African Journal of Geography and Regional Planning ISSN 3627-8945 Vol. 7 (8), pp. 001-007, August, 2020. Available online at www.internationalscholarsjournals.org © International Scholars Journal

Full Length Research Paper

Petrographic identification and physical behavior of building materials in the archeological site of "Banasa" (Morocco)

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Accepted 02 July, 2020

The archaeological site of "Banasa" is a historical heritage which is an asset of cultural tourism in the region of Gharb (Morocco). A petrographic characterization was carried out for the building materials of the site, and for the lithofacies which resemble to those of "Banasa" and come from geological formations close to the site. Comparison of the results allowed us to identify the different lithofacies of the site, found in majority to be sedimentary rocks, originated from well known geological formations of which we have determined the locations in this study. The three most abundant lithofacies are i) calcarénites from Bouknadel, ii) Biocalcarenites from Lalla Zahra, and iii) quaternary sandstone from the Gharb. A study of the physical behavior (density, porosity, water absorption, permeability and resistance to salt crystallization) of these three most abundant lithofacies was performed. The results showed that the calcarénites and the Biocalcarenites hold more porosity (respectively 16.76% and 14.87%) than the sandstones (8.82%). According to the salt crystallization tests, the sandstone samples have lost more than 10% of their weight, which means, that these sandstones have a low resistance to the salt crystallization than that of the two others lithofacies. This is likely a direct result of the pore size, which is smaller in the case of sandstones. The valuable results obtained in this study will serve as a database for a future restoration of the site, and to ensure a better preservation of this heritage.

Keywords: Petrographic study, Physical behavior, Building materials, Geographic origin, Archeological site of "Banasa".

INTRODUCTION

The cultural heritage in Morocco is of great benefit for the cultural tourism in the country. However the majority of monuments are poorly preserved. Their restoration represents a scientific and economic task, it must be preceded by a detailed study of their building materials. Unfortunately, the majority of the studies on the archeological sites and the historical monuments have been focused on the historical and architectural aspects. Less attention has been given to the characterization of building materials, and very few sites have been studied for example "Bab Agnaou" in Marrakech (Lazzarini et *al.,* 2007) and the archeological site of "Volubilis" (Antonelli et *al*., 2009; Dekayir et *al*., 2004).

The Roman site of "Banasa" (Figure 1) is located in the center of Gharb basin (Figure 2), on the left river bank of Sebou. Its building materials have never been studied or identified, and the site is in a highly advanced state of degradation, and it requires a rapid and efficient intervention to preserve it for future generations.

Two objectives are fixed for this study:

• Petrographic identification of the lithofacies used in

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Figure 1. The archeological site of "Banasa", the thermal buildings.

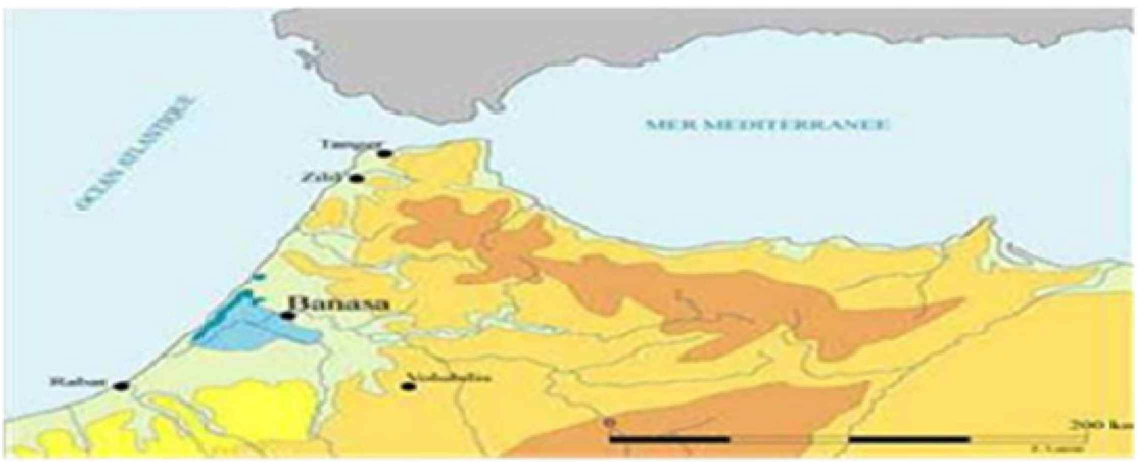


Figure 2. Location of the archaeological site of "Banasa" in the map

the construction of the ruins, in order to determine the geological formations of origin.

