

# *Deterioration patterns of building limestone in the Septimius Severus family Temple in the Roman ruins of Djemila (Algeria)*

[NaïmaTouloum, Ahmed Brara]

**Abstract**— The Roman ruins of Djemila (Cuicul) provide a typical example for limestone weathering in semi-arid and continental climate. Investigations on the Septimius Severus family temple located in this antic city are conducted, with the aim to determine the mechanisms of the major decay patterns of building limestone. The role of both intrinsic factors (limestone petrography, and porosity) and environmental factors (moisture variation, thermal gradient) are studied. The investigations demonstrate that the weathering process is mainly triggered by rain-dry cycles combined with thermal gradient.

**Keywords**—Djemila, limestone, decay, conservation, semi-arid climat

## I. Introduction

Conservation of archaeological sites around the Mediterranean basin constitutes a major challenge for the future. In order to achieve this goal, it is important to study the health of the archaeological sites. Several researches have demonstrated the importance of the conjunction of the intrinsic characteristics of the material and extrinsic factors for the weathering process [1, 2]. Since these multiple influences and the long-term behavior of building stones cannot be simulated in laboratory to full extent, in-situ observations and investigations of weathered building stone have to be carried out on historical monuments. This approach constitutes the best way to enhance the knowledge about weathering process of natural stone.

The weathering behavior of building stone used in the archaeological sites has been largely investigated in word within the last decades. Unfortunately, around the Mediterranean basin, only few studies have been conducted, [3].

Algeria possesses an important archaeological heritage dating from different periods, with various historical sites widespread through the whole territory (amongst others the numidian royal tomb Imedrassen, the antic cities Djemila and Tipaza,..), [4].

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Djemila (Cucul), one of the most beautiful roman architecture in North Africa, is remarkably adapted to the constraints of the mountainous site. Included by UNESCO in the World Heritage List since 1982, Djemila represents the most celebrated archaeological site in Algeria after the Numidian royal tomb Imedrassen and one of the best-preserved and most significant archaeological context of North Africa.

A large variety of building stones are used in the construction of this antic city such as limestone, shale, sandstone, marble, travertine ...etc. Locally extracted limestone is largely used in this construction. Generally, the masonry of the antic city was laid dry (i.e. without any jointing mortar). Despite some visible alterations, the fragile archaeological structures of Roman ruins of Djemila, remain well conserved.

The objective of this research is to identify the main decay patterns of the limestone used to build the Septimius Severus family Temple and to determine the causes of its deterioration.

## II. The antic city of Djemila

### A. Historic presentation of the roman ruins

The site of Djemila is located in the High Plateaus (1080 m height above sea level) in north-eastern part of Algeria, Figure 1.



**Figure 1. Localization of Djemila in Algeria**

The Roman ruins of Djemila is located in a rural area that has a semi-arid continental climate. The veterans of Nerva built the antic city of Cucul (Djemila) of Algeria, at the end of 1<sup>st</sup> century (96 or 97 B. C.) [4]. The Roman town occupies a singular defensive position and exposes a current area of 42 hectares, Figure 2. Christianity in the form of

several cult buildings has also marked the site: a cathedral, a church and its baptistry are considered among the biggest of the Paleochristian period. The site of Djemila comprises an impressive collection of mosaic pavings, illustrating mythological tales and scenes of daily life.



**Figure 2. Part of Roman ruins of Djemila**

### **B. *Environment conditions of the studied area***

The conditions refer here to the geological setting and the climatic conditions in the region of Djemila. As these conditions interact directly and/or indirectly with monuments of the Djemila site including the Septimius Severus family Temple, they conditioned not only the extraction and use of stone but also its degradation and durability.

Djemila is situated in the inland region, which is characterized, by a continental Mediterranean cold semi-arid or steppe climate or temperate zones, [5]. The climate of the Djemila antic city is characterized by hot and dry summers (often exceptionally hot) and cold winters. This climate has an average or means annual temperature above 18 °C, and a mean temperature of - 3 °C in the coldest month. Rainfall is important between October and April but rather rare from May to October. Mean monthly relative humidity is about 50 % in dry season and rises to 80 and 90 % in rainy season. Mean monthly temperatures are above 20 °C the whole year long and rise up to 30 °C in the hot season.

