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A GEOARCHAEOLOGICAL STUDY OF THE ANCIENT QUARRIES OF SIDI GHEDAMSY ISLAND (MONASTIR, TUNISIA)*

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Amongst a large number of ancient quarries scattered along the North African coast, those at Sidi Ghedamsy (Monastir, Tunisia) have supplied building stones of Pliocene age. Two lithofacies have been distinguished in the quarry faces: (i) fine sandy limestone, which has been used in the construction of Roman and Arabic monuments; and (ii) porous and coarse limy sandstone, which is of bad quality for construction. Laboratory analysis results confirm that the exploitation of stone in antiquity was well focused on the levels containing the first type. This is confirmed by geotechnical tests, which show that the fine sandy limestone is harder and less porous than the coarse limy sandstone. Extraction of these stones began in the Roman period. The Romans exploited the quarries using steel tools that permitted the extraction of blocks from several levels. In the eighth century, Arabic quarry workers continued the stone extraction using the same technique, but they produced blocks of small and medium size. Statistical measurements have been done on the quarry faces and on the walls of the Ribat in order to understand the degree of conformity between the dimensions of the extracted blocks and those used for building, and ultimately to attempt to date the quarries and the construction of the Ribat.

KEYWORDS: QUARRY, UPPER PLIOCENE, LIMESTONE, POROSITY, RIBAT, MONASTIR, BLOCK, BUILDING STONE

INTRODUCTION

Along the Mediterranean coasts, there are a large number of ancient quarries that date from the Faraoun and Punic periods (Bloxam *et al.* 2005; Storemyr *et al.* 2006; Heldal *et al.* 2007). The extraction and transport of large and heavy blocks represents a feat of skilled engineering as well as a knowledge of the lithology and stratigraphy of the building stones. Although such quarries have been documented, little is known regarding when and how they were exploited and where their stones were used for construction. In Tunisia, only four or five ancient quarries have been studied (Harrazi 1995; Gaied and Ouaja 2000; Younès and Ouaja 2008). Some of them are mentioned in a general work about the Tunisian coast (Oueslati 1993; Slim *et al.* 2004).

This work intends to study the ancient quarries of Sidi Ghedamsy by analysing the petrographic and geotechnical properties of their stones. It attempts to retrace the ancient extraction technique and to quantify the dimensions of the extracted blocks, and to see if they have conformity with the blocks used to build famous Islamic monuments such as the Ribat of Monastir. It also tries to suggest a dating of the quarries.

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Sidi Ghedamsy ancient quarries are located on the Monastir peninsula, which is 162 km south-east of the capital Tunis and 20 km south-east of the town of Sousse (Fig. 1). The Romans, whose constructions have been found on the island, were perhaps the first people to exploit the quarries. The Muslim settlement in the peninsula brought more dynamism to the construction of buildings such as the Ribat,[1] a great fortress built from AD 796 onwards, with blocks extracted from these quarries situated nearly 1 km from the construction. One of the quarries was still being exploited in the middle of the 14th century. The blocks extracted from this quarry were used to build a watchtower reserved for tuna fishermen.

Several interesting geological and archaeological studies deal with Sidi Ghedamsi Island. The first geological map of this region was published in 1956 (Castany *et al.* 1956), and a neotectonic study was made in the Sahel region in 1981 (Kamoun 1981). The archaeological studies date from 2004 (Slim *et al.* 2004) and 2008 (Younès and Ouaja 2008).

GEOLOGICAL SETTING

The Monastir peninsula shows an anticline structure essentially constituted by Miocene and Pliocene outcrops, covered by a discordance of marine Quaternary deposits folded up by a Pleistocene compressive phase. Sidi Ghedamsy Island, mainly constituted by marine Pliocene deposits, is located on the eastern flank of the anticline structure with a 25° southeastward dip (Fig. 1).

Four quarries are situated on the western and eastern flanks of this island. Only two of them, located on the northern part, are studied here (3 and 4, Fig. 1), because they are better preserved than the other two (1 and 2, Fig. 1). Two lithological sections were described in the two well-preserved quarries (3 and 4). In the section of quarry 3 (Fig. 2), most of the thickness of the section (15 m from a total of 17 m) is made up by sandy limestone, which is very rich in fossils. The section of quarry 4 (Fig. 2) shows that 11 m of the 14 m is made up of sandy limestone. Only 3 m out of 14 m is constituted by porous limestone and hard sandstone. In both quarries, the sandy limestone is particularly interesting in the building domain because of its homogeneity in colour and texture.[2]

SAMPLING AND ANALYTICAL PROCEDURE

Four blocks were cut out from the quarry faces (3 and 4) using hammers and picks. These samples were representative of the two lithotypes. The amount of calcite has been measured (calcimetry method) and the different constituents and textural features of the stone have been identified by optical microscopy (OM). Moreover, geotechnical analyses have been made, such as standard water behaviour tests, determined according to French norms NFB 10-502 to NFB 10-504, and resistance to simple compressive strength measurements have been realized thanks to a hydraulic press at the Superior Institute of Technological Studies of Sfax (ISETS).

ANALYTICAL RESULTS

Petrographic results

Optical microscopy (OM) observations confirm the presence of the two lithotypes in Sidi Ghedamsy stones. The first is characterized by sandy limestone with a pack-wackestone

[1]The Sidi Ghedamsy quarries are not far from the Ribat (only 0.5 km) and the stones used have the same lithology and the same age.
[2]In the construction field, stones must be homogeneous in their colour and texture.

