Water weathering in rocks discontinuities

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WATER WEATHERING IN ROCKS DISCONTINUITIES

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Abstract:

The behavior of rock discontinuities at different spatial scales remains a major challenge for scientists who want to understand the rock alteration, both in the triggering of rock-fall and in the evolution of the cliffs. Our research aim to take into account the geomorphological features related to the slopes and rock discontinuities subject to weathering conditions. Several studies show the physical effect of water in the alteration of rock through cracks and micro cracks. In Cultural Heritage point of view, a rock discontinuity could be described or analyzed as the interface between stone and joint in buildings. The mechanical and physical discontinuity behavior and its time evolution have a strong influence on the onset of instability of the blocks and on their strength. The effects of climate change (increase of rainfall, temperature fluctuation…), may significantly increase the inception of phenomena such rock falls, stone degradation and damages on monuments. The aim of this study is to characterize the chemical influence of water flowing inside the discontinuity and also through the porous stone matrix. This paper focus on experiments performed in order to analyze the effects of physical and chemical alteration on the mechanical behavior of porous limestone. Limestone is a both commonly stone used in construction of cultural heritage buildings and found on French territory. These experiments could have some interesting results in restoration or conservation of building. We'll present the results of the first two experiments performed in quasi-static and dynamic of the flowing process. The observation and the monitoring of the alteration process are performed in order to determine the physical and chemical reactions involved in this phenomenon. This one we'll be linked to the mechanical aspect of the massif and or the building.

Keywords: rock discontinuities, water, alteration, cultural heritage, stone.

1 Introduction:

Chemical weathering exerts a major control on the Earth's geologic landscape. Most chemicals are solvated; the water becomes a major agent of degradation of rocks and stones. The behavior of rock media is mainly due to their fracturing and crack distribution which occurs at different scales. Failure in the rock masses occur mainly by opening of existing discontinuities and relative sliding blocks or benches [ASR05]. Runoff, which will produce mechanical erosion by removal of particles, is also quite active [KUP85]. Hydrostatic pressure can cause a decrease in the tensile strength of rock bridges fatigue [FRA05] [DRU11].

The study presented in this paper concerns the characterization of the types of chemical alteration appeared during a given period and to quantify the effects of water. Understanding its phenomena is crucial in view for number applications including civil engineering, but also in the study of delicate heritage monuments in order to draw up plans for restoration and conservation.

The second part of the paper is devoted to an overview of different materials and experimental methods used. The third part presents the experiments, the forth gives the first results, the fifth announces the discussion; the part six expose the conclusions and perspectives and possibilities of our research in the different fields of applications as civil engineering, cultural heritage conservation.

2 Materials:

The main material used in the experiments are limestones from French quarