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ALTERATION OF SIDI GHANEM MOSQUE LIMESTONE. INFLUENCE OF THE LITHOLOGICAL NATURE AND THE ENVIRONMENTAL CONDITIONS

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Abstract

Over time and under exposure to atmospheric agents, the monumental stone are exposed to physicochemical mechanisms which generating alterations. These alterations destroy the monuments' surfaces, and eventually may affect the supporting structure and its stability. In this article we studied: a) the influence of the sequence of humidification and drying on the alteration of the Sidi Ghanem Mosque limestone; b) a morphological, petrographic, mineralogical, chemical and petrophysical characterisation on the stone; c) temperature and humidity measurements inside the mosque for one year by means of thermo-hygro-bottons followed by d) an aging test through cycles of humidification and drying on the unaltered stone. The results presents: a) the stratigraphic composition and the condensation of water on the surface of the stone and b) the diffusion through the porous network of the stone, as well as its drying have led to the formation of ferric hydrates $Fe_2O_3{\cdot}H_2O$. This ferric hydrate is a complex form of iron oxide which represents rust of ocher color and that thickness of the altered part depends on the penetration depth of air and water.

Keywords*: Sidi Ghanem Mosque; Limestone; Alteration; Environment*

Introduction

The mosque of Sidi Ghanem is considered ~~as~~ the oldest mosque in Algeria, certain historical source attributes the building of the latter to the Muslim conqueror Abu Muhadjir Dinar in 674 A.D. on the rubble of a Roman church reusing the building materials from previous eras especially the stone [1-4].

Maslama appointed Abu al-Muhajir to the position of amir or general of the Umayyad forces in Ifriqiya. This position was already occupied by Uqba ibn Nafi, a member of the Banu Quraish. Maslama advised Abu al-Muhajir to relieve Uqba of his position with due deference, but it seems that this did not happen. Uqba was shackled and thrown into prison, from which he was only released when the Caliph requested to see him. As Uqba left Ifriqiya for Damascus, he vowed to treat Abu al-Muhajir as he had been treated [5, 6].

This monumental building mainly constructed of limestone has been suffering over the past few decades from a potential acceleration of their alteration due of the influence of environmental conditions [7]. This work is conducted to describe this form of alteration, and to

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identify the responsible factors and the mechanisms involved. The investigation methodology is based on a morphological, petrographic, mineralogical and petrophysical study on altered and good stone, which (the latter) is considered as the unaltered part in the same stone [8-10].

Then, a follow-up on the internal environment of the mosque by monitoring the temperature and the humidity using thermo-hygro-buttons over a period of one year [11, 12]. Finally, the simulation of this alteration by undertaking an aging test through cycles of humidification and drying in pure water to highlight this phenomenon of alteration [13, 14].

Description of the alteration form

The alteration is in the form of a patina, a colored layer with orange-brown hue, not very resistant to touching and friable with a depth of 2 to 5cm (Fig. 1).

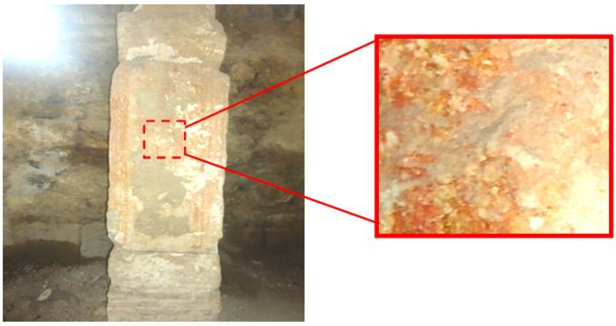

Fig. 1. Stone pillar inside the mosque

Experimental part

Materials

The collected sample has several different macrovisible layers (Fig. 2).

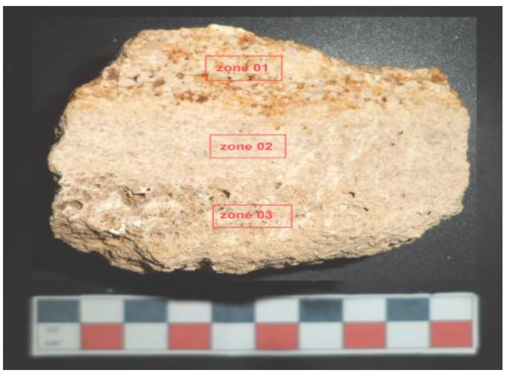

Fig. 2. Section of the collected sample

Methods

The sample was divided into three zones (Zone 01, Zone 02 and Zone 03), each of these parts underwent a series of analyzes: observation under binocular magnifier, petrographic analysis on a thin section, X-ray mineralogical analysis, chemical X-ray fluorescence analysis and petrophysical analyzes.

Results and discussion

***Observation under Binocular Magnifier*:**

Zone 01: characterized by orange-brown color which resembles rust, with the presence of some macrospores (Fig. 3).

Zone 02: characterized by a light beige color and a less compact structure (Fig. 3)

Zone 03: characterized by a light beige color and a less compact structure than Zone 02, with the presence of some macrospores (Fig. 3).