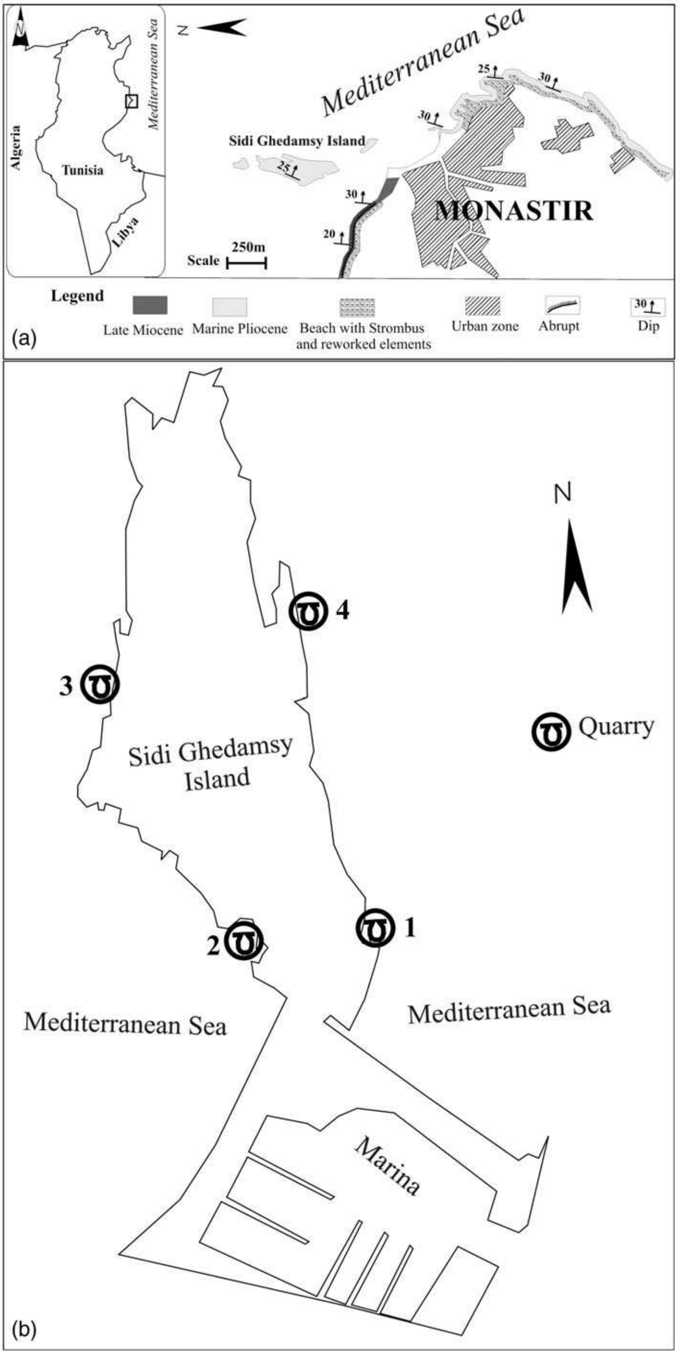

Figure 1 *The location of Sidi Ghedamsy Island: (a) a geological map of the Monastir peninsula; (b) the positions of the quarries.*

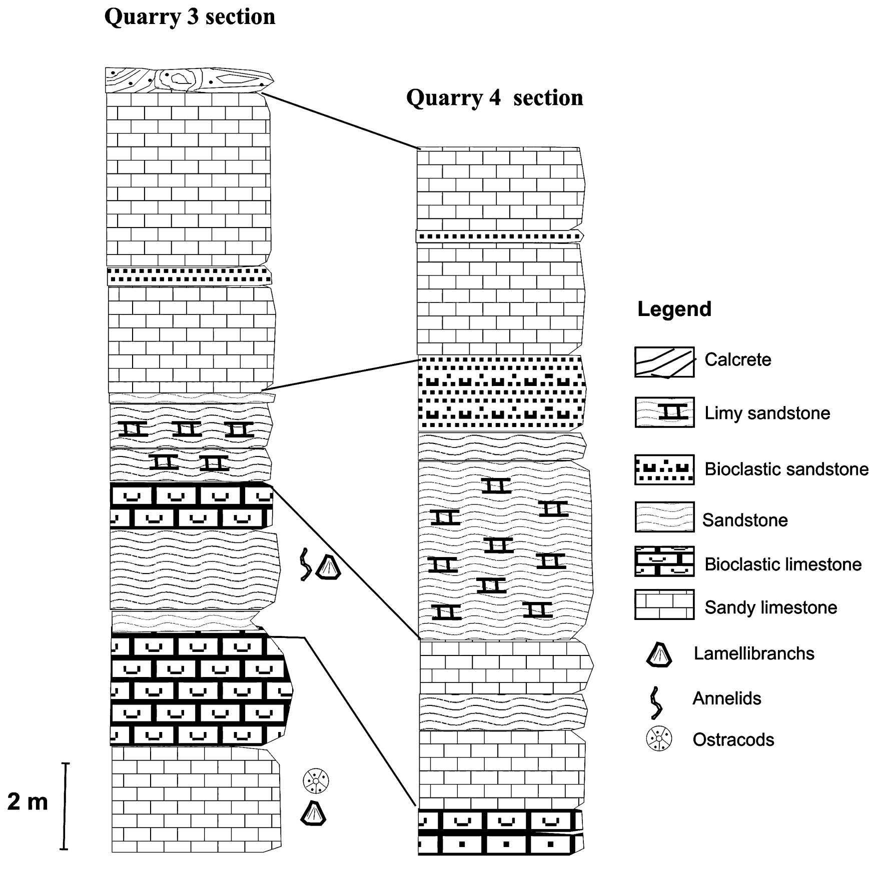

Figure 2 *Lithological sections of the quarries studied.*

texture, containing scarce bioclasts and abundant mud fractions. This stone is relatively homogeneous with rare microporosity, and presents a yellowish colour that was well appreciated by the ancient builders[3] (Figs 3 (a) and 3 (b)). The second lithotype (Figs 3 (c) and 3 (d)), constituted of limy sandstone with a grainstone texture, contains abundant coarse grains (or carbonate allochems) represented by fragments or whole lamellibranch shells cemented by a very thin quartz matrix. Although this lithotype seems harder than the first one, it shows, in fact, numerous micro-cavities and consequently a high porosity (particularly internal porosity).

