THE SALT CRYSTALLIZATION WEATHERING OF BUILDING ROCKS OF THE ARCHAEOLOGICAL SITES CALCARENITES OF NORTH-WESTERN MOROCCO (LIXUS, BANASA AND THAMUSIDA)

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Abstract

The archeological cities of north-western Morocco: Lixus, Banasa and Thamusida represent an international heritage, with a great social and cultural importance for the history of the country. This work is dedicated to study the salt crystallization weathering, reaching the building rocks of the monuments in order to preserve and restore them. These monuments show a variety of lithological facies implemented in its construction.

The degradation of these materials is accelerated by climate influence of El Gharb and Prerif area, characterized by a high humidity and an important atmospheric and soil salinity. The most affected building rocks by the weathering are generally represented by limestones (calcarenites).

When salt crystallizes in the pores of the rock after evaporation, the crystal dissociates the grains surrounding by expansion. Therefore, there is a loss of material. The accelerated aging test laboratory shows that calcarenites present the highest rate of weight loss among the samples of different lithologies. This is rendered in a significant susceptibility to degradation; a physical degradation by salt crystals expansion and a chemical degradation by a carbonates dissolution in the presence of the saline fog and a high temperature (50 °C).

Lixus calcarenites are more resistant to weathering by salt, when compared to the calcarenites of the other two monuments.

Keywords: Building rocks, Salt crystallization, Weathering, Monuments

Introduction

This study concerns the building calcarenites alteration by salt crystallization of Lixus, Banasa and Thamusida which are archaeological sites, with a social and cultural importance for the country. In the light of previous works on alteration of historical monuments building materials, this study comes to elucidate these mechanisms of degradation and to explain their behavior towards the salt incorporation and especially this deterioration, therefore to restore the monuments in adequate and sustainable ways.

Presentation of the archaeological sites

Archaeological excavations have highlighted several historical sites in the north-western Morocco. Those who are subject of this study, are located along rivers, it is indeed three fluvial ports. This geographical situation is characterized by climatic conditions with an Atlantic influence, high humidity and presence of salt spray.

Geologically, this built heritage belongs to the western Prerif, dating to a marly clay mesozoic upon which a cenozoic marly sandstone cover sits and the lowland of El gharb formed by quaternary clayey alluvium.

Lixus is 4 km from Larache, it extends over 62 hectares, of which only 10% outcrops. This is one of the most important archaeological sites of the Mediterranean. It has a large industrial plant for the production of brine (Fig.1). Lixus experienced several successive civilizations: Phoenician, Punic, Mauritanian, Roman and Islamic (Brignon. 1996).

Figure 1 - Photograph of the industrial complex of brine production at Lixus (OUACHA, 2012)

Banasa is 17 km from Bel Ksiri Mechraa, it extends over 8 hectares, however only a part of it outcrops (Fig.2), it dates from prehistoric times and includes valuable information from the Roman and the Mauritanian period(El Amrani, 2008, El Amrani *et al.*, 2012).

Figure 2 - Photograph of Banasa remnants covered by lichens (OUACHA, 2012)

Thamusida is 10 km from Kenitra, it is a fortified camp dating to the Mauritanian period, and was rebuilt by the Romans (Fig.3)

Figure 3 - Photograph of Thamusida remnants (OUACHA, 2012)

The study of salt crystallization weathering of building rocks

Building stones are exposed to various types of mechanical and chemical weathering, such as dissolution, gullying, blackening, arenitisation the alveolisation, biodegradation, inadequate restorations and salt crystallization weathering which is the subject of this work.

The salt effect on rock materials

In general, the salt alteration is first occurred by the salt incorporation in the rock, a process that can take place in two ways, and whose scale varies according to the material properties. Indeed, when it comes to porous rocks, salt spray is adsorbed on the surface of the material before it enters the cracks of the rock. As low porous rocks, like granites, salt occurs primarily by a saline solution infiltration into the rock by a capillary process. (Theoulakis and Moropoula, 1999).

Determination of physical and chemical characteristics

In Morocco, the salt crystallization study of rocks, is still new. The experiments are based generally on European standards: (EN 12440 European standard (2001); European standard EN 12670 (2002); European standard EN 13755 (2005); EN 14147 European standard (2003)),

In the field the lithologies of the building rocks were identified and their state of conservation was observed. Fresh and altered calcarenite samples were also collected.

Then, in order to compare the results of the salt crystallization test on calcarenites with other lithologies, it was planned to prepare different samples such as: Crystalline limestone from Akrach (CCA), Porous sandstone from Salé (Gr) porphyritic granite (Gp), travertine (Tr), gabbro (G) and pink granite (G. Ro). At the laboratory of Earth Sciences Department, at the Faculty of Science and Technology of UNL, the samples were cuted to parallelepipeds of 20 cm^3. Some adjustments to the standard were required during the experiment.