This inland region of Djemila, located in the alpine of northern Algeria is made up of young mountains formed during Tertiary times by the Alpine orogeny. Alpine Algeria consists of a number of structural-sedimentary units, directed from north to south. The High Plateaus are the foreland of the Alpine range bearing a thin sedimentary cover (Liassic target).

### **C. *Case study : Septimius Severus family Temple***

Around the beginning of the 3<sup>rd</sup> century, the city of Cuicul expanded beyond its ramparts with the creation of the Septimius Severus Temple, Figure 3.



**Figure 3. Septimius Severus family Temple**

The most material used in the construction of the Septimius Severus family Temple is a hard gray veined limestone with calcite. This stone is characterized by a large vein (streak) of calcite, extracted locally, and commonly called micritic limestone, Figure 4.



**Figure 4. The hard gray veined limestone with calcite extracted locally**

The macroscopic and microscopic observations of this stone showed an heterogeneous structure and the presence of veins of calcite. According to the mineralogical analysis with XRD, this gray limestone is principally composed of calcite with some quartz. This stone characterized by a very negligible total porosity (<1%) and very fine pores size. In relation to the climate nature of the region, the linear expansion coefficient of the stone used was determined in the laboratory using the high temperature dilatometer. The obtained thermal expansion coefficients  $\alpha$  for the vein, matrix and matrix + vein parts of the rock are respectively  $\alpha_v = 3.9 \cdot 10^{-6} \text{ K}^{-1}$ ,  $\alpha_{m+v} = 2.4 \cdot 10^{-6} \text{ K}^{-1}$ ,  $\alpha_m = 2.2 \cdot 10^{-6} \text{ K}^{-1}$ .

Currently, this stone shows in-situ many deterioration features due the action of temperature related to the semi-arid climate.

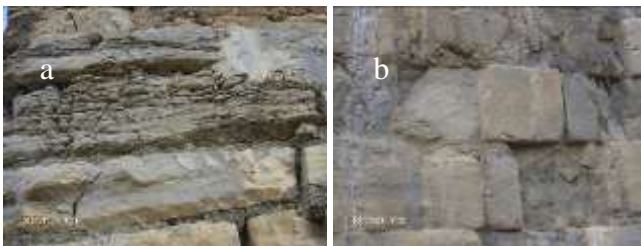
### **III. Distribution of weathered areas - In situ degradation**

An in-situ survey of the Septimius Severus family Temple revealed many deterioration patterns of building limestone. These patterns are identified accordingly to the illustrated glossary published by ICOMOS [6].

The visual inspection revealed that different dimensions of masonry elements were used as construction units. The stone masonry elements suffer from a concentration of damages in the top of the walls and columns of the temple, as shown on Figure 3 above. The concentration of damage results visibly from stagnant rainwater and snow of the cold seasons. From the top to the bottom, rainwater slowly penetrates downward by capillary suction or seeps by gravity into the masonry stones. At the same time, the water penetrates into the adjacent columns and walls by capillary rise. Between the single rain events and in subsequent dry season it evaporates again mainly over the vertical stone surfaces of the bases exposed to sun and wind. The degradations listed are essentially material loss, cracks, contour scaling and biological deposits.

The detachment and loss of stone material were observed mainly on the stone surfaces of the elements, subjected to temperature variation combined with dry and humid cycles. These deterioration patterns are the most observed on the temple compared to the other patterns, [7].