Calcimetry results

The calcimetry results show that the coarse limy sandstone has a low percentage of $CaCO_3$ (28%). A high percentage (83%) corresponds to the pack-wackestone texture, because mud is constituted by micritic carbonate calcium.

[3]The ancient builders had chosen stones based on their colours. The yellow ones show good geotechnical and petrographic characteristics.

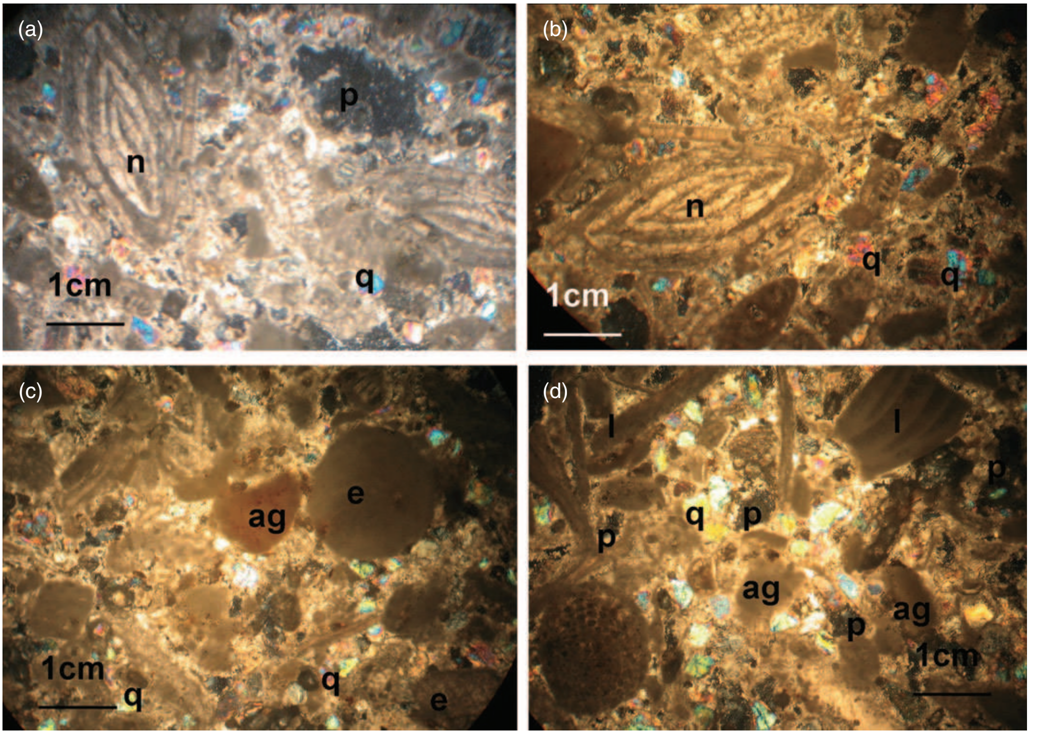

Figure 3 *Microfacies of Sidi Ghedamsy stones: limy sandstone (a, b) and sandy limestone (c, d): ag, red algae; e, echinoderm; l, lamellibranch; n, nummulite; p, porosity; q, quartz.*

Geotechnical results

Five geotechnical parameters are determined: the density, water absorption coefficient, capillarity, porosity and resistance to simple compressive strength. These parameters are necessary to evaluate the resistance of Sidi Ghedamsy stones against corrosion, bad weather and compression. They can be considered as the principal criteria of durability and longevity for archaeological monuments.

Density The apparent density is determined by immersion of the sample in a graduated test tube according to the French norm NF B 10-503 (Association Française de Normalisation 1973c).[4] The real density is evaluated after immersing the sample in water for 24 h according to French norm NF B 10-504. The results of this test show that sandy limestone is denser than limy sandstone (2.26 and 2.16, respectively).

Water behaviour tests *Water absorption*: water absorption is evaluated by immersion of the samples in water and by measuring mass variations over 1 h according to French norm NF B 10-504 (Association Française de Normalisation 1973a). For all the samples, the water behaviour is characterized by two phases:

[4]The geotechnical tests were carried out using laboratory equipment made in France. Consequently, these tests are conceived according to AFNOR standards.

- The first is a rapid mass increase, due to the filling of exterior pores with water.
- The second is a period of mass stability. This indicates the full water saturation of the sample.

The length of the first phase depends on the nature of the sample. In the coarse limy sandstone, water absorption is relatively very slow. It lasts for about 40 min before reaching saturation point. However, the fine sandy limestone mass increase is very quick during the first 10 min. However, this does not mean that the saturation point is reached, because this rock still continues to absorb water even after the first hour of immersion.

Water absorption coefficient: this parameter is measured according to French norm NF B 10-504. The fine sandy limestone has a water absorption coefficient that is relatively high compared to that of the coarse limy sandstone. This can be explained by the following relation:

$$C' = \text{volume of absorbed water/emptiness volume (total pore space)}.$$

When the emptiness volume is very important, the water absorption coefficient is very low, and vice versa.

Water capillarity absorption: this parameter is determined according to French norm NF B 10-502 (Association Française de Normalisation 1973b). About 1 cm of each sample's height is immersed in water. The capillarity coefficient (C) is calculated according to the following formula:

$$C = 100M/S\sqrt{t}$$

where M is the total mass of absorbed water after 1 h of partial immersion, S is the area of the basal section expressed in cm^2, and t is time (3600 s).

The results show that the capillarity coefficient of fine sandy limestone is inferior to that of the coarse limy sandstone.

Porosity: the porosity test is done according to French norm NF B 10-503. Coarse limy sandstone shows a higher percentage of porosity than fine sandy limestone. This fact is confirmed by the petrographic study, which reveals the presence of abundant micro-cavities in the coarse limy sandstone.

