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THE ROMAN GRANITE QUARRIES IN THE TYRRHENIAN SEA DURING THE IMPERIAL PERIOD: A TECHNOLOGICAL STUDY

SÉBASTIEN CLERBOIS, NADINE MATTIELLI, ANTOINE TRIANTAFYLLOU, GAËL BRKOJEWITSCH *

ABSTRACT

Granite is a highly valued material under imperial Rome, particularly the production of monolithic columns, used in both public and private architecture. In the western Mediterranean, the main quarries are located around the Tyrrhenian Sea. The Romans were looking for a particular stone, i.e. leucocratic granodiorite, with colors and textures similar to that extracted from the Egyptian quarries of *Mons Claudianus*, used for many imperial programs. The extraction of large columns in such a hard material requires proper organization and techniques. This paper aims to study the granite exploitation of granite in the Tyrrhenian Sea from a technological point of view, along the entire *chaîne opératoire*, from sites prospection to extraction, block cutting and production of finished objects. This contribution also seeks to understand how geological patterns have been advantageously exploited by quarrymen, and to identify sets of technical features to explain their origin and systematics, in a local and regional context. In the absence of absolute dating, technology is also useful to make phasing hypotheses, given that many of these quarries have been used from antiquity to the present day. From a methodological point of view, the approach combines technology and geological observations to produce a holistic study of the stone, from its characterization to its exploitation.

KEYWORDS : Stone extraction, Roman Quarries, Archaeology, Technology, Tyrrhenian Sea

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A. INTRODUCTION

The production of granite monolithic columns, particularly valued in imperial architecture, is at the heart of Roman-style luxury. On one hand, the great imperial programs, particularly from the Antonine period (EDMUND 2007), exploited these rocks on a colossal scale and sublimated the stone through monumentality. Several examples include e.g. the columns of the Ulpien basilica in the forum of Trajan or the Corinthian columns of the Pantheon built under Hadrian, with impressive proportions (shafts of 12.5 m high, 1.5 m in diameter at the base and 69 tons each). These imperial commissions contributed to popularize the use of granite in architecture among the elite of society. On the other hand, granitic rocks, that were assimilated to marbles by the Romans, contributed to the taste of the elite for the polychromy due to the lithological variety of the quarried stones (DE NUCCIO, UNGARO 2002; BRADLEY 2006). Indeed, either in public or private Roman architecture, granite columns offered beautiful color variations from white to grey, pink or red, with subtle speckled patterns due to grain size and heterogeneous compositions enhanced by polishing.

This stone trade is supported by the large amount of granite quarries during the imperial period. These quarries were

thoroughly listed by Ben Russel (RUSSELL 2013), among which the imperial quarries of Mons Claudianus (*granito del foro*) in the eastern desert of Egypt (Aegyptus), those of Kozak Dağ, in northwest Turkey (*Marmo Misio*, Mysia), of Hadjret-en-Nous (Algeria, Mauretania Caesariensis) or, among others, those of the Strait of Bonifacio (Corsica-Sardinia) in the western Mediterranean Sea.

These quarries have been the source of several geological studies, both in terms of stone characterization (WILSON 1988; GALETTI, LAZZARINI, MAGGETTI 1992; PEACOCK, WILLIAMS-THORPE, THORPE, TINDLE 1994; PONTI 1995; LAZZARINI 1998; DE VECCHI, LAZZARINI, LÜNEL, MIGNUCCI, 2000; HARRELL, LAZZARINI 2002; ANTONELLI, LAZZARINI, CANCELLIERE, SOLANO 2009; CIRRINONE, FIANNACCA, ORTOLANO, PEZZINO, PUNTURO 2013; YAVUZ 2014), the origin of architectural granites (WILLIAMS-THORPE, THORPE 1993; WILLIAMS-THORPE, POTTS 2002; POGGI, LAZZARINI 2005; WILLIAMS-THORPE, RIGBY 2006; WILLIAMS-THORPE, RIGBY 2007; WILLIAMS-THORPE 2008; RODÀ, PENSABENE, DOMINGO 2012), granitic rocks' circulation and economics (DUNCAN-JONES 1974; GARNSER, SALLER 1987; FANT 1993; HIRT 2010; MAIURO 2012; RUSSELL 2013; PENSABENE, RODÀ, DOMINGO 2015; LONG 2016) and

extraction techniques (RÖDER 1959; RÖDER 1965; BESSAC 1986, KOŽELJ 1988; KOŽELJ, WURCH-KOŽELJ 1992; BESSAC 1996; KOŽELJ, WURCH-KOŽELJ 1998; BESSAC 2000; 2014; BABIST, VÖGEL, GNIRß).