- Characterization of the physical behavior of the lithofacies most used in the construction.

METHODOLOGY

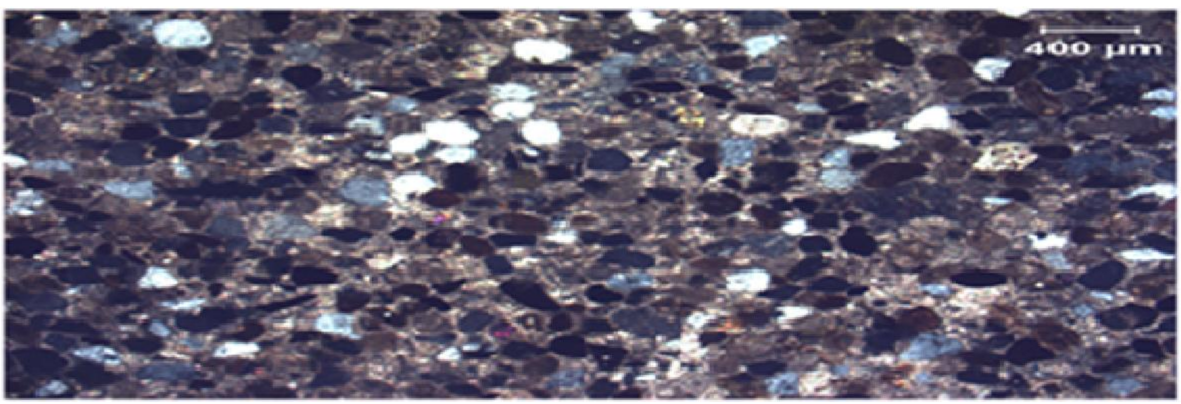
A sampling was first carried out in all the ruins of the site (on the Forum, the houses and the thermal buildings), and another one of the lithofacies similar to those of "Banasa", in the geological formations, that are close to the studied site. The different samples were analyzed by optical microscopy (Assioscop Microscope Zeiss) and the scanning electron microscope (SEM Hitachi S-3000 N) with a detector of X-ray Bruker model Flash 3001 for micro-analysis (EDS spectral imaging).

The real density of the samples was determined by helium pycnometer technique (AccuPyc 1330 Pycnometer), and the apparent density was calculated according to the rule UNE-EN 1936. For the characterization of the porous medium, we used a mercury porosimeter Autopore 9510 Micromeritics; it is the technique the most universally used to access to the pore diameter distribution of a porous medium. There is an abundant literature on this technique (Dullien, 1979; Klute, 1986; Metz and Knöfel, 1992).

The absorption of water at atmospheric pressure was calculated according to the rule UNE-EN 13755. The water absorption by capillarity is a very effective method for evaluating the penetration of water into the mass of the stone and the measurement of capillary absorption (Peruzzi and al., 2003). The coefficient of water absorption by capillarity was determined by using the rule UNE-EN 1925. The Resistance to salt crystallization was determined based on the rule UNE-EN 12370 which is widely applied (Goudie and Viles, 1997). The samples were subjected to repetitive cycles (15 cycles) of 24

Table 1. Comparison between the samples of “Banasa” and those of the geological formations close to the site.

	Calcarénites			Biocalcarenites			Sandstone	
Sample	E1	C1	C2	E2	C3	C4	E3	C5
Origin	Forum of “Banasa”	Sidi Bou-knadel	quarries Tlat Ben Slilman	Forum of “Banasa”	Formation of Lalla Zahra	quarries Hssinate (Moulay Bouslha)	thermal buildings of “Banasa”	Quaternary of Gharb
Color	Beige-gray	Beige-gray	light beige	Beige-yellow	Beige-yellow	Gray-yellow	Light brown-pink	Light brown-pink
particle size	medium	medium	medium-fine	medium-fine	medium-fine	medium	medium-fine	medium-fine
cement	calcareous cement	calcareous cement	calcareous cement	calcareous cement	calcareous cement	calcareous cement	calcareous cement + ferruginous matrix	calcareous cement + ferruginous matrix
Description	Rich in quartz, and fragment of rocks, high porosity	Rich in quartz, and fragment of rocks, high porosity	Very rich in fossil, pores clogged with amorphous quartz	Very rich in fossil large size	Very rich in fossil large size	Large pores, rich in fossil and amorphous quartz	Rich in quartz and fragment of rock	Rich in quartz and fragment of rock