Resistance to simple compressive strength Simple compressive strength testing is carried out on cubic samples, each one being sized at 64 cm^3 ($4 \times 4 \times 4$ cm). Fine sandy limestone is more resistant than coarse limy sandstone because of the presence, in the latter, of micro-cavities that promote numerous micro-fissures.

ANCIENT STONE EXTRACTION TECHNIQUES

Amongst the four quarries (Figs 4–7), two (2 and 3) are located on the western side of the island, whereas the other two (1 and 4) are situated on the eastern side (Fig. 1). Quarry 3 is almost rectangular (Fig. 8), with a markedly north-east/south-west orientation. Its exploited area is around 120 m^2, but it is difficult to evaluate the amount of stone extracted, because of a discontinuous and not homogenized extraction. Quarry 2, the largest of the four, is rectangular and oriented east–west. Today, its area is about 3128 m^2 and the amount of stone extracted is around 12 513 m^3. However, it is difficult to know whether this area measured nowadays corresponds to the original one, because the quarry underwent a transformation in the mid-19th century. Indeed, it was changed into a square for use by tuna fishermen.

Figure 4 *Quarry 1: marks of extracted blocks left on the quarry face.*

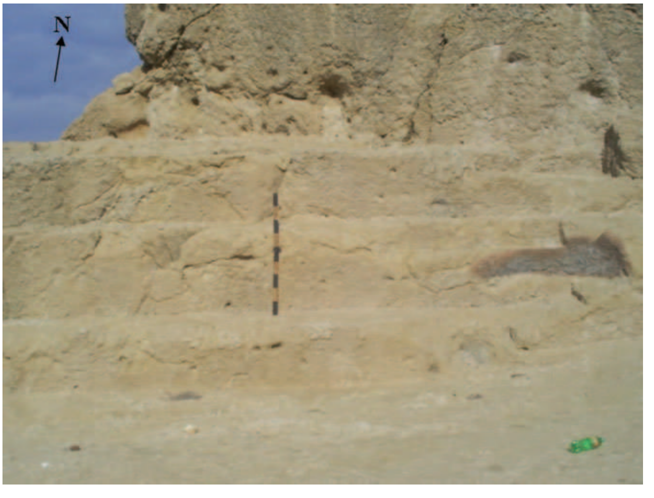

Figure 5 *Quarry 2: part of the northern face of the quarry, showing three levels left on the quarry face after the extraction of blocks.*

Quarry 1 is oblong, with a north–south orientation. Its area is around 1028 m^2, but the amount of stone extracted is difficult to evaluate, because of depth variation inside the quarry. Quarry 4, almost rectangular in shape, has a north–south orientation (Fig. 9). Its area is around 199.5 m^2 and, as for the previous quarry, the amount of stone extracted is hard to evaluate.

Was the location of the four quarries on the island a voluntary choice made by the quarry workers who were looking for good quality stones, or solely the result of a spontaneous extraction of blocks? According to the geological and petrographic study made on the quarry faces, the quarry workers were, very likely, looking for good quality stone when exploiting the quarries. Thus, blocks were extracted from levels of homogeneous hard sandy limestone situated more or less near the ground level (see the lithological sections of quarries 3 and 4). In quarry 3, the stone

Figure 6 *Quarry 3: part of the eastern face of the quarry, showing marks of extraction blocks left on the quarry face. In the middle distance and on the left of the photograph, a pre-cut block can be seen.*

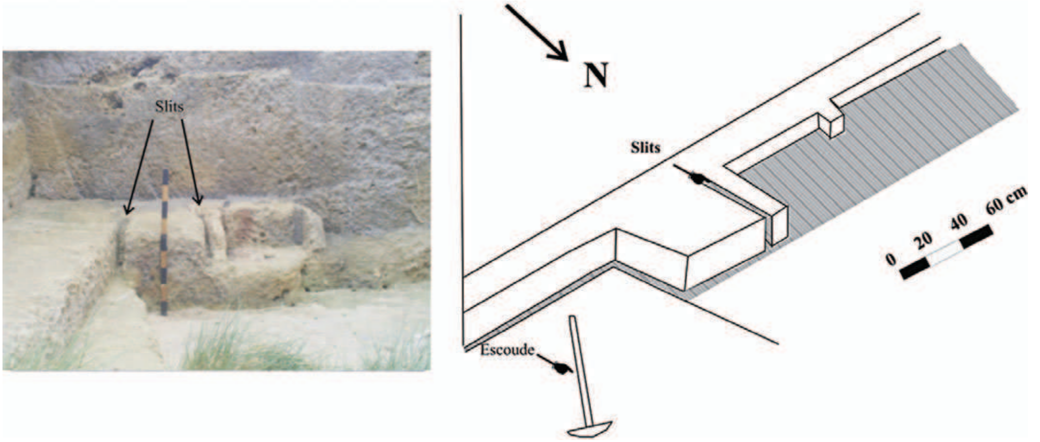

Figure 7 *Quarry 4: part of the southern face of the quarry, showing marks of extracted blocks left on the quarry face. A pre-cut block can be seen in the foreground, with an extracted one just to its side.*