Petrographic examination on thin sections

Those investigations were carried out according to standard BS NF EN 12407: 2000 [15, 16].

Zone 01 (**Z_{01}**) **-** the sample is a highly recrystallized; micritic limestone of dark-colored microsparithic structure heavily contaminated by pelitic impurities of a very fine ferruginous nature of iron forming, in places, accumulations in the form of rust stains (Fig. 4).

Zone 02 (**Z_{02}**) **-** the sample is a highly recrystallized; micritic limestone with dark hue microsparithic structure. Moreover, this micritic matrix has undergone an intense crystallization in larger calcite crystals developing, in places, with irregular clusters appearing as a thin section in the form of light stains. These clusters are formed by assemblies of small polygonal calcite crystals of whitish colors arranged according to a mosaic structure (Fig. 5).

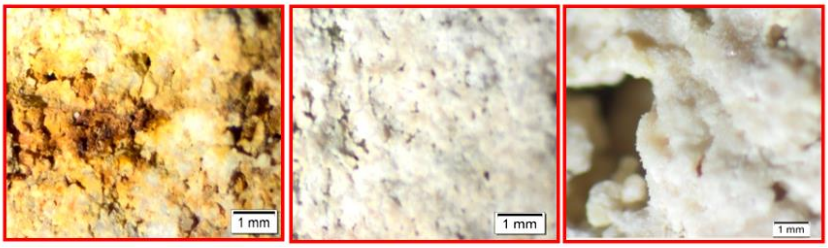

Fig. 3. Macroscopic view: **left** - Zone 01; **center** – Zone 02; **right** – Zone 03

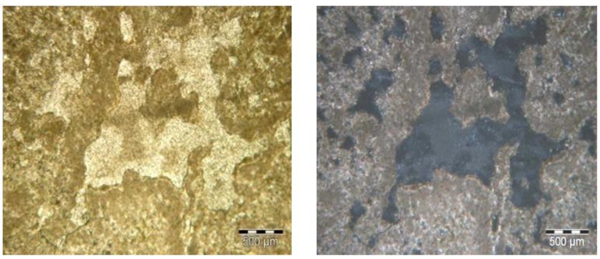

Fig. 4. Zone Z_{01} under polarizing microscope in polarized light (PL) (on the left) and analysed polarized light (APL) (on the right)

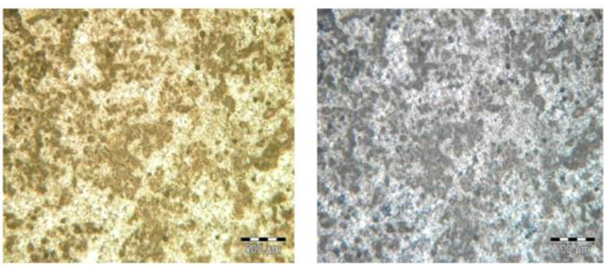

Fig. 5. Zone Z_{02} under polarizing microscope in PL (on the left) and APL (on the right)

Zone 03 (**Z_{03}**) - the rock is a highly recrystallized; micritic limestone with dark hue microsparithic structure. The micritic matrix has undergone an intense crystallization. In this part, the recrystallization was carried out to a greater degree than Z_{01} and Z_{02} (Fig. 6).

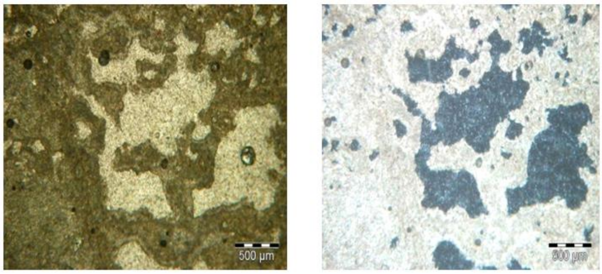

Fig. 6. Zone Z_{03} under polarizing microscope in PL (on the left) and APL (on the right)

Chemical Analysis

The chemical analysis by X-ray fluorescence is carried out by the borax pearl method [17]. The results are shown in Table 1.

Table 1. Result of chemical analysis

Oxide	Z_{01} (%)	Z_{02} (%)	Z_{03} (%)
CaO	55.4	55.1	55.5
MgO	0.21	0.47	0.18
Fe_2O_3	**0.74**	0.03	**1.08**
SiO_2	0.18	0.41	0.13
SO_3	0.17	0.16	0.17
Na_2O	0.14	0.13	0.12
SrO	0.08	0.08	0.07
Al_2O_3	0.06	0.01	0.04
ZnO	0.01	-	0.01
TiO_2	-	-	-
MnO	-	-	-
Ignition loss (1000ºC)	43.3 %	43.5%	42.6 %

The results show and confirm that our samples are mainly composed of calcite, with the presence of Fe_2O_3 which is slightly higher in Z_{01} and Z_{03}.

Petrophysical analysis

The porosity and the density are determined according to standard BS NF EN 1936 (1999) [17, 18].

The water absorption is determined according to standard BS NF EN 13755 (2003) [19, 20]. The results are presented in Table 2.