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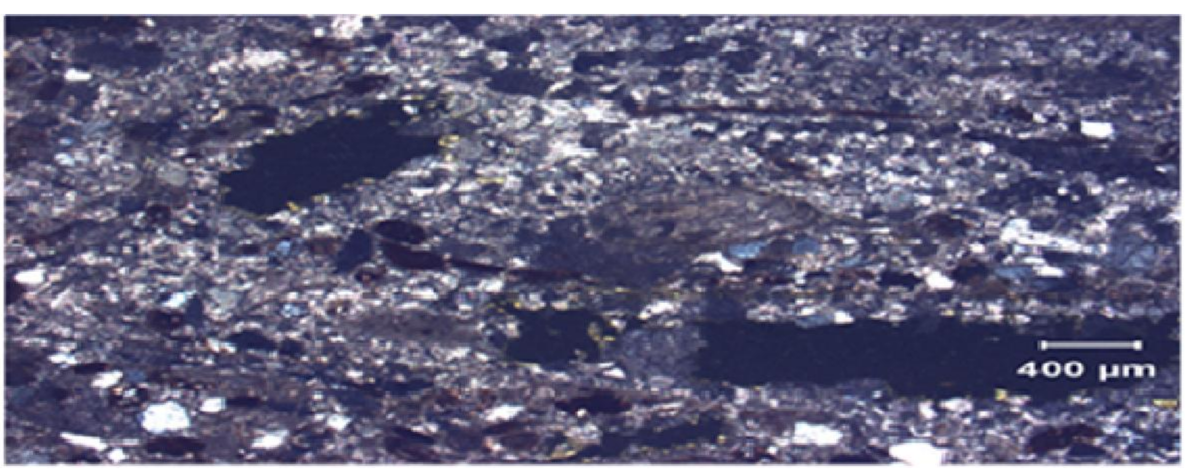

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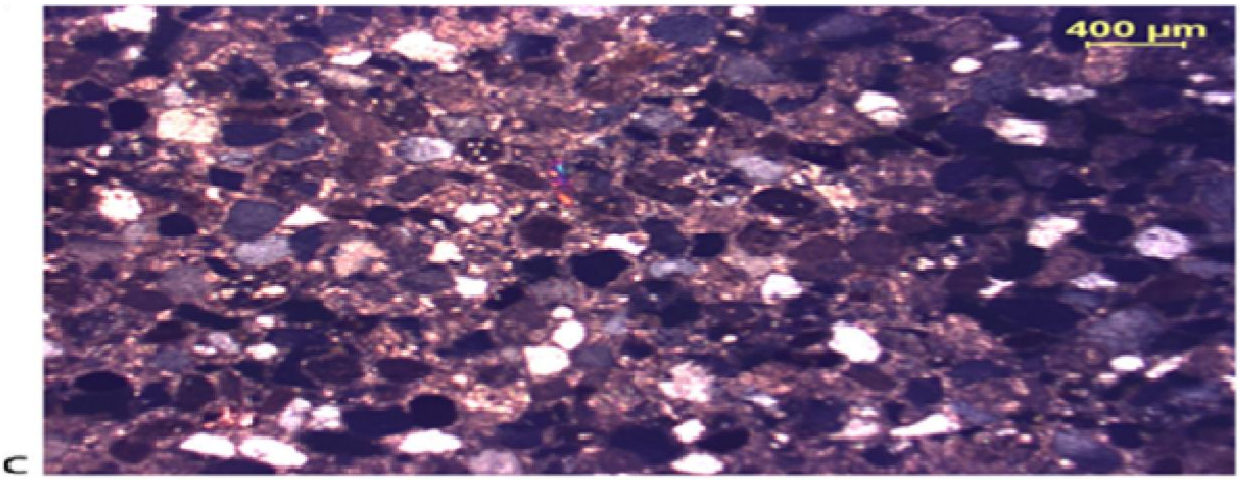

Figure 3. Photomicrographs of the samples from "Banasa" (observation in polarized-analyzed light). a) lithofacies E1, b) lithofacies E2, c) lithofacies E3.

hours (2 hours of salt intake, 16 hours drying at 105 ± 5°C, and 6 hours of drying at 20-25°C). After each cycle, the samples were weighed by a balance precision (± 0.01 g).