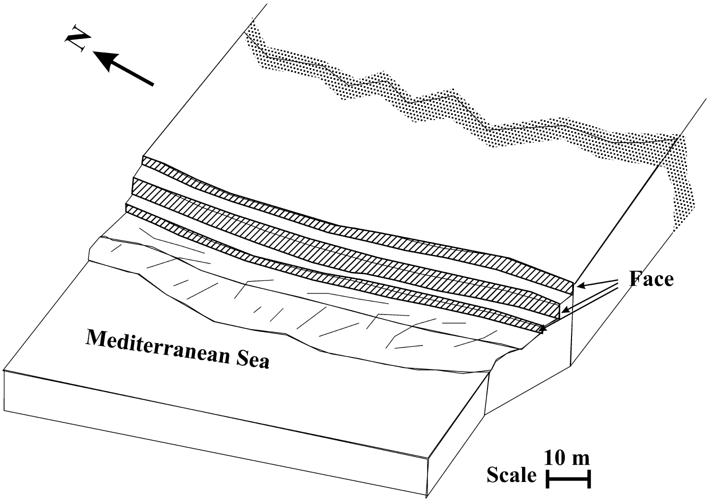

Figure 8 *A diagram of quarry 3.*

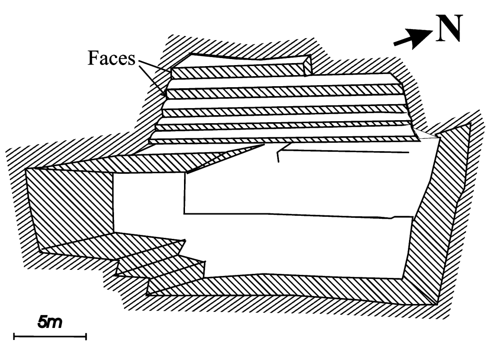

Figure 9 *A diagram of quarry 4.*

of good quality is found almost at the ground level, whereas in quarry 4 the same stone is situated below the outcropping carbonate crust.

Traces of extracted limestone blocks are better preserved in quarries 2, 3 and 4 than in quarry 1, because the latter is exposed to the violent waves caused by the southeastern wind (the '*chlouk*') (Fig. 4). Marks left on the quarry faces are an important testimony concerning the quarrying technique used by the quarry workers to extract stones. The quarry workers were extracting blocks by progressing from the seaward side to the inside of the island. This technique has been identified in other quarries of the Tunisian littoral (Slim *et al.* 2004; Younès and Ouaja 2009), between *Sullecthum* and El Alya (Sahil region), at Bizerte, Sidi Daoud (Cap Bon region) and so on. While progressing inland, the quarry workers left an uncut strip of rock, which was used as a 'wall' to avoid sea water entering the quarries. Other littoral quarries situated between *Sullecthum* and El Alya have been also been protected from sea water by a 'wall' (Younès and Ouaja 2009). This kind of 'wall' is still preserved in quarries 3 and 4, but it is no longer visible in quarries 1 and 2. In the latter case, it may have been destroyed when the quarry was changed into a watchtower for use by tuna fishermen.

Extraction of blocks was done in stages. First of all, the quarry workers would take off the upper layer of rock, which was of poor quality and useless for construction. This rock layer, also called the 'recovered layer' (Adam 1984; Bedon 1986), corresponds to a consolidated carbonate crust, which reaches a thickness of 0.5 m. After this preliminary work, the quarry workers would outline the blocks to be extracted by making slits using a pick or '*escoude*' (Dworakowska 1975, 1983; Adam 1984; Bessac 1991; Goette *et al.* 1999; Hayward 1999). In the best-preserved quarry faces, natural planes of weakness (joints and stratigraphic levels) were non-existent, contrary to the quarries situated on the Tyrrhenian dune line (Rejiche formation), where the quarry workers exploited the natural fractures (Younès and Ouaja 2008). In quarries 2 and 3, the width and depth of the extraction slits depend on whether they concern pre-cut or extracted blocks. The slits preserved on the former are 3 cm wide, and their depth ranges from 6 to 8 cm; whereas on the latter the width ranges from 5 to 7 cm, and the depth from 20 to 30 cm. Perhaps the extraction slits were widened and deepened with one of the two percussion tools (the pick or the '*escoude*') or the awl (Fig. 7). According to Bessac (1991), the slit width concerning a block that does not exceed 20 cm high is 5–6 cm; whereas for a block whose height is more than 20 cm, the trench width spans from 9 to 12 cm, whatever the nature of the stone (hard or soft).

Because of a lack of precise documents, it is difficult to determine the kind of tools (a pick or an '*escoude*', possibly along with an awl) used to realize this kind of operation in ancient and medieval periods. According to an ethnographic survey (Younès and Ouaja 2008) conducted on quarry workers living at Sayada and Rejiche (Sahil region), up to recent times the quarry workers have used picks to make extraction slits. After making extraction slits on three sides of the block, because the upper horizontal and lower upright side has been previously isolated, the quarry workers make a line of fracture and wedge holes on the lower horizontal side in order to insert metallic wedges. Then, the quarry workers can extract the block from the bedrock by hammering the wedges. Traces of wedge holes are preserved on quarry faces. This technique of extracting sandy limestone blocks has been pointed out in other ancient quarries (Younès and Ouaja 2008, 2009).

Marks of extracted blocks give a stepped profile to the faces in quarries 2, 3 and 4, sometimes composed of several 'steps' or 'levels' (Figs 5–9). For example, the western face of quarry 4 shows a terraced profile consisting of six steps spanning in size from 0.65 m to 1.80 m wide and from 0.50 m to 0.60 m high (Fig. 9). In order to calculate the sizes of several extracted blocks from quarries 3 and 4, we have deducted the extraction slit widths (5–7 cm) (see Table 1).

RESULTS OF QUARRY MEASUREMENTS

Although the blocks recorded in the two quarries represent only a small proportion of the number of extracted blocks, they give us useful information about their sizes, which are even more interesting when combined with data on the blocks employed in the Ribat.

The medium-sized blocks, which range from 40 to 55 cm long, from 40 to 50 cm wide and from 20 to 30 cm high, are more numerous (87/103) than the small-sized blocks ($25 \times 20 \times 20$ cm), which represent only 3/103. The large-sized blocks are situated in between (13/103), and are 60–80 cm in length, 40 cm wide and 30, 25 or 20 cm high. According to these sizes, the blocks were not cut following the ancient measuring units (the Punic foot, 343–345 mm, or cubit, 514–517 mm, or the Roman foot/cubit employed in Africa, 294 mm/460 mm; Hallier, 1989, 1993). However, the quarry workers may sometimes have used both the Arabic *dhrâa* (the Arabic cubit, 480–500 mm) and the Arabic *chebr* (200–250 mm), as used in the Sahil

Table 1 *The sizes (length × width × height, in cm) of pre-cut and extracted blocks according to the marks left on the faces of quarries 3 and 4*

Number of blocks	*Length (cm)*	*Width (cm)*	*Height (cm)*
Quarry 3			
1	80	40	25
2	70	40	20
8	60	40	30
2	60	40	20
2	55	40	25
4	50	40	20
3	40	25	20
6	40	20	20
3	40	15	20
Total = 31			
Quarry 4			
19	50	45	30
20	50	20	30
28	50	20	20
2	40	25	30
3	25	20	20
Total = 72			

region (at Sousse, Monastir and Mahdia) in the 19th century. Indeed, a great number of the blocks are 500 mm long. According to Fleury (1895), the Arabic *dhrâa* dates back to the 10th century, whereas for Lejeune (1984) and Legendre (1958), it varies according to the towns and regions. In most of the Sahil towns, the size is 500 mm.