The samples were studied based on specific methods of physical and chemical characterization to assess the porosity and the absorption capacity of water before and after the accelerated aging test by crystallization of the salt. Therefore, this calculation will determine the rocks alterability. Introduced into the salt fog machine, the samples are submitted to a temperature of 50 ° C. Two cycles of 8 days comprising 8 hours of salt fog and 16 hours of drying, were performed. During the experiment, the deterioration of samples was monitorized using a binocular stereoscopic microscope. At the end, the samples were washed with deionized water for 96 hours.

Results and data processing

Interpretation of the weight change

During the two cycles in the salt fog machine, the weight of samples increases, resulting from the incorporation of salt in the pores of the rocks. After washing the samples a weight loss was registered.

In order to represent this relatively weight changing, the histogram (Fig. 4) illustrates the average weight variation of the different samples compared to the initial weight, during the stages of the experiment.

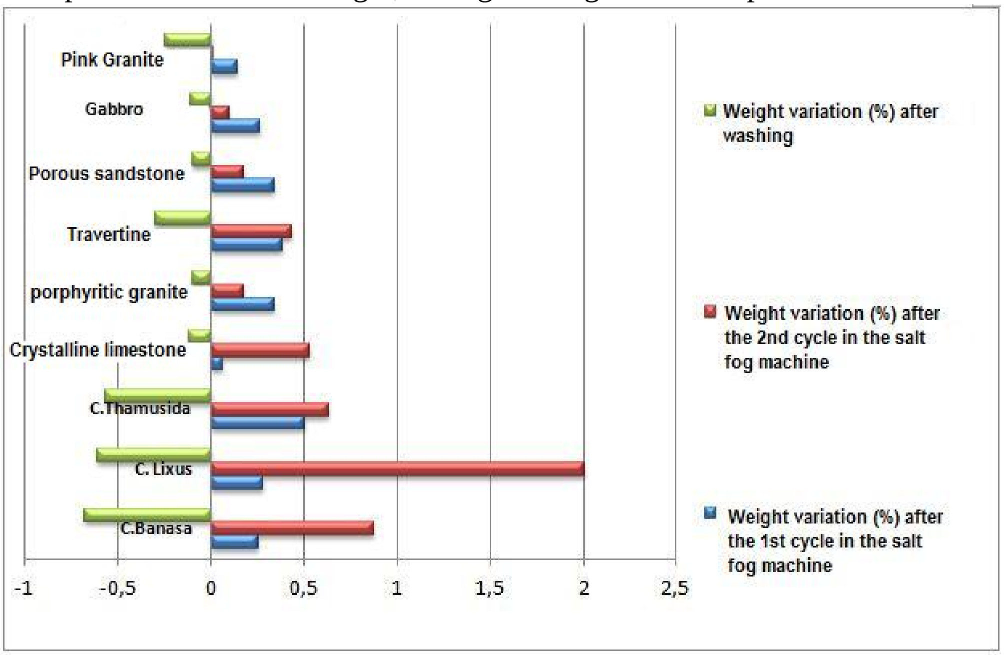

Figure 4- Histogram showing the change in weight of the samples at each stage of the experiment (OUACHA, 2012)

The calcarenites samples, show an increase in weight after the first cycle of exposure to salt fog and also after the second cycle. This means that these rocks compared to other lithologies have sufficient porosity to incorporate more salt. As for the weight loss after washing, it is explained by the growth of salt crystals in the pores, destroying the links between neighboring grains. These effect leads to a disruption of particles (Fig.5) and removal of material by leaching and, therefore, a decrease in weight of the samples.

These samples have values of loss that are proportional to the degree of particles cohesion of each lithology. It means, more grain consolidation, the less it occurs material loss. This explains that the material loss of gabbro and granite is insignificant, compared to sandstone samples that are more friable.

In summary, the processes responsible for the rate of gain or weight change are closely conditioned by lithology and physical and chemical properties of the rock.

A chemical phenomenon is also at the origin of this variation. Indeed, the samples in this study contain carbonate material, may be dissolved in the presence of a salt solution, at a temperature of 50 ° C. Carbonate dissolution followed by leaching could also explain the weight loss. In this case, the external volume of the samples decreased as well.