RESULTS AND DISCUSSION

Petrographic identification

The results of the petrographic characterization of building materials of "Banasa" and the samples coming from geological formations which might be sources of extraction of these materials are presented in table 1. Their comparison has allowed locating the original geological formation:

• Calcarénites (E1) beige-gray, rich in grains of quartz and fragments of rocks and shells (Figure 3a) were compared with samples from the quarries of Bouknadel (C1) Plio-Quaternary age, and with samples from Ben Slimane (C2) Pliocene age. According to the petrographic analysis, the sample (E1) was found very similar to the lithofacies of Bouknadel (Atlantic coast).

• Biocalcarenites (E2) beige-yellow, very rich in fossils and rocks fragments (Figure 3b), were compared with samples of Lalla Zahra (C3) Neogene age, and samples of the quarries of Hssinate (C4) (Moulay Bouslham). The results showed that (E2) are identical to those of Lalla Zahra (C3).

• Sandstones (E3) rich in fragment of rocks (Figure 3c), were found to be similar to the samples of the quaternary sandstone (C5) that outcrop at the top of the Gharb Pliocene.

These three lithofacies (E1, E2 and E3) are the most used in the construction; they are sedimentary rocks easy to operate and cut, and which are found to be extracted from geological formations very close to the studied site.

The two first lithofacies (E1 and E2) have been widely used in the construction, for instance in the Forum and houses, while the sandstones (E3) have been used in the construction of thermal buildings (Figure. 1).

Other lithofacies used as ornamental rocks, have been found in the ruins of "Banasa":

• Oolitic limestone similar to the Jurassic limestone originated from Jbel Zerhoun, and reported to be used in the construction of Volubilis (Feray and Paskoff, 1966; Jodin, 1987).

• White marble found to be similar to the Greek marble type as a microscopic analysis showed (Antonelli et al., 2009), used as ornamental rock. The samples studied contain dolomites, micas, with a predominance of calcite and traces of sulfides of iron oxides.

• Pink marble similar to the Portuguese marble type (Lapuente and Turi, 1995; Antonelli et al., 2009).

• Basalts of Middle Atlas, used in the mosaics (Dekayir et al. 2004).

The typology of marbles of "Banasa" was established based on a visual comparison with the marbles of the site of Volubilis (Antonelli et al., 2009). This observation is very preliminary, and must be followed by a more detailed study; the comparison of the respective isotopic compositions of the different marbles will allowed us to determine its origin with a high accuracy.

The mortars used in the construction, are calcitic lime mortars with aggregates of different sizes (mainly quartz, rock fragments and pottery) and occasionally the organic components. The fragments of pottery are those which present a wide variation of sizes in the mortars:

• The hard mortar of the thermal buildings with frescoes contains sand and lime in addition to other large aggregates like rocks fragments, fragments of pottery, and brick.

• Mortar of the large public thermal buildings, with a very brittle texture and contain the cement which is rich in

Table 2. Physical behavior, and the resistance of the samples of “Banasa” against the salt crystallization

Samples	E1	E2	E3
Actual density Kg/m3	2786	2721	2681
Apparent Density Kg/m3	2335	2173	2115
Hg Porosity (%)	16.76	14.87	8.82
Average pores diameter (µm)	1.645	5.742	0.163
Water Absorption (%)	6.6	7.1	4.95
Permeability C ($g/m^2s^{0,5}$)	58.4	35.0	17.0
Loss of mass due to the salt crystallization (%)	0.7	1.8	10.1