The extraction of identically sized squared blocks attests that the quarry workers were proceeding to an extraction in series, as ordered by builders. This technique was used in the underground quarries situated in eastern *Byzacium* (Younès and Ouaja 2008). Two advantages result from this way of working: reductions in both working time and the volume of stone chips, because the block does not need to be cut and carved before being used in construction. The quarry workers gave up quarrying inside the quarries, because while progressing towards the inland part of the island the upper layer of the rock, which is useless for building purposes, becomes rather thick and/or inhomogeneous. For example, in quarry 4, exploitation of the stone has been interrupted on the western side because the upper layer of the rock becomes rich in bioclasts, making it unsuitable for construction.

RESULTS OF ARCHITECTURAL MEASUREMENTS

The survey conducted on the ancient and Muslim constructions located on Sidi Ghedamsi Island, in the town of Monastir and in the neighbourhood reveals that most of these constructions (the Ribat, the mosque and Qasr Sidi Dhwib) were built with stones extracted from the quarries situated on the island. Our work has consisted of measuring the sizes of the blocks used for building the Ribat, because its architecture and the stages of its construction have been precisely studied (Lézine 1956).

The Ribat (Fig. 10) was built on a strategic site on the Monastir peninsula. Its area is around 2 ha, with a rectangular shape flanked by towers on its sides, and markedly turned towards the north-west/south-east. The construction was built in stages. First of all, the citadel (*qasaba*), square in shape and equipped with four towers, was built in AD 796 by the Abbassid governor Harthama Ibn Ayum. It was first enlarged in the ninth century by the Aghlabid princes, and then in the 10th–12th centuries under the Fatimid and Zirid rules. During the 13th–16th centuries (the Hafsid period), small works were carried out, such as the building of a polygonal tower and the widening of the courtyard at the expense of the northern part of the primitive *qasaba*. From the end of the 16th century to the 19th century, the Turks added both the circular and polygonal bastions and the artillery platforms. Later, in 1954, a few works of restoration were carried out on the western and southern ramparts (Lézine 1956; Djelloul 2007).

In this present work, it was impossible to measure all the blocks of the Ribat, so we selected sections of walls built in different periods (the 8th, 9th–12th, 13th–16th and 17th–19th centuries) and which were not restored in 1954:

- The walls of the watchtower and the arches situated at the southern entry of the primitive *qasaba*. According to Lézine (1956), both structures date from the eighth century.
- A horizontal row (1.50 m in height from ground level), chosen from sections of the ramparts situated on the northwestern side (11th century) and on the eastern side (16th–19th century) (Lézine 1956; Bouzeguenda 1999; Djelloul 2007; see also Fig. 11). As the blocks belong to the same row, it is easier to observe changes in their sizes.

Although the number (360) of blocks measured only represents a small fraction of the whole set of blocks used to build the Ribat, it gives us some idea about the sizes of the blocks and which ones occur most often. Thus, a preliminary comparison can be made between the cut blocks of the quarries and those employed in the Ribat.

The large-sized blocks (60–100 cm long by 20–45 cm high) only represent 16.6% of the measured blocks. They are mainly found in the watchtower of the primitive citadel dating from AD 796, in the northwestern side rampart and in a section of the eastern side rampart dating from the ninth century (Table 2, and nos. 1, 10, 15 and 16 in Fig. 11). The blocks that occur very often measure (length by height) 90 × 40 cm, 75 × 40 cm and 70 × 40 cm. The block sizes do not correspond to the conventional measurement units, such as the Punic or Roman cubit in Africa, or the Arabic *dhrâa* (cubit) or *chebr*.

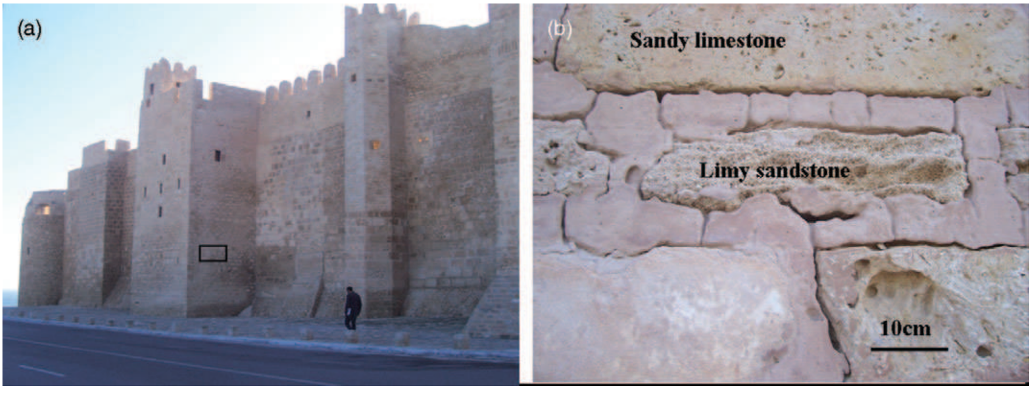

Figure 10 *A panoramic view of the Ribat (a) and a detail of the wall (b).*

The medium-sized blocks (35–55 cm long by 10–40 cm high) are more numerous (38.9%) than the large ones, and they are found in all the measured sections of the Ribat (Fig. 11). The blocks of most frequent occurrence measure 50 cm long and their width ranges from 15 to 50 cm. The block length is similar to the Arabic *dhrâa* (50 cm) used in the Sahil region in the 19th century (Legendre 1958). It is likely that some blocks have been measured according to the Arabic *dhrâa*, which has probably been in use since the medieval period (Fleury 1895; Legendre 1958).

