m³.

The Ossola Basin covers a wide area in the Western Alps (Piemonte Region), close to the border of Switzerland. It is conveniently located at the proximity of two large cities of the Northwest (Fig. 3), and also has a variety of good-quality dimension stones. Products are mainly gneisses ("Serizzo", massive and coarse grained, and "Beola", fissile) followed by granites (white, pink, green) and, marginally, marbles (both calcitic and dolomitic). The typical products of the quarries are commercial blocks usually of 3 m x 2 m x 1.5 m in size, and they seldom exceed 30 t (the limit weight, not to be exceeded because of traffic regulations).

A "concentration process" is underway in the basin. There were 120 active quarries in the 1980s and there are 80 at present. Though the overall output has practically not changed, in the meantime the mechanisation index (kW/worker) has increased from 60 to the present-day figure of about 100. Total annual production is about 100,000 m³, with 350 workers in the quarries (400 more people work in processing plants and 100 in the administrative, technical, and supervision activities). Product to excavated ratio is about 0.5 for the Serizzo Gneiss and 0.65 for the Beola Gneiss. The higher ratio for the latter is achieved basically because undersize and shapeless pieces can be profitably worked by splitting at the quarry site. Total investment in equipment for the quarries is US$ 35–40 million and a comparable amount is also invested in processing machinery.

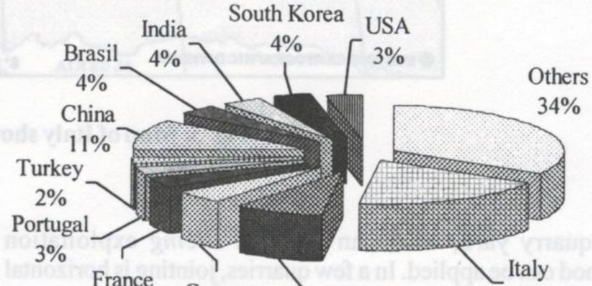

Fig. 1: World production of dimension stones (after Mancini et al. 1996b)

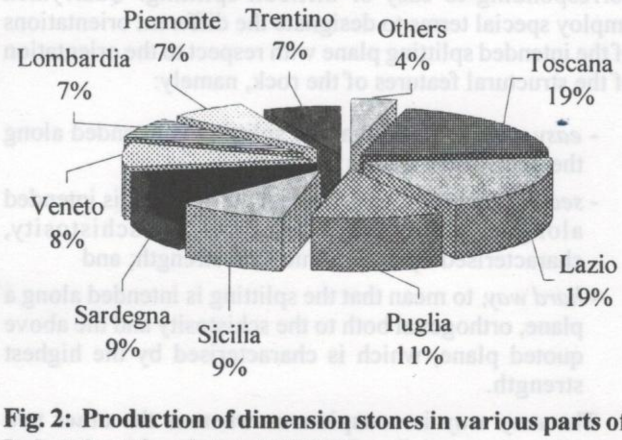

Fig. 2: Production of dimension stones in various parts of Italy (after Mancini et al. 1996b).

ROCK PROPERTIES AND EXPLOITATION METHODS

Quarries are not very wide. Generally, their width is determined by the reach of one or two large fixed cranes for rock handling. In gneisses, a set of weak planes or discontinuities, parallel to the schistosity is usually present. These planes are spaced by 5–15 m and dip 0–90° towards