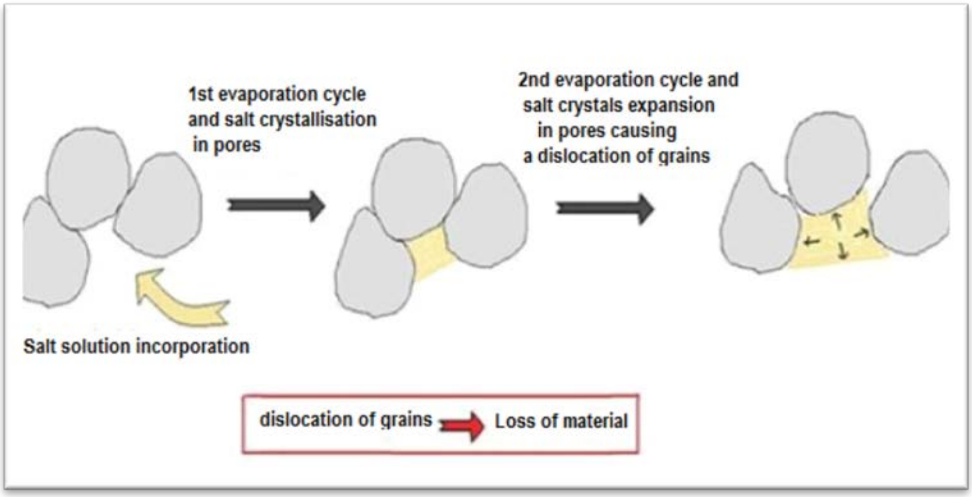

Figure 5- Schematic illustration of the mechanical action of the salt crystals in the rock (OUACHA, 2012)

Interpretation of the porosity variation

The difference between saturated weight and dry weight corresponds to the pore volume in cm^3, therefore the water absorption rate for each sample is giving a large idea about the
porosity of the sample.

During the exposure of rocks to the salt spray, the salt solution is introduced into the pores of the samples, which reduced the volume of the latter. However, after washing, the data shows that the porosity decreases for the majority of samples due to the occupation of the pores by salt, which was not totally removed.

Monitoring the progress of degradation under salt effect

The salt crystals precipitate on the surface of Lixus calcarenites as a thin film. These samples show some impurities in places, and its evolution during the experiment was followed. (Fig.6).

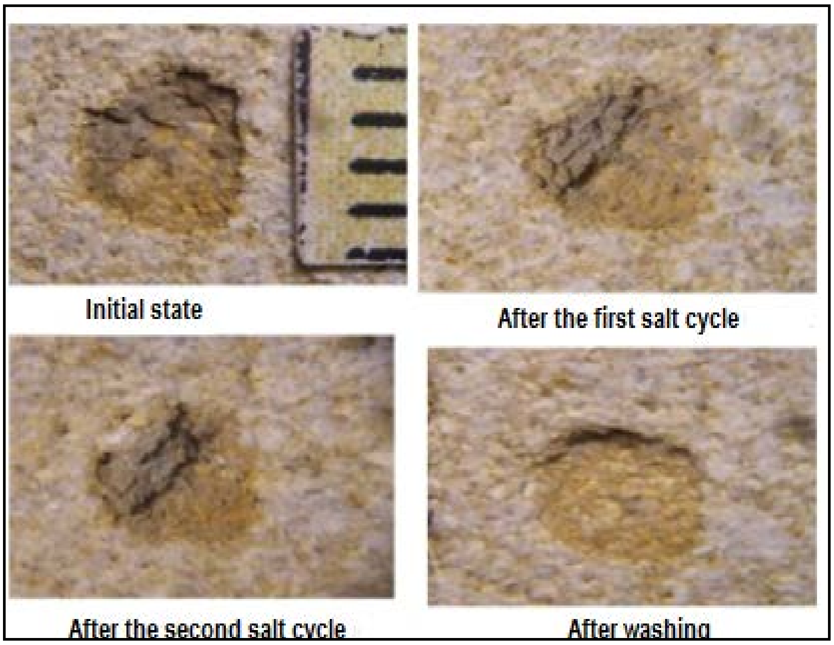

Figure 6- Picture showing the evolution of an impuritiy on the calcarenites surface of Lixus during the experience (OUACHA, 2012)

The salt was deposited as agglomerations of small crystals on the surface of Banasa's samples, those contain some bivalves shells fragments. Throughout the experiment, it had been noticed that salt solution infiltration is more important around the fossil.