Nevertheless, except for the Mons Claudianus case studies (PEACOCK, MAXFIELD 1997), these quarries have never been surveyed with stratigraphic excavations and, hence, with a detailed archaeological investigation, particularly in the Tyrrhenian Sea. This is most likely due to their location on coasts, islands or peninsulas making them difficult to access. In addition, erosion processes in coastal environments often weaken their archaeological potential. Mediterranean vegetation, in particular scrub or invasive species such as «witches' claws» (*Carpobrotus*), make the conditions for prospecting difficult. Beyond excavation, the establishment of provenance links between quarried rocks and architectural objects is challenging, as it requires the use and the development of robust, reproducible and non-destructive methods for a precise identification of the minerals and a rock discrimination among a relatively homogeneous typology of granitoids.

Since 2016, the authors have taken part in a Collective Research Program (PCR, 2017-2020) promoted and funded by the

Ministry of Culture (Regional Archaeology Service of Corsica), directed by Gaël Brkojewitsch, dedicated to the archaeological study of the Strait of Bonifacio in Roman times and involving the Archaeological Centre of Metz Métropole, the Camille Julian Centre, the CEREGE, the INRAP, the DRASSM, and the Université Libre de Bruxelles (ULB). The ULB's team brings together archaeologists and geologists for a holistic understanding of stones' exploitation. Their research was focused on the study of granite quarries scattered throughout the islands of the Lavezzi archipelago in Corsica, including the large quarry located on the contiguous islands of Cavallo-San Bainzu.

As part of this program, in addition to the Corsican quarries, namely those of Cavallo-San Bainzu and Lavezzu (I Becchi and Cala Giunco) located in the Lavezzi archipelago, a large panel of known granite quarries in the Tyrrhenian Sea was visited for comparative purposes. The latter ones include those of North Gallura (Sardinia), namely the islands Municca and Marmorata, the locality Capicciolu, the Punta Acuta (Li Pedri Taddati) and the Cala Spinosa on the peninsula of Capo Testa, the Punta Falcone, near the town of Santa Teresa di Gallura. We also visited the Calabrian (Italy) quarries of Parghelia and Nicotera, within the Capo Vaticano

(FIGS. 1-2) although our understanding of these exceptional sites is partial due to the invasive vegetation and the absence of heritage maintenance. The Sardinian quarry of Cala di l'Ea, on Capo Testa, and those of Elba and Giglio (FIGS. 1-2), are more complex because of their apparent re-exploitation during medieval and modern times. These case studies require an in-depth field investigation and will therefore be the subject of a separate publication.

Our study aims at documenting and studying the visible traces of extraction in these quarries; exploring and conducting a technological study of these markers, witnesses of former extraction techniques, provide a robust scientific basis for any further archaeological interpretation.

Because the exploitation techniques have not evolved sufficiently over time (WOOTTON, RUSSEL, ROCKWELL 2013), we avoided using technical markers as chronological indicators. Instead, our study focusses on identifying and distinguishing technological features that can be investigated following Jean-Claude Bessac's archaeological methodology (thoroughly described in his studies on stones from *Gallia Narbonensis* and the Bois de Lens quarries; see BESSAC 1996; BESSAC 1986, 80 and sq; BESSAC 2000). By combining the technological observations with geological data of the extracted blocks, we are convinced that it

is possible to determine a robust set of technical features. If they cannot lead to an absolute dating, these features shed light on the understanding of quarries' phasing, as much as they support the questioning relating to the quantification of the exploitation, of the extraction methods, including its evolution/adaptation to geological contexts.

In parallel, portable field instruments offering non-invasive analyses (e.g., handheld XRF and magnetic susceptibilimeter) will be used to characterize the mineralogical and geochemical signature of each extracted stone material for each studied quarry (MATTIELLI, TRIANTAFYLLOU, CLERBOIS, BRKOJEWITSCH, NONNE, PARIDAENS, AUTHOM 2020, 22186). This innovative multi-methodological approach could bring quantified arguments for future provenance study that could be applied to certify the origin of the rock materials used within archaeological monuments and by extension, to evaluate the vectors of exchange and trade on a regional scale.