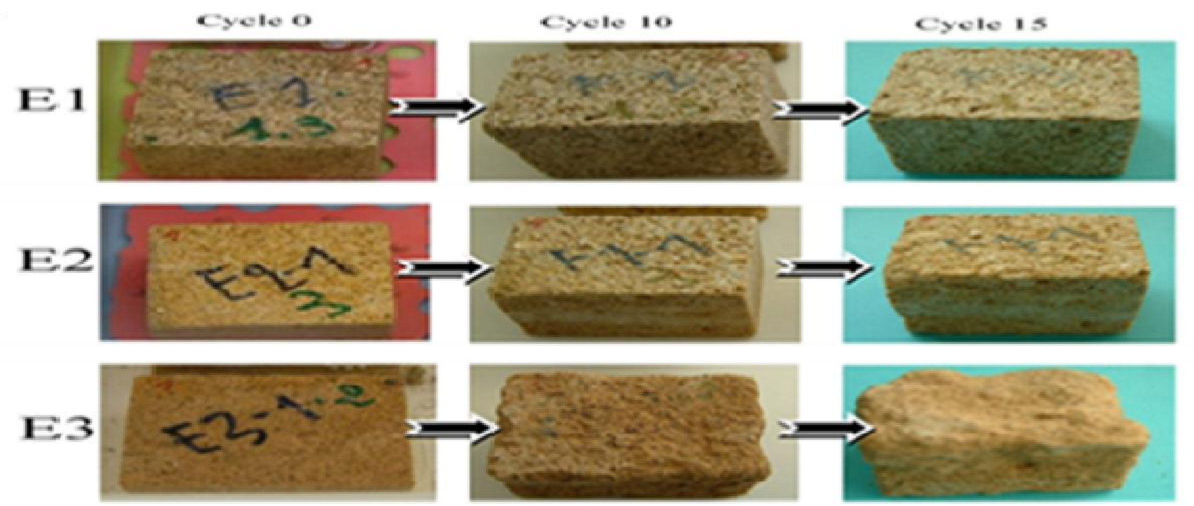

Figure 4. deterioration of the samples of “Banasa” by salts crystallization

sand and lime, in addition to very small aggregates like rocks fragments, bioclastes, bricks, and pottery.

• Mortar of the swimming pool in the thermal buildings with frescoes, is rich in organic matter, and covered by a thin white layer. This layer was found to be calcitic lime as showed by EDS analysis.

Physical behavior

The results of the characterization of the physical behavior of the three lithofacies studied are summarized in Table 2.

According to the analysis performed, the results (Tab. 2) showed that the lithofacies E1 and E2 are more resistant to the crystallization of salts compared to the lithofacies E3. Indeed, the samples of this lithofacies (Figure. 4) lost more than 10% of their weight after 15 cycles in a sodium sulfate solution (Na_2SO_4, $10H_2O$). That can be explained by the low porosity (8.82%) and permeability (17 $g/m^2s^{0,5}$), and the pores size which are found to be smaller (0.16µm) for this lithofacies compared to those found for the two others.

The size of the pores plays a major role in the phenomenon of deterioration by salts. This conclusion is in agreement with previous studies (Benavente et al. 2004; Lazzarini et al. 2007). This result explains the advanced state of degradation in which the lithofacies in the site is found. Indeed, specific morphologies of alteration by salt crystallization were observed in the thermal buildings that are mainly built by the lithofacies E3.

In the site, lichens colonize almost all building materials, and especially the lithofaciesE1 (Figure.5) and E2. These lichens can play a major role in the biodegradation. EDX analyzes have been performed on some mortars, and the result shows that they hold diatom frustules (Figure. 6) and that are most probably related to the flooding processes to which the region of lowland Gharb is frequently exposed.

CONCLUSION

A petrographic study was carried out for the building materials of the site of “Banasa” and for samples which