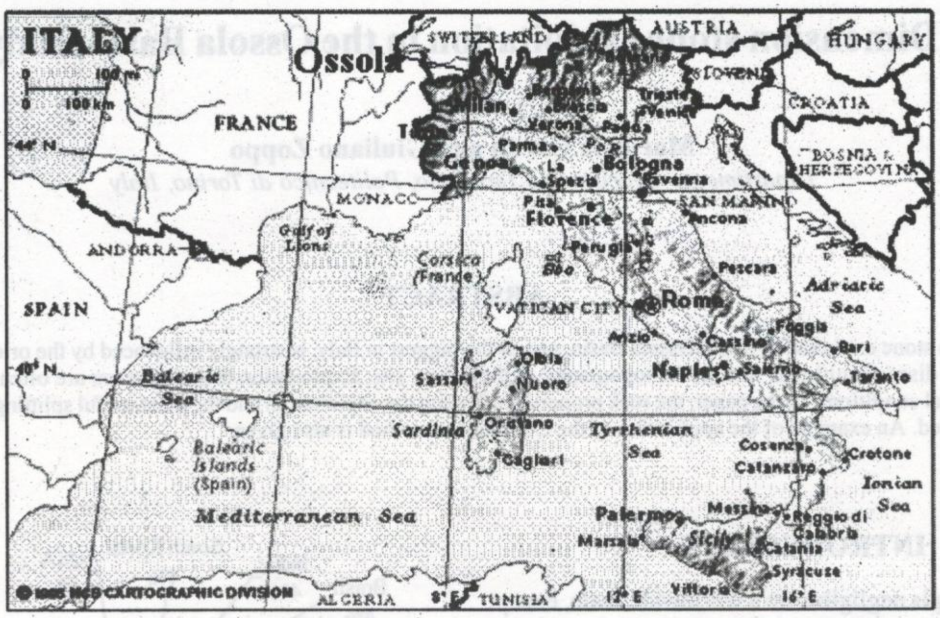

Fig. 3: Map of Italy showing the location of Ossola

the quarry yard, where an *inclined slicing* exploitation method can be applied. In a few quarries, jointing is horizontal or sub-horizontal, and the exploitation is by *horizontal slicing*. The difference resides in the different role of gravity in the two cases, as explained later. Besides visual and mechanical anisotropy, a hidden anisotropy can be detected in gneisses, represented by planes orthogonal to schistosity corresponding to easy or difficult splitting. Quarrymen employ special terms to designate the different orientations of the intended splitting plane with respect to the orientation of the structural features of the rock, namely:

- *easy way*, to mean that the splitting is intended along the schistosity planes;
- *second easy way*, to mean that the splitting is intended along a plane orthogonal to the schistosity, characterised by an intermediate strength; and
- *hard way*, to mean that the splitting is intended along a plane, orthogonal both to the schistosity and the above quoted plane, which is characterised by the highest strength.

The *easy way* is conspicuous whereas the other two mutually orthogonal directions are not so, but the quarrymen are able to detect them on the basis of their practical experience. In order to check the strength anisotropy of the materials and the correctness of the quarrymen's judgement, more than 100 indirect tensile strength tests were done on these materials, whose results are summarised in Table 1.

Some anisotropy is apparent also in compression tests, but not so conspicuous as in tensile strength tests, being the strength measured on specimens loaded normally to the schistosity larger by only 20–30% than the strength measured on specimens tested under load parallel to it. Compression strengths (measured normally to the schistosity) are in the range of 150–190 MPa for the Serizzo type and 160–190 MPa for the Beola type. However, the tensile strength and the tensile strength anisotropy are technically the most important strength parameters affecting both the splitting technique and the practical use of the product.

Plate 1 represents a typical gneiss quarry. The *easy way* is selected for the main splitting planes and, at places, coincides with widely spaced transverse joints.

Inclined slicing implies the separation of very large prisms with vertical primary split planes, obtained as a rule by the detonating cord method, and the sliding, spontaneous or induced, either by a slight overcharge or by other means, of the prisms, along the basal discontinuity, down to the horizontal quarry yard, where the prisms rest (in most cases capsized) in a stable position and within the reach of the crane for re-cutting operations.

Primary split can be helped by vertical channels opened with diamond wire, orthogonal to the rear split obtained by cord (the explosive is preferred in this case both for economical and safety reasons: to assure that movement starts at the desired time). The volume of the primary prisms amounts to some thousands of m^3. In *horizontal slicing* the primary prisms are simply split and capsized, close to the face. Re-cutting, down to the commercial size, is obtained again with detonating cord and, in some cases, with diamond wire.