B. QUARRY CONFIGURATION

1. TYPOLOGY OF ROCK SELECTED FOR QUARRYING

On the basis of the observations made on the islands of Lavezzi and San Bainzu-

Cavallo, it seems that the quarries were primarily exploited for a specific visual appearance, combining rock color, grain size and quality. This valued stone corresponds to a medium to coarse grained and greyish colored granite to granodiorite showing a greyish color. This particular rock type is made of pluri-millimetric to centimetric grains of plagioclase, alkali feldspar averaging half a centimeter long along with quartz, biotite, few green amphibole, and small accessory oxides. Altogether, the size of the outcrop, the rock homogeneity along with its massive aspect were additional important criterion for quarrymen. The uniformity of the stone also looks to be an important selection criterion: when fractures are too numerous and badly oriented, the presence of mafic or aplitic dykes, veins or mafic enclaves are observed, the explored site is abandoned (e.g., the quarry of Cala Giunco on Lavezzi). Finally, the orientation of major fault and joints were clearly used to facilitate the extraction of blocks and undoubtedly guided the the operating strategy for quarrying massive natural boulders.

2. GENERAL COMMON FEATURES OF TYRRHENIAN SEA QUARRIES

The prospected Tyrrhenian quarries are «maritime», which means that they are

located in close proximity to the sea, in order to facilitate rock transport by sea (BRAEMER 1986, 275). More specifically, quarries are located along coastlines, as in Calabria, on islands or small islets (Cavallo, San Bainzu, Corsica; Marmorata, Muccia, Sardinia) or peninsulas (all the quarries of Capo Testa, Sardinia). The rocky masses exploited are either on the waterfront or on very steep coasts from where blocks can be easily transferred and transported via the sea (Parghelia and Nicotera). In Capicciolu, the transport was carried out from a pontoon located on the edge of the quarry; an access ramp leading to a dock – currently submerged – can still be observed from the beach. The mode of blocks's transportation is beyond the scope of this paper and will be investigated further with the support of detailed archaeological results.

Most of the extraction sites are open-pit quarries, with a stepped profile, consisting of working faces and stepped benches (FIG. 3). This technique is particularly efficient since the removal of a parallelepipedal block mechanically exposes two faces of the block that can be extracted subsequently. The quarry bed is usually located at the level of the bedrock, allowing a levelled circulation floor within the quarries, from the extraction points to the storage or loading areas. In a few places, the extraction spots consists of pits,

most likely because the quality of the rock was good enough to justify extraction below ground level, even if it meant that heavy rock transport would require lifting equipment.

3. CHARACTERISTICS OF CUT BLOCKS

The blocks cut in the format of architectural or usual elements are mostly columns (most often monolithic columns) or drums, simple or with astragalus. One block, on Lavezzu, is interpreted as a capital draft (FIG. 4). In Parghelia, blocks coming from local quarries are used for the decoration of private houses in the village. These ones can be identified as thresholds and millstones, attesting that these particular objects were also extracted. These millstones do not correspond to the Roman typology and would evidence a subsequent exploitation of the quarry in modern or contemporary times (FIGS. 5-6). In Nicotera, several large basins were observed in addition to the columns (FIG. 7), possibly contemporary. In San Bainzu, a punctual extraction in a part of the quarry produced some tympana, probably during the modern times (FIG. 8). In Municca, blocks of a very particular format, which we believe to be quay borders, were also extracted during modern or contemporary times (FIG. 9).

C. A SINGULAR *MODUS OPERANDI*?

The quarrying techniques widely used in the Roman times to produce granite monolithic columns consist in cutting the block at a given dimension on three sides using extraction trenches. This block is then extracted from the bench using a series of sockets (called «*emboîtures*» in French; translations based on ABDUL MASSIH, BESSAC 2009). These sockets are intended to receive the wedges, that will be driven into the stone until it cleaves along a straight line (FIG. 10). In order to produce a column, the quarryman had to either extract a parallelepiped block which was used to carve a column once extracted, or to shape the column directly on the bench. These two techniques have been highlighted and described in the imperial quarries of Mons Claudianus (PEACOCK, MAXFIELD 1997, 177-216).

In the Tyrrhenian quarries, such a *modus operandi* is however poorly documented. Similarly, in the Capicciolu quarry on Capo Testa (Sardinia), on a bench located in front of the water, a column drum with an astragalus was observed, roughly shaped in the quarry itself (length 190 cm, diameter 120 cm, width of the talus 30 cm). On the same bench, a large parallelepiped (Length 550 cm x width 11 cm x irregular depth 90 cm) was excavated by a large trench («*emboîtures*»)

in its lower part (FIGS. 11a-b). At the other sites, the blocks were never cropped, and no columns were carved directly on the quarry benches. On the contrary, all examples of column carving work are made, as a second intention, on blocks previously extracted from the quarry.