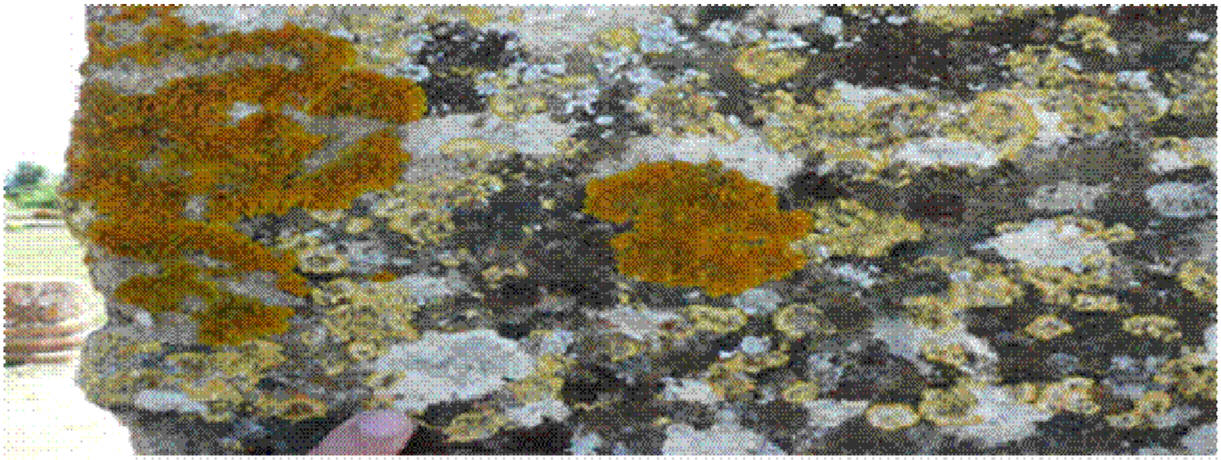

Figure 5. Lichens colonize the surface of the calcarénites

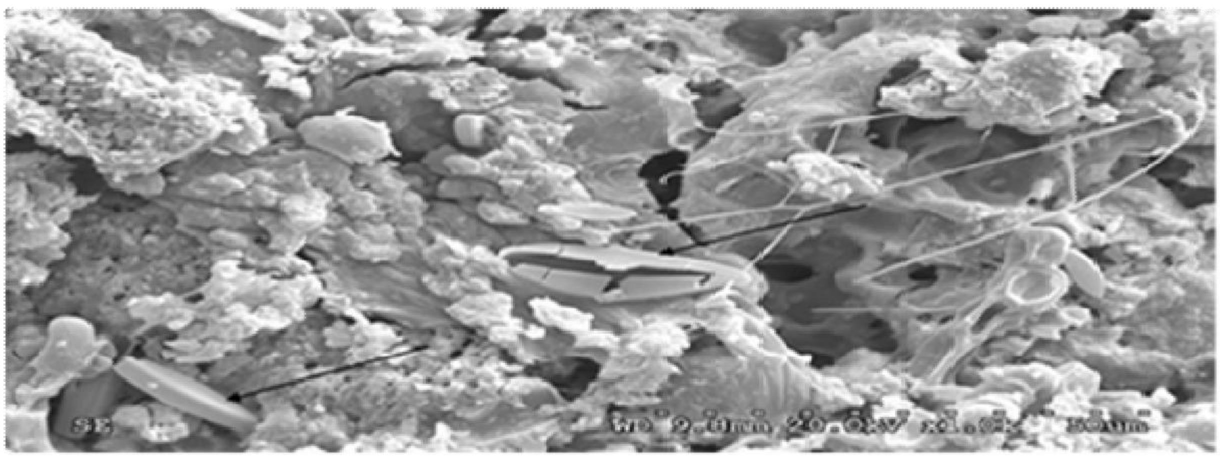

Figure 6. SEM photomicrograph of the inner surface of a mortar in the thermal buildings rich in diatom frustules.

resemble to those of the site and that come from geological formations close to the site, has allowed the identification of lithofacies used in the construction of this site, after having compared them to each others.

The results show that the three most abundant lithofacies in the site are sedimentary rocks of local origin: calcarénites of Bouknadel, Biocalcarenites of Lalla Zahra and Quaternary sandstone from the Gharb. The geological origin of ornamental rocks was given based on a comparison with the literature.

The physical behavior has been carried out where the density, porosity, absorption, capillarity and resistance to the salts crystallization for the three lithofacies the most abundant have been determined. The results showed that the pore size plays a major role in the degradation by salts crystallization. Indeed, the lithofacies E3 which was found to have the smallest pore size has undergone a loss of 10% of its weight during the salt crystallization test. On the other hand, the lithofacies E1 and E2 have showed a better performance against deterioration by salts. However they are subject to a biodegradation by lichens covering their surface. This can be seen visually in the site. Eventhough we still recommend strongly using the lithofacies E1 and E2 in the restoration of the site because of their resistance to salts alteration and their availability in quarries near to the site (Bouknadel 20 km from "Banasa" for the calcarénites E1, and Lalla Zahra 30 km from "Banasa" for the Biocalcarenites E2).

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