Table 1: Results of laboratory test

Material	Mean value (MPa)	Standard deviation (MPa)	Variance (MPa)
Serizzo Gneiss – *easy way*	7.73	0.87	0.75
Serizzo Gneiss – *hard way*	14.08	2.03	4.12
Serizzo Gneiss – *second easy way*	13.94	0.97	0.93
Beola Gneiss – *easy way*	4.96	0.67	0.45
Beola Gneiss – *hard way*	15.95	2.34	5.46
Beola Gneiss – *second easy way*	10.57	0.47	0.22

Plate 1: Example of a typical gneiss quarry (after Zoppo 1997)

A classification of the exploitation methods applied in the basin has been made, aimed mainly to quickly pinpoint the most common types of working safety, stability, and access problems pertaining to the individual quarries. Methods are: I – by horizontal slicing; II – by vertical slicing; III – by mass caving; IV – by trimming free blocks; V – by benching, starting from top (descending benches); and VI – by benching, starting from bottom (ascending benches).

COMMONLY USED SPLITTING TECHNIQUES

The choice of techniques to be employed depends on various factors: safety, costs, efficiency, applicability (as a function of the properties of the stone to be quarried and the country rock), available equipment, and the like. The most common techniques in use are summarised in Table 2.

Non-explosive breaking agents and diamond chain saw are not industrially employed in the Ossola Basin. Water jet, jet channelling, and line drilling have been tested in some quarries, only at an experimental level, while splitting by explosives and mechanical cutting by diamond wire saw are the most common practices.

Splitting by explosives

Yearly consumption of explosives (12 g/m PETN detonating cord, gunpowder, and dynamite) in the basin is more than 40 t. The relationship between this amount and the production (100,000 m^3) gives a specific consumption

Table 2: Techniques employed for siliceous dimension stones exploitation

Cyclic operations	Continuous operations
Splitting by explosives	Diamond wire saw
Mechanical split	Jet channelling
Line drilling	Water jet
Non-explosive breaking agents	Diamond belt cutter

value of 410 g/m^3, which is very high, if compared to the very low design powder factor (usually lower than 100 g/m^3) for the single blast. The reasons are that, firstly, the blasted volume exceeds by a factor of 2 to the marketed volume and, secondly, the product of the primary blasts requires more blasts to reach the commercial block stage.

Detonating cord is employed both as an explosive and as a means to obtain simultaneous ignition of gunpowder charges, whereas dynamite is used mainly in waste stripping. Detonating cord consumption per unit volume of commercial product is around 18 m/m^3. The value is lower than in granite-producing basins, where figures over 25 m/m^3 are common. The reasons are that the exploitable natural discontinuities are more frequent in the gneisses than in the granites, and most of the re-cutting and trimming works in the gneisses are done mechanically.

In rock splitting, the explosive is employed to produce a force capable of tearing apart the inter-hole resisting rock. Conditions for successfully splitting are:

(a) The holes have to be accurately drilled in the desired splitting plane (skid mounted drills guided by rails are a common system);

(b) The spacing of the holes is commonly 20 to 30 cm, in order to avoid irregular splitting surfaces;

(c) The explosive shock effect has to be negligible: either a low explosive (gunpowder) or water-or sand-stemmed detonating cord are used;

(d) The tearing force (= explosion pressure x hole diameter x charged length) exerted by explosive orthogonal to the splitting plane, must exceed the resisting force (= rock tensile strength x split surface area);

(e) The forces have to be simultaneously applied to all holes, to avoid wandering fractures;

(f) The drilling diameter should preferably be small (30–45 mm), within the constraints posed by the necessity of avoiding deviations, to better exploit the explosive pressure;

(g) Excess charge must be used (with respect to the minimal tearing charge) to provide the separated rock mass with enough momentum (in order to obtain the desired displacement) and to better warrant the splitting effect. Hence, the correct charge depends both on the split surface area and the volume to be moved; and

(h) The prism to be separated must be free on the front and on one side. In order to take the first prism from a bench, auxiliary lateral free surface can be obtained by diamond wire cutting or, sometimes, by line drilling.