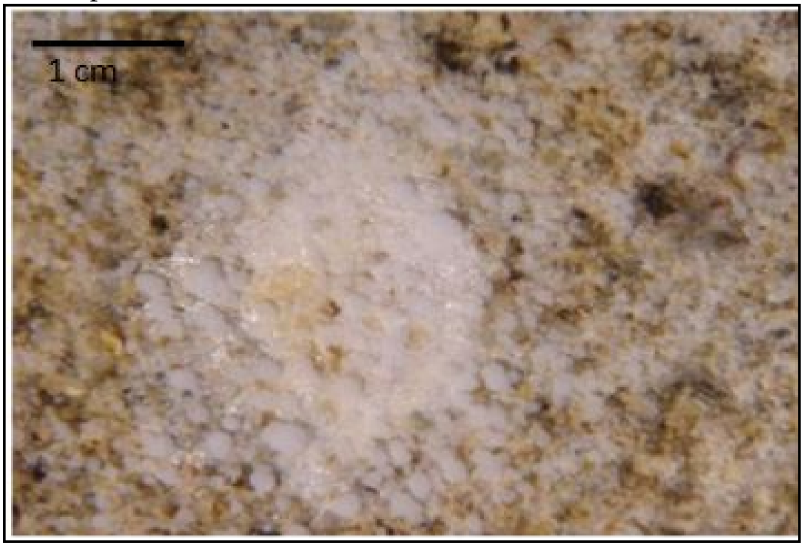

Figure 7- Photograph of agglomerations of small salt crystals on the surface of Banasa's samples (OUACHA, 2012)

Thamusida samples contain also shells fragments. The pictures below (fig. 8), show that there has been a color change, and a closure of some open pores at the surface, due to the salt incorporation.

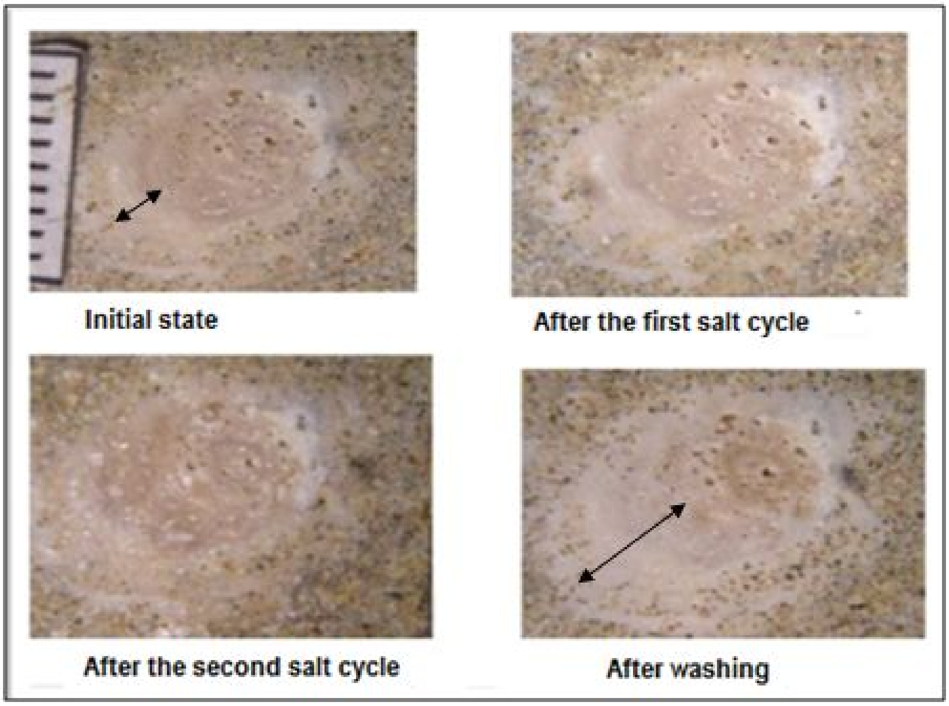

Figure 8- Picture showing the evolution of salt crystallization on the surface of Thamusida's samples (OUACHA, 2012)

Conclusion

This study concerns salt crystallization weathering of building Calcarenites of Lixus, Banasa and Thamusida, which are archaeological sites, with a big social and cultural importance. In hence, the necessity of an efficient restoration, which requires several studies about the building material.

According to the results of this experiment; calcarenites present the highest rate of weight loss among all the witnessing samples from different lithologies,

That reflects a big susceptibility to degradation; a mechanical degradation by the expansion of salt crystals in the pores and the separation of grains, and a chemical degradation by the dissolution of carbonates, in the presence of the salt solution and moderately elevated temperature.

This study also showed that the Lixus calcarenites are more resistant toward salt alteration, compared to the other two calcarenites of the studied monuments.

For the restoration of building calcarenites, it is recommended to use a more consolidated material, such as sandstones of the Middle Eocene and Oligocene, given their proximity and abundance.

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