The small-sized blocks (10–30 cm long by 10–20 cm high) are more numerous (44.5%) than the large and medium ones. Almost all of them have been employed in the sections of the rampart built from the 16th century to the 19th century (nos. 11, 13 and 14 in Fig. 11). The large majority of them (110/160) are 22 or 25 cm long and 108/110 are found in the parts of the Ribat built from the 16th century to the 19th century (nos. 11, 13 and 14 in Fig. 11). These two lengths of the blocks correspond to those of the Arabic *chebr* (22 or 25 cm) used, among others, by the joiners and the marble workers of Tunisia in the 19th century (Fleury 1895; Legendre 1958). In the towns situated in the Sahil region, the length of the *chebr* used at Mahdia is 22 cm, while it is 25 cm at Sousse (Legendre 1958). The blocks may have been cut following these two Arabic *chebr* lengths.

The sizes of several blocks recorded in the Ribat are similar to those extracted in quarries 3 and 4. The large-sized ones (80×40 cm, 70×40 cm and 60×40 cm), very likely extracted from

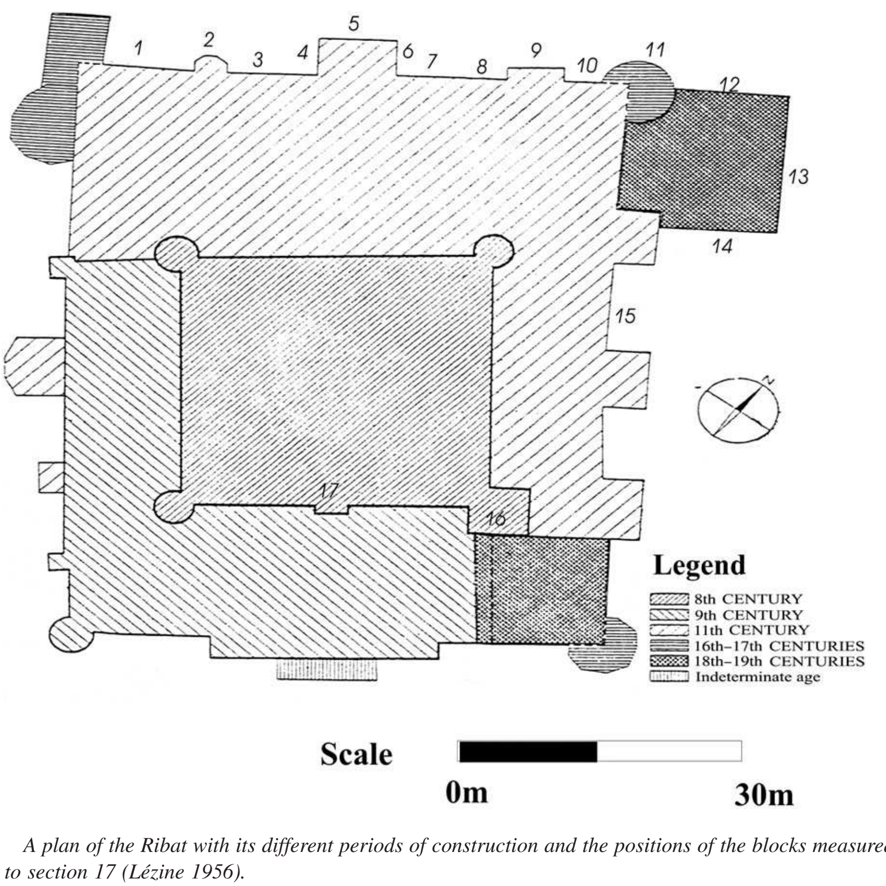

Figure 11 *A plan of the Ribat with its different periods of construction and the positions of the blocks measured, from section 1 to section 17 (Lézine 1956).*

Table 2 *The sizes (length × width × height, in cm) of the blocks measured in the different parts of the northwestern side rampart of the Ribat, shown in Figure 11*

Location of the blocks	*Number of blocks*	*Length (cm)*	*Height (cm)*
Part 1	1	100	45
	1	90	45
	1	90	40
	2	80	40
	2	75	40
	2	70	40
	Total = 9		
Part 2	1	85	40
	3	75	45
	4	75	40
	1	70	45
	Total = 9		
Part 3	2	95	40
	2	90	40
	2	70	40
	2	60	40
	1	55	40
	Total = 9		
Part 4	2	45	20
	1	40	25
	3	40	20
	1	35	30
	1	35	20
	1	35	15
	1	30	20
	1	25	20
	Total = 11		
Part 5	2	70	20
	3	50	20
	2	50	15
	3	45	20
	1	45	15
	2	40	20
	1	40	15
	1	30	15
	Total = 15		
Part 6	3	45	20
	1	40	20
	5	30	20
	Total = 9		
Part 7	20	35	10
	1	30	10
	Total =21		
Part 8	8	55	40
	1	40	15
	Total = 9		

Table 2 *(Continued)*

Location of the blocks	*Number of blocks*	*Length (cm)*	*Height (cm)*
Part 9	1	100	40
	3	90	40
	1	80	40
	1	75	40
	2	70	40
	Total = 8		
Part 10	1	80	40
	2	70	40
	1	65	40
	1	50	40
	1	40	35
	1	40	25
	1	35	40
	1	35	20
	1	30	15
	Total = 10		
Part 11	1	50	15
	1	45	20
	2	40	15
	11	35	15
	7	30	15
	2	25	20
	5	25	15
	1	20	15
	Total = 30		
Part 12	1	50	35
	2	50	30
	1	45	30
	2	45	25
	2	45	20
	1	40	20
	2	35	20
	Total = 11		
Part 13	1	40	15
	1	40	10
	5	30	10
	5	25	10
	3	20	10
	3	15	10
	1	10	10
	82	22	12
	Total = 101		
Part 14	3	50	20
	2	45	20
	2	35	20
	8	30	20
	14	25	20
	12	20	20
	Total = 41		