Mechanical cutting by diamond wire saw

Diamond wire sawing is presently a standard production method in dimension stone exploitation. The running of this system requires the following operations:

(a) Drilling of two communicating holes, to allow the diamond wire passage through the perimeter of the detaching surface. At least two free surfaces are therefore, generally, required. If an open cut already exists, only one hole is needed;

(b) Running the wire through the communicating holes;

(c) Closing the loop of the wire; and

(d) Wrapping the wire loop around the pulley to start the cut at low speed in order to smooth the sharp deviations of the wire.

Being the wire very expensive (generally exceeding US$ 100 per metre, and up to US$ 300 per metre for special purposes), its performance is defined by two parameters: productivity (m^2/h) and wire service life (m^2/m). The latter parameter is only loosely defined, because the wire can be reconditioned many times before discarding (up to 5 times, usually from 1 to 2 times). Reconditioning is a high skill and labour-intensive task, entailing wire disassembling, selection of reusable beads, replacement of worn-out beads, and reassembling of the wire. The reconditioning rate depends on the "reasonable" judgement (which means, economically proficient) of local circumstances.

Data on wire service life and productivity of most common materials used in the Ossola Basin are given in Table 3.

The main problem to be solved, using this technique, is the increase of the service life in abrasive stones. Diamond is harder than any material and therefore it can, in principle, cut everything, but the metallic matrix that holds the diamonds in place on beads is subject to wear.

Wire saw beads fall into two basic types: electro-deposed (a single layer of coarse diamonds is fastened to the bead by electrolytically deposed metal) and impregnated (a fine diamond/metal sintered layer is applied to the bead). The former type, more productive, cheaper, but less durable, is commonly used in marbles, and the latter, slower in action but longer lasting, is applied in hard rocks.

In granites, diamond wire sawing is not competitive with detonating cord on a surface production basis. However, a part at least of the cost difference can be compensated by

Table 3: Wire service life and productivity of most common materials used in the Ossola Basin

Rock type	Wire service life (m^2/m)	Productivity (m^2/h)
Serizzo Gneiss	10	4
Beola Gneiss	12	4
White granite	6	3.5
Pink granite	-	-

the better quality of the blocks obtained and by the lower production of waste, and progresses in wire performances are rapid. The lower production of waste represents a benefit whose importance grows as the commercial value of the product grows, hence, while in low value materials the splitting by explosive is the lower cost option, in high prize materials the wire option is preferable, as shown in Fig. 4. Consequently, the granite or the Serizzo Gneiss producers started to employ, for economical reasons, diamond wire saw, at least to cut the *hard ways* (Fig. 5), due to the fact that, when splitting by explosive the *hard way*, some fractures can occur near to the splitting surface, in an orthogonal direction with respect to the *hard way* direction, and spoil a sizeable fraction of the production.

An inquiry on primary block quarrying in the Ossola Basin was done to compare the main technologies (detonating cord, diamond wire sawing, and compounded technique) in use. The qualitative results are given in Table 4.

NEW EXPLOITATION METHOD FOR CRITICAL AREAS

The most common method is by benching, starting from the bottom, as shown in Fig. 6-1. According to this procedure, the quarry width grows, until the lateral permit boundaries are reached, then the excavation face height and the basal yard depth progressively grow along the whole width of the quarry, until the upper permit boundary is reached.

In the most difficult conditions found in the examined basin (say, schistosity dipping towards the hillside by 45°), it is advisable to adopt a different exploitation method, where at first a sort of trench is driven in the rock. It is narrower than the planned width of the fully exploited quarry, and then the material is no longer extracted by ascending benches starting from the toe, but by vertical slices starting from the trench side, and therefore the quarry develops sidewise instead of vertically (Fig. 6-2 and following).

The exploitation no longer entails the skidding of large volumes on the *easy way* plane, but it involves the lifting by crane, or by capsizing on the yard (at least, at the lowest levels) of small blocks. Many advantages can be seen in the quarry development by this method: the method can improve the blocks recovery, avoiding breakage during skidding, can allow safer working conditions (since there are no longer high rock walls uphill), and allows to gain a better knowledge of the material under exploitation, having been exposed a sort of geological cross-section of the hillside.