Daily and seasonal fluctuations of ambient temperature create climate cycles that can cause alteration of the stone. It is known that limestone is especially vulnerable to repeated moisture changes and temperature variation [8]. It is admitted that a change in temperature always corresponds to a volume change. When the temperature gradient repeated with a given frequency, it may decrease the intrinsic characteristics of stone materials by anisotropic thermal expansion. Principally the mineral of calcite that has a large anisotropy of thermal expansion composes the limestone studied. Moreover in the case of the studied limestone, this expansion is high the vein of calcite compared to the matrix of the stone. The result is a warm up repeatedly shattered the intergranular spaces grains of calcite. Furthermore, dilatation and contraction during wetting/drying in parts of the structural elements of the temple cause stresses in the limestone structure, resulting in material fatigue indicated by cracks and material loss in the end as shown on Figure (5) a and (b).



**Figure 5. Cracks and material loss**

Erosion and contour scaling (Figure 6, a and b) of the veined limestone are the second most common type of damage observed at the temple. These patterns are frequently occurring in parts of the temple elements intensively wetted from the surface during the rainy season. They are due in one hand to the dynamic change of water saturation of the veined limestone surface during and after rain events and the subsequent wetting and drying behavior. Here in the temple, the mechanism of contour scaling may also work without any salt loading (because the site is situated in rural area), only driven by moisture changes, [9].

On the other hand, the temperature on the surface is higher than deeper parts of the stone, which causes thermal

dilatation. This will cause shearing stresses in the transition zone from the surface and the deeper parts of the limestone. The absorption of radiant energy rises surface/subsurface temperature gradients and accentuates rates of surface temperature change ultimately contribute to stone breakdown through 'fatigue' effects. This absorption of energy reduces cohesive strength of intergranular bonds and initiates micro-fracture development, Figure 6 (b).



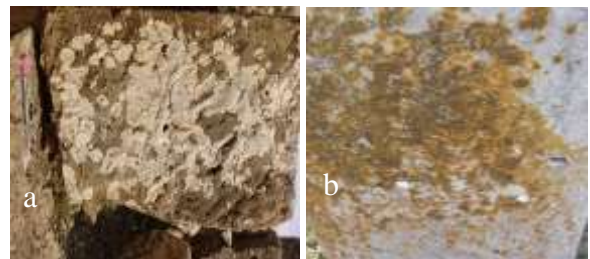
**Figure 6. Erosion and contour scaling**

In some part of the temple, masonry element were placed parallel to bedding planes of the rock (Figure 7 (a) and (b)) which causes cracks resulting from anisotropic behavior. It is evident that tensile load is higher perpendicularly to bedding planes whereas the strength of the material in the same direction is lower in tension.



**Figure 7. Material loss and cracks**

Moreover, as can be seen from Figure 8 (a) and (b), white and orange lichens cover a large part of the monument. Lichens discolor and adhere strongly to the surface of wall stones. Lichens covering occurs mainly in the northwestern sides sheltered from the sun. According to ICOMOS Glossary, [6] microbiological activity potentially results in biocorrosive and biooxidation activities due to the excretion of organic acids and the oxidation of iron-containing minerals. Additionally, biofilms might be of importance for thermal and moisture balance of the stone surface, thus indirectly affecting physical weathering processes.



**Figure 8. White and orange lichens**

Furthermore, orang patina also occurs on the majority of masonry element of the temple, Figure 9. There have been controversial discussions about the origin of these orange films, [6-11]. Various mechanisms are assumed to be at the

origin of their apparition, namely the biological activity, in this case may probably be the major source of oxalate crusts.



**Figure 9. Orange patina**

## IV. Conclusion

The study presented in this paper dealt with deterioration mechanisms of the gray limestone veined with calcite of the used in the construction of Septimius Severus family Temple in the archaeological site of Djemila (Cuicul), Algeria. In addition to lichen colonization, cracks and material loss, scaling and erosion are the main deterioration patterns affecting this stone. The latter four deterioration patterns are the most damaging since they induce detachment and loss of micritic limestone material while lichens discolor it. With regard to the climatic conditions, this study showed that the deterioration of the stone is related to thermal gradient, wetting/drying cycles weathering. In the light of this study, many actions could be carried out in order to preserve this historical patrimony.

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