Table 2 *(Continued)*

Location of the blocks	*Number of blocks*	*Length (cm)*	*Height (cm)*
Part 15	1	80	35
	3	70	35
	1	65	35
	1	60	35
	1	55	35
	3	50	35
	2	45	35
	10	40	35
	2	35	35
	1	25	35
	Total = 25		
Part 16	*2*	*100*	*45*
	2	*90*	*45*
	1	*90*	*25*
	2	*85*	*45*
	1	*85*	*30*
	1	*80*	*45*
	1	*75*	*40*
	3	*70*	*40*
	1	*70*	*30*
	1	55	50
	1	55	40
	1	55	25
	1	50	50
	2	50	40
	1	50	30
	3	50	25
	1	45	40
	1	30	30
	Total = 26		
Part 17	1	60	50
	2	50	50
	3	50	35
	1	50	30
	2	50	20
	1	45	50
	1	45	40
	2	45	30
	1	45	10
	1	40	45
	1	40	30
	Total = 16		
Total number of blocks = 360			

quarry 3, are mainly employed in the sections of the rampart dating from the 11th century (Fig. 9 and Fig. 11, nos. 1, 3, 9 and 10). The medium-sized ones (45 × 40 cm, 50 × 40 cm, 50 × 20 cm, 50 × 15 cm, 40 × 25 cm and 40 × 20 cm), probably cut out from quarries 3 and 4, are used to build parts of both side ramparts dating from the 11th century and from the 18th–19th centuries

(Fig. 11, nos. 3, 4, 5, 6, 8, 10 and 14). Concerning the small-sized blocks (25 × 20 cm), they have been extracted from quarry 4 and mainly employed in the part of the rampart dating from the 18th–19th centuries (Fig. 11, no. 14).

AN ATTEMPT TO DATE THE QUARRIES

The Ribat construction is almost entirely built with sandy limestone blocks dating from the superior marine Pliocene extracted from the quarries situated on Sidi Ghedamsi Island. The monument was restored during the First World War by German prisoners and during the second half of the 20th century by Tunisian workers (Djelloul 2007). The Tyrrhenian limestone blocks used in the restoration were taken from ancient constructions probably situated at the Roman site of Ruspina.

The stages of its construction span in time from AD 796 to the 18th–19th centuries. According to the marks left on the quarry faces, some blocks extracted from quarries 3 and 4 may have been employed in the parts of the Ribat built in AD 796, in the 11th century and in the 18th–19th centuries. Some parts of the two quarry faces may have been abandoned since the 11th century, while others have been exploited since the 18th–19th centuries. However, this hypothesis can be confirmed only when all the blocks of the Ribat have been measured and studied.

In quarry 2, stone was still being exploited during the second half of the 19th century. Medium-sized blocks (50 × 25 × 25 cm) extracted from this quarry were used to build the watchtower reserved for tuna fishermen situated a few metres north-east of the quarry.

Ancient exploitation cannot be asserted solely on the basis of the quarrying technique, because the latter did not undergo any great changes until the second half of the 19th century. However, other evidence found in quarry 3 may date its exploitation to antiquity. Indeed, well-developed marks of corrosion have been identified on the quarry floor (Fig. 12), along with shards of African Sigillata (A) and Roman amphorae (Oueslati 1993; Slim *et al.* 2004). Moreover, a few tens of metres north of this quarry, a Roman construction has been found that was transformed into a small Ribat (qasr ibn al Jaad) in the ninth century. The walls of this construction were partly built with sandy limestone blocks extracted from the island quarries (Slim *et al.* 2004).

CONCLUSIONS

The geological, petrographic and geotechnical study carried out on blocks extracted from the four quarries situated on Sidi Ghedamsy Island reveals two different lithofacies. The first one is composed of thin sandy limestone with a pack-wackestone texture, much appreciated by the builders for its homogeneous texture and its yellowish colour. The second one, constituted of coarse limy sandstone with a grainstone texture without carbonated mud, presents many micro-cavities, which promote micro-fissures that make it less resistant to alteration.

Traces of cut and pre-cut blocks reveal that the quarry workers were extracting blocks by progressing from the seaward side to the inside of the island, leaving sometimes a 'wall' to protect the quarry from sea water, as in other quarries situated between *Sullecthum* and El Alia. Moreover, due to the block marks, the quarrying technique and the sizes of the extracted blocks can be studied. Indeed, the quarry workers began to outline the blocks to be extracted using a pick or '*escoude*' in order to obtain extraction slits whose depth varies according to the block height. Then, metallic wedges were introduced into the holes made on the non-detached block side, and the quarry workers hammered the wedges in order to extract the block. This technique has been

Figure 12 *A view of corrosion marks left on the floor of quarry 3.*

identified in ancient quarries situated in eastern *Byzacium.* Most of the extracted blocks are small and medium-sized. In order to measure the blocks, the quarry workers did not use the Roman or Punic cubit, but rather the Arabic *dhrâa* (cubit) and *chebr*.

A comparative study made between the extracted blocks from the best two preserved quarries (3 and 4) and a number of blocks employed in the construction of the Ribat reveals that their sizes are similar. The quarry workers may have extracted blocks according to orders made by builders. The exploitation of the quarries dates from the Ribat construction period (from AD 796 to the 19th century). However, other evidence linked to marks of corrosion and to archaeological artefacts—identified both in quarry 3 and in a Roman building on the island, that was transformed in the Middle Ages into a small Ribat—prove that one quarry, at least, dates from the Roman period.

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