Table 2. Petrophysical analysis result

Petrophysical analysis	Z_{01}	Z_{02}	Z_{03}
Density - ρ_a (g/cm^3)	01.56	01.94	01.61
Total porosity - N_{tot} (%)	28.10	10.33	24.48
Water absorption (%)	17.60	05.23	20.11

The values of the density are low for samples Z_{01} and Z_{03}; (*1.56 and 1.61 respectively*); the total porosity is 28.1 and 24.48 for Z_{01} and respectively Z_{03}; the water absorption is 17.60%

and 20.11% for Z_{01} and respectively Z_{03}, which are higher compared to Z_{02} which is more compact, characterized by much lower values: 10.33% for porosity and 05.23% for water absorption.

According to petrography, chemistry and the petrophysical characteristics, each of the three studied zones Z_{01}, Z_{02} and Z_{03} represents a stratigraphic layer of different geological formation.

Measurement of temperature and humidity inside the mosque

The thermo-hygro-button is fixed on a pillar inside the prayer hall (Fig. 7). The latter runs a humidity and temperature control every two hours over a period of 12 months of the year 2013 [11, 12]. The results are presented on figure 8.

Fig. 7. The thermo-hygro-button location.

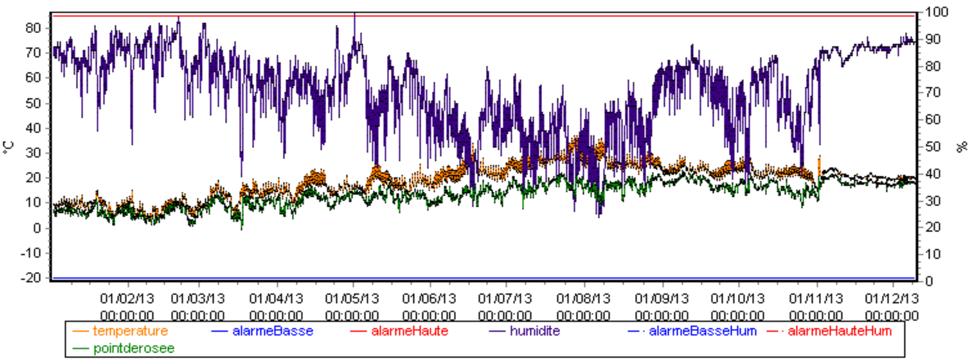

Fig. 8. Thermo-hygro-botton sampling result

In Figure 8, the maximum and minimum value of the recorded temperature is 37.5 vs 3.5°C and 100% vs 24% concerning the humidity, with registration of several condensation points, dew point (temperature curve in yellow below the green dew curve) for the months of January, February, March, April, November and December. Therefore, the stone of Sidi Ghanem mosque undergoes a regime of significant temperature and humidity variation with very frequent condensations.

The lithographic composition can not explain the formation of this patina because both zones Z_{01} and Z_{03} have almost a similar composition except that zone Z_{01} is exposed to the atmospheric agents (humidity and temperature) whilst Z_{03} zone is not. For that reason, it`s simulated the humidity and drying for zone Z_{03} through an aging simulation by cycles of humidification – drying, observing the influence of this sequence on zone Z_{03}.

Aging test

The sample underwent imbibition-drying cycles in order to monitoring the effect of the distilled water, without any added pollutant [21, 22].

The imbibition is carried out with distilled water untill complete saturation of the sample at atmospheric pressure. The drying is carried out in an oven at 50°C, the drying time is approximately 24 hours. The results are shown in figure 9.

After 50 cycles of imbibition - drying, the rust stains begin to appear and after 100 cycles the corrosion becomes increasingly important; touching the lower part i.e. the zone Z_{03}.

a **b** **c**

Fig. 9. The samples: a – at the beginning; b - after 50 cycle, c - after 100 cycles

The appearance, distribution and growth of corrosion on the stone implemented in the construction of the Sidi Ghanem Mosque depends on the nature itself of the stone; an intrinsic parameter related to the geological formation and the lithographic composition of the latter; translated by variable iron oxide content that turns into a ferric hydrate forming a rust complex [23]; this formation of rust is observed on zone Z_{01} at the beginning because of its contact with the humid air and the temperature i.e. in the atmosphere the external factor which promotes this reaction. Zone Z_{02} does not present a sign of corrosion because its iron oxide content is almost zero, zone Z_{03} shows no signs of corrosion because of the high compactness of the zone Z_{02} which did not allow the water to cross it in order to arrive at zone Z_{03}, but after its exposure to humidity and drying, the free circulation of water in the porous network of zone Z_{03} led to the same phenomenon of corrosion.

Conclusions

The alteration identified on the stone of the Sidi Ghanem Mosque is an alteration formed by hydratations of iron oxide in composed ferric hydrate (rust complex) [24]. The latter is caused by the combination of two factors: the first intrinsic factor which is the lithographic composition of the rock i.e. the iron oxide content, the second extrinsic which is the environmental conditions (the water under its shapes and temperature). The depth or thickness of the patina depends on the petrophysical characteristics of the rock, namely the compactness, absorption and water circulation water in the porous network of the stone.

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