The modified exploitation method described is underway in the quarry of Plate 1. In this case, the lateral opening has already made conspicuous the commercial characteristics of the materials of the lower levels, and the mixed technique (diamond wire saw on the *hard way* cut and detonating cord in the other cuts) gave appreciable results as far as safety and economy are concerned.

Table 4: Qualitative comparison between main quarrying techniques used in the Ossola Basin.

Attributes	Detonating cord technique	Diamond wire technique	Detonating cord + diamond wire
Cut accuracy	Low	High	High
Cut productivity	High: 7–10 m^2/h	Average: 1–4 m^2/h	High: 10 m^2/h
Energy consumption	Low	Average - low	Average–low
Capital cost (machinery and equipment)	Low	Average	Average
Tools consumption	Low	High	High
Environmental impact	High	Low	Average
Recovery on primary blocks	92 %	98 %	95 %
Possibility of mechanisation process	Low	Average	Average–low
Working conditions (safety)	Low	Average	Low
Water consumption	Low	Average	Average
Influence of ore body shape and structure	Low	High	Average

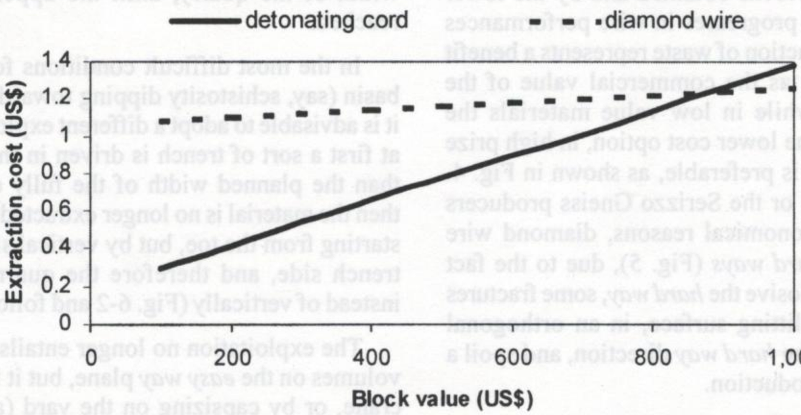

Fig. 4: Comparison of splitting costs of commercial blocks by using detonating cord and diamond wire cutting (after Zoppo 1997)

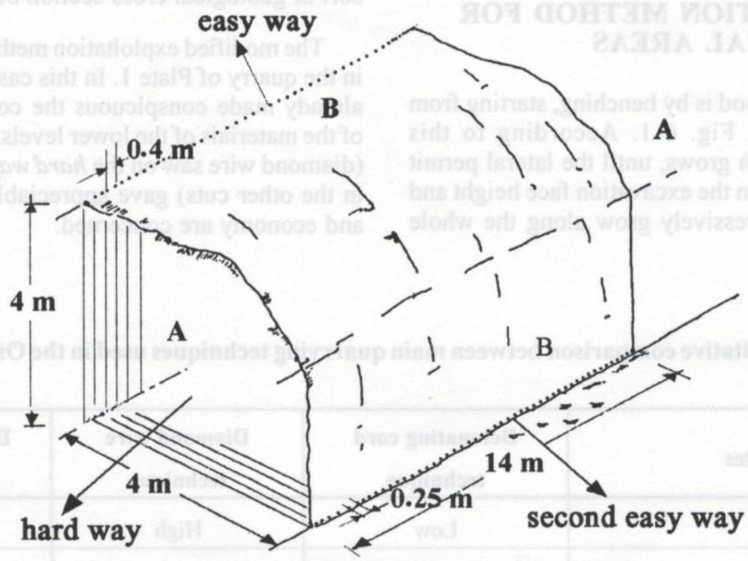

Fig. 5: Opening a bench in a Serizzo quarry (after Mancini et al. 1996a). In this example, the prism has not free lateral surfaces, being the first to be removed, and two vertical cuts (channels) have to be obtained by diamond wire (A) before commencing the splitting operation by detonating cord (B). Each one of these vertical cuts requires two crossing holes, vertical and sub-horizontal, to be drilled in the intended cut plane, to give passage to the wire. As wire cutting is completed, split holes are drilled, charged and simultaneously detonated. The total volume of the prism is about 200 m^3 and the area of lateral cut surface is about 14 m^2 each. Basal plane of the intended prism is sub-horizontal and, though being a weak plane, requires explosive splitting. The total split surface is about 112 m^2. Holes are charged with 2 strands of 12 g/m PETN stemmed with water and fired by master cord. Explosive consumption is 1,000 m of cord (specific consumption: 60 g/m^3) and holes consumption is 520 m (specific consumption of drilled holes: 2.6 m/m^3).