The most commonly used technique consists in digging into the rock, through by successive furrows, wedge trenches (named «*encoignures*» in French) marked by a characteristic negative stepped profile with a V-shape (FIG. 12). These trenches are not deep enough to crop the blocks. Their dimensions are surprisingly homogeneous: 20 cm wide, 20 cm deep, with a 5 cm width channel at the bottom of the trench. Their length varies according to the length of the extracted block. These channels allow the insertion of wedges in order to split the rock in the direction of the trench. The negative imprints indicate the use of fairly wide wedges, (10 cm long in average), that were placed at regular intervals of approximately 10 cm. These wedges are 5 cm wide, corresponding to the width of the channel at the bottom of the trenches (FIG. 10). Consequently, the blocks abandoned in the quarries have remarkable edges on which one can see the successive furrows of the V-trenches as well as the negative traces of the wedges.

In general, quarrymen first extracted parallelepipedal blocks before shaping

them. In Parghelia, this *modus operandi* is illustrated by an abandoned block that was left just after a quarryman began to shape it into the cylindrical format of a column (with a length of 230 cm and a irregular diameter of ~ 50 cm; FIG. 13a-b). In Cavallo, two rough-cut columns with traces of trenches furrows (sizes: length of 407 cm, average diameter of 60 cm; length of 420 cm, average diameter of 60 cm) were clearly shaped from two parallelepipeds, as evidenced by the negative shape of the working faces located alongside these blocks. In Cavallo again, a large parallelepiped block shows, on the reverse, the outline of a very large column with an astragalus (preserved length of the column 250 cm, height of the astragalus: 30 cm and 150 cm in diameter; FIG. 14). In general, the negative imprints of these furrows' trenches are visible on most of the working faces of the studied quarries (FIG. 15).

Why shaping columns from granite's parallelepipeds after their extraction? In terms of profitability, this choice probably implies more work. On the other hand, the separation between the phase of block's extraction and the shaping of the columns induces a division of work which most likely allows a better work organization and eventually a good profitability. The work of shaping a granitic column is long and tedious. Shaping columns directly into

the bedrock could be an inefficient approach hindering the extraction activity itself, which again may have stimulated the division of labor.

Sockets are present, but relatively rare. We found the negative of a trapezoidal socket, carved with a cutting hammer, whose traces are clearly visible, on a block unfortunately out of context, located on a beach near the Calabrian quarry of Parghelia (Length: 10 cm, depth: 8 cm; FIG. 16). A socket line has been documented on one of the extraction points of the Capicciolu quarry on Capo Testa, Sardinia (FIG. 17), and another one on a granite chaos of Punta Falcone, on the northern coast of Sardinia (FIG. 18). For these two case studies, the sockets' lines are not complete, and the blocks were not extracted. These sockets have an average dimension of 30 cm in length and 10 cm in width and are spaced with an average value of 8 cm.

In Corsica, we found negative traces of sockets as well as wedge V-trenches on the extracted blocks. Some authors consider that this combination is characteristic of the Roman period (KOŽELJ, PERISTERI, WURCH-KOŽELJ 2006, 674).

It has been proposed that the wedge trenches are used to detach the upper faces of the blocks; the socket being used to separate the lower faces of the stone benches. Nevertheless, several aborted

wedge trenches were found on the working face of the large Cavallo quarry, and thus not only on the upper faces (FIG. 19). Some groups of abandoned blocks show a significant concentration of sockets. This is typically observed on blocks abandoned in front of the Cavallo pit quarry from which they probably originated (FIG. 20). In contrast, in the large open-pit quarries, only a few sockets could be documented. Several hypotheses could account for these observations.

One hypothesis would propose that the pit quarries, presenting a more classical technique, predate the large quarries where extraction by large V-trenches is used. Only further excavation in these specific sites could support this idea.

Another explanation would be based on a double observation concerning the technical capacity of the quarrymen to adapt their extraction strategy to the geological configurations of the granite massifs. This is observed in large quarries (especially in the Cavallo quarry) which are characterized by specific shape and fractures' network of the granitic boulder. Indeed, the boulders consists of massive units often cropping out as flat rocky outcrops marked by sub-horizontal but highly penetrative fractures (FIG. 21). This peculiarity configuration explains why, if quarrymen were extracting the upper parts of the boulders by wedge trenches, there

was no need to separate the lower blocks from the bedrock. These blocks were abandoned as soon as their eroded lower faces were unsuitable for exploitation, and therefore showed no traces of sockets. In the pit quarry, on the other hand, the imperatives of the extraction forced the workmen to separate the undersides of the blocks from the bedrock using sockets, which explains the over-representation of negative traces at this location.

The other explanation is probably due to the technological advantages of the wedge trenches and sockets. The large trenches allowed a better control of the geometry of the cut face. Their systematization could then be linked to the size of the blocks. In the large quarry at Cavallo, where the blocks are up to 15 meters long, the quarrymen even made trenches on the working faces. However, in the small pit quarry, a few meters away, the size of the blocks (barely 3 meters long) certainly allowed a more classical use of wedge trenches and sockets.

In the Tyrrhenian Sea, this technique is most often associated with the extraction, as we have seen, of large parallelepipedal blocks, subsequently transformed into columns. The dimensions of the extracted blocks correspond to the size of the shaped columns abandoned in the quarries. Blocks of about 350-500 cm are commonly found, which are to be matched with columns

often between 420 and 495 cm, with diameters ranging between 50-55 cm, for the thinnest, to 80/90 cm for the thickest ones. The fragments of the few abandoned columns found in Cavallo-San Bainzu quarries often show thin columns, about 50 cm in diameter, with a simple astragalus, whose length is complex to determine as they are often either broken or partially buried and/or trapped in the heaps of rejected blocks. These columns are similar to those discovered at Tarraco, consisting of monolithic columns of greyish granite with astragalus, generally 50 to 55 cm in diameter and with an average length of around 415 cm. These columns were exported from the quarries of Troy and were accompanied by Corinthian capitals in marble from the Proconnesus quarries (RODÀ, PENSABENE, DOMINGO 2012, 222).

It should be noted that these measurements reflect fairly well the Vitruvian ratio of 1-6 between length and diameter (some examples: 495-89/90; 492-82, 5; 407-57/70; 407-67; 450-60/70). Therefore, one might be tempted to approximate some measurements to multiples of the Roman foot (29, 62 cm): 450 cm, for example, is approximately equivalent to 15 feet (15.8), or 10 cubits.

Larger blocks, with average dimensions of 800-1200 cm, could correspond to huge monolithic columns, of which no examples

are preserved in the quarries studied, except for a column of considerable size that was taken in 1932 from the San Bainzu quarry to serve as a war memorial in the municipality of Bonifacio (FIG. 22). Its apparent height today is 500 cm. Gueymard reports a height of 878 cm before its transportation in Bonifacio (about 30 Roman feet or 20 cubits; GUEYMARD 1883, 65). In his book about Bonifacio during World War I, François Canonici gives it a length of 9 m, with a mass of 20 tons (CANONICI 2014, 125), which would correspond to the format of the largest blocks found in the quarries. The sketched column of Cavallo (FIG. 14) could also correspond to this format, assuming it is partly broken.

In his paper, *A thousand and one columns: observation on the Roman Granite Trade in the Mediterranean Area*, Olwen Williams-Thorpe attempts through several geological methods (e.g. magnetic susceptibility) to establish the relationship between cut columns and quarries. He analyzed the provenance of 1176 columns present on Roman sites around the Mediterranean Sea. The corpus seems to us partially distorted by the fact that the author curiously includes columns found in quarries (for example at Capicciolu in Sardinia; WILLIAMS-THORPE 2008, 75); but his paper shows that architectural columns quarried in Corsica and Sardinia

(the author does not include Calabria in his corpus) are indeed Roman, as they were used in well-dated imperial buildings.

These results combined to our observations appears to establish an indirect link between the V-trenches technique and the imperial period. However, we are still convinced that even if Roman, this technique may also have been used long after the end of the Empire and thus, requires further archaeological and geological investigations.

D. A TECHNOLOGICAL/REGIONAL SINGULARITY?

The use of long wedge V-shaped trenches is well documented in the Mediterranean Sea, although it seems more systematic in the granite quarries of the Tyrrhenian Sea. These large V-shaped trenches, with a furrowed profile, are found, for example, in the paleochristian quarries of Aliko (Thasos), in the B2 and N sectors (SODINI, LAMBRAKI, KOŽELJ 1980, 97, FIGS. 30 and 56). The authors designate the trenches by the French term «*enjarrots*», which, as Jean-Claude Bessac pointed out, can be confusing, as «*enjarrots*» are extraction corridors dug marking the perimeter of the block to be cropped.