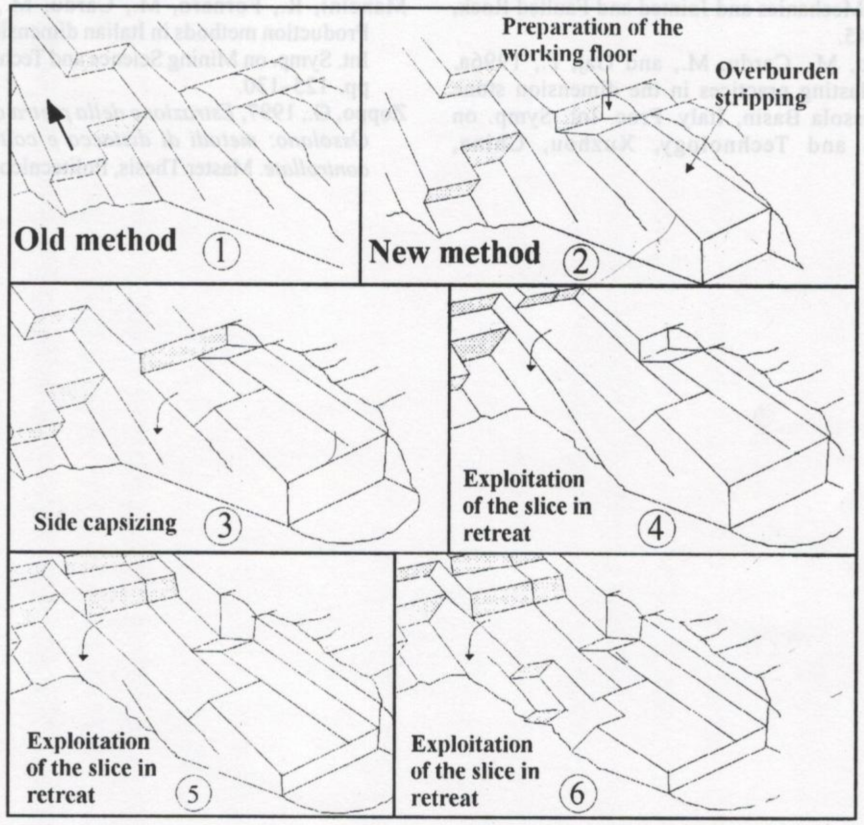

Fig. 6: Examples of existing and modified exploitation methods in a gneiss quarry.

CONCLUSIONS

As to the stone splitting method in the Ossola quarries, the explosive is presently the prevailing system, and what has been observed proves that the explosive, when skilfully used, is a highly productive, cheap, and safe means to quarry stones. It can be added that it is delicate enough to avoid damage to the product, at least on the *easy ways* cuts.

Different quarries developed different styles in designing blasts, and probably an optimal procedure simply does not exist, due to the peculiarities of the geomechanical features of the quarries. But the Ossola quarries, especially the largest ones, are very attentive to the progresses of explosive competitors, and compound methods, employing both the explosive and the mechanical cutting, are becoming popular, showing advantages over the use of the explosive alone.

As to the exploitation method, in the cases of rock bodies characterised by steeply dipping weak planes, the most elementary method, consisting in causing an artificial rock slide, is replaced by a quarry face design allowing for a more controlled exploitation of the gravity, at the cost of more important preparation works, both for safety and stone recovery improvement reasons.

Safety and recovery factors are becoming more and more important, and hence to simply blast down the largest possible amount of rock at the lowest possible cost is no longer a reasonable objective.

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