Anna Gutiérrez García Moreno has described this technique in the Hispanic quarries of Tarraconaise, particularly in the

quarry of Mar d'en Manassa, near Emporiae (Empúries), and Barranc de la Llet, near Dertosa (Tortosa) (GUTIÉRREZ GARCIA-MORENO 2009, 36-38; 229-245). In this part of present-day Catalonia, the limestone quarries (e.g., the quarry at Barranc de la Llet exploited the famous decorative limestone, *broccatello*), depicted the typical technology of deep wedges trenches and sockets, whereas this technique of V-trenching is the least common. According to the illustrations of Gutiérrez Garcia Moreno's book, trenches appear to be more rectilinear in their V-profile. In contrast, they are not made of successive furrows as observed in the Tyrrhenian Sea. In turn, the wedges' imprints are close to those we are studying: 9-10 cm long, 2 cm wide and between 5 and 15 cm apart. Gutiérrez Garcia Moreno, in his discussions on the chronology of the quarries, proposes two phases for the exploitation of the quarry of Barranc de la Llet: one imperial Roman, already dating back to the Augustan period, with an increase of activity in the Flavian period (2nd half of the 1st c. A.D.) and an Empire-wide export during the Severan dynasty (3rd century A.D.), the other during the Renaissance and Baroque periods, with a peak of activity in the 16th century. Beyond the Mediterranean, these markers are also described, among others, in the Roman quarries of the Sarre, especially in

Felsberg. The authors (BABIST, VÖGLER, GNIRB) associated this technological pattern with a second late-Roman phase in the 4th century, based on Röder's publications (1959; 1965) on Roman pink granite quarries in Aswan.

How to explain the over-representation of this technique in Tyrrhenian granite quarries? Should the under-representation of the socket's technique, often associated with abandoned extraction attempts, lead us to believe that quarrymen first applied a traditional technique, commonly used in the Roman world, before producing a singular technique, systematically using wedge V-trenches?

From a technological point of view, the very unfavorable value of the efficiency/labor ratio must be highlighted if we analyze the technique of digging trenches or «*enjarrots*» intended to crop the extracted block. In a hard rock such as granite, this technique is long and exhausting, whereas it is well suited for digging soft stone.

Similar large trenches are used in Mons Claudianus quarries; although the case of Mons Claudianus is particular, as it consists of a gigantic imperial quarry with an important working force, as shown by the analysis of the ostraca found on the site. The Tyrrhenian quarries, obviously much smaller in size, may have had a smaller workforce, implying the

development of an efficient and labor-saving technique.

On the other hand, extraction by wedge fracturing, without trenches, or by sockets is perilous; the risk is that some wedges do not work properly. The socket can indeed be defective, as shown by Jean-Claude Bessac in Aksum (Ethiopia) for example (BESSAC 2014, 156 FIG. 9). This would imply the extraction of large blocks with curved profiles that are unusable for the production of objects with predefined formats, such as monolithic columns.

The large size of the blocks produced at Cavallo-San Bainzu quarries could be an additional criterion. Extraction success requires the perfect control of the fractures' geometry, otherwise tedious grinding work would be mandatory to smooth out the working faces, not to mention the loss of material, which would be detrimental to such an economically valuable stone. The wedge trenches allow a better control and a more precise cutting of the rock masses. It defines break lines closer to the surface of the extracted blocks. Looking at the granite coasts we visited, only few sites gather all the conditions for the exploitation and production of large monolithic columns, i.e. granitic chaos of sufficient size, correctly cleaved/fractured rock masses, without too many and too large enclaves and advantageously positioned in relation

to maritime accesses. The exploitation of such a rare resource undoubtedly implied an adapted, economical and precise technique.

However, wedge V-trenches are also used for much smaller blocks, such as, for example, on the Cala Giunco quarry in Lavezzu. In this case, the use of these V-trenches, and not the wedges cutting technique, is not completely justified from a technical point of view, especially since, as we shall see below, the use of this technique has not prevented the production of curved blocks. The use of a technique may respond to a specific problem, but in some cases, it may also result from a cultural and/or regional pattern.

The geological configuration most likely reinforces the observation of this systematization of V-shaped trenches in the granite quarries of the Tyrrhenian Sea. As mentioned above, the morphology of the granite chaos was made of boulders separated from the bedrock by large horizontal joints. Therefore, the blocks at the bottom of the quarry did not have to be separated from the bedrock by sockets, probably leading to a kind of routine systematization of the wedges V-trenches approach.

That being said, some negative traces of wedge trenches could also be artificially over-represented. For the extracted blocks shaped in a column format, the negatives

of sockets were erased by the carving, while for the primary blocks, extracted from the surface of the boulders, with eroded surfaces, still present in the heaps of rocky residues. This could mislead our observations by showing an artificial over-representation of V-trenches. However, this argument is not supported considering the abandoned quarries, such as the one at Cala Giunco de Lavezzu, where there are only very few sockets. Even for small granitic quarries, the quarrymen have therefore mainly used the V-shaped wedge trenches.

The systematic use of this technique may follow a chronological logic, assuming that the pit quarries, where the sockets are over-represented, were in activity earlier than the others. Nevertheless, this pattern is preferably explained by a technological *habitus* originally linked to the necessity of controlling the cutting plans for the extraction of large monoliths instead of a regional *modus operandi*.

E. A CONTEMPORARY TECHNIQUE AS TERMINUS ANTE QUEM?

In addition to the three techniques described above, two other technological features could be emphasized in the Tyrrhenian quarries. The first traces, observed at Parghelia, Capicciolu and Cala Spinosa, are limited to circular holes

(average diameter: 5 cm) dug by mechanical means vertically to the working plans, associated with large masses of broken rock around the sites (FIG. 23). These traces are related to stone breakage.

These traces are also visible in the quarries, exploited in the 19th and 20th centuries, of Cala Francese, on the island of Maddalena. Today, these quarries are used for holiday rentals, but still have spaces that can be visited at the extraction sites, as well as a small museum that documents the exploitation and the quarrying techniques. Thanks to the study of visible traces and archive documents, we can establish that these holes were intended to insert black powder that was used for the rock breakage. These marks evidence the resumption of activity in the second half of the 19th or in the 20th century.

It can be noticed that no socket is visible in these quarries.

The other technical set consists of characteristic extractive marks: lines of parallelepipedal holes for the insertion of wedges, directly carved in the rock, without sockets or wedge trenches. The holes may have parallelepipedal or almond-shaped openings; their dimensions are 8 to 9 cm long, 4 or 5 cm wide. They are spaced at intervals of variable length, between 2 and 5 cm (FIG. 24). In some

cases, these traces occur within extraction sites along with V-trenches. This is the case, in particular, in the large quarries of Cavallo-San Bainzu and Capicciolu. In other quarries with V-trenches, they are totally absent, i.e. Nicotera, Parghelia, Lavezzu and Marmorata. In other quarries, only these lines of holes for the use of wedges were used for extraction, particularly in Muccia and Cala spinosa on Capo Testa.

These observations can be compared with the technical traces studied in the contemporary quarry of Cala Francese, on the island of Maddalena, Sardinia (FIG. 25). This leads us to believe that this technological pattern clearly belongs to the 19th and 20th centuries, which does not mean that it was not used earlier, since this technique is attested for the Roman period (ADAM 2011, 33).

This technique is however never present on columns or blocks carved in columns. On Muccia peninsula, it was used to produce long parallelepipedal blocks (FIG. 8), from which it is impossible to produce a column, and which we interpret as quay borders, unless they are long flat blocks for cutting «quadrans», construction blocks, cut across the width. In Cala Spinosa (Capo Testa, Sardinia), the blocks were clearly used to produce construction quadrans, most likely intended for the construction of a small dock in the immediate vicinity of the

quarry, located next to an underground shelter that was one of the defensive facilities of the Second World War (FIG. 26). In the quarry of I Becchi (Lavezzu), the blocks extracted using this technique were used for the construction of the lighthouse during the years 1872-74. At Cavallo-San Bainzu, Muccia and Capicciolu, this technique is associated with the extraction of blocks that, fortunately, are still in place (FIG. 27). For example, in Muccia, the blocks are 80 cm long, 70 and 75 cm wide and 95 cm high, and in San Bainzu the dimensions are 95 x 65 x 100 cm, respectively. We think that these blocks could match the format of the construction quadrans found in all the agro-pastoral and private Corsican architecture throughout the 19th and 20th centuries. Their average dimensions are 40-50 cm long, 30-40 cm wide and 40-50 cm deep, which implies that each block can be cut to produce 8-10 quadrans.

F. ABANDONMENT OF EXTRACTION SITES

Several extraction sites were abandoned. On Lavezzu, at the Cala Giunco quarry, probably all the blocks resulting from extraction were still in place. Only one block bears the traces of a secondary carving which probably gave it the profile of a capital (FIG. 4). On Muccia, most of

the blocks also seem to be abandoned near the quarry. On Cavallo and San Bainzu, at least on one extraction site, large parallelepiped blocks appeared to be abandoned *in situ*.

What are the reasons for these abandonments? First of all, we must call for caution by pointing out that it can overlap different reasons, such as, for example, prospecting, abandonment as a result of a technical problem, or simply the historical end of exploitation following particular events or contexts.

The intense prospecting carried out in the granite coasts is certain. On Parghelia, the granodiorite intrusion is emplaced within a second intrusion of much coarser granite (FIG. 28). In this case, prospecting by rock breakage was intended to ensure the quality of the rock at depth.

The abandonment was probably motivated by the same quality principles that guided the prospecting, as well as by technical problems related to the extraction itself. The heterogeneities of the stone, preventing the exploitation of a product of good quality when polished, seem to have been a crippling factor. We think that on Lavezzu, the dark mafic enclaves (FIG. 29), more present than on the other extraction points of the Lavezzi, led the quarrymen to abandon the site. From a technical point of view, we found that on the abandoned quarries, there were a high

number of curved blocks or working faces (FIG. 30). These profiles imply flatness defects, which require important rectification, an operation probably considered too tedious in terms of profitability.

A final rationale is probably related to the ability to ship the blocks from natural or constructed docking points. This is what happens in Muccia (FIG. 9): with several attempts made with impediment to bring the large, long blocks to the coast, but due to the difficulty of the terrain, flat and rocky, the quarrymen abandoned them on the spot.

CONCLUSION

In light of our research, we could argue for a successive phasing of the quarrying techniques. The attested but rare technique of combination of wedge trenches/sockets would correspond to a traditional of primary technique, gradually replaced by the use of characteristic wedge V-shaped trenches, perhaps during the 2nd and 3rd centuries. The systematic association of these technical markers with the blocks cut in columns, as well as their total absence in contemporary quarries (especially in Cala Francese, on Maddalena), attest that this technology is indeed Roman.

But beyond chronological considerations, which only stratigraphic excavations can

establish, this evolution would reflect a technical adaptation to the hardness of the granitic rock. In fact, it appears that within extractive complexes outside the Tyrrhenian Sea (for example: Catalonia and the Alikí quarries in Thasos), this technique of wedge V-shaped trenches is the least common, whereas it is over-represented in the Roman granite quarries in the Tyrrhenian Sea, especially in the Corso-Sardinian Strait. The peculiar configuration of the granite boulders, separated from bedrocks by horizontal joints/fractures, made the sockets gradually obsolete, until the quarrymen eventually systematized the V-shaped trenches, even to detach the blocks from the benches on the bottom side. However, we must be extremely careful in our interpretations, because a few counterexamples remain: e.g. at Punta Falcone (FIG. 10), a block has been cut out of a large granite massif with a V-trench, but the block itself is cut with the sockets method, which shows the complexity of the interpretative models. Technically, the V-shaped trenches offer a more than optimal work/efficiency ratio. The trenches avoid the problem of faulty sockets and make possible to create straight and controlled cutting plans. Methodologically, the Romans relied on the rock geometries and established their quarries in boulder chaos or massive granitic blocks whose bases were parallel

to natural horizontal fracture plans and adapted their extraction strategy, accordingly. Therefore, the goal was to find the most massive and homogeneous blocks, which at the same time had the appropriate geometry of fracture and faults. This drastic selection undoubtedly explains the intense prospecting documented in particular in the Strait of Bonifacio.

If we can distinguish at least two phases of exploitation, one imperial, the other contemporary, then we should see a Roman occupation in the quarries of Parghelia and Nicotera; in the Strait of Bonifacio, in the quarries of Marmorata, Capicciolu, on Capo Testa, and Punta Falcone in Sardinia, Cavallo-San Bainzu and Lavezzu in Corsica. The quarries of Cala Spinosa on Capo Testa, Munnica, and Cala Francese on Maddalena, would be contemporary (19th-20th centuries).

However, the phasing is delicate in view of the very slow evolution of the extraction techniques between the Roman period and the end of the 19th century. The results of the geological analyses and the archaeological findings will hopefully validate and support the technological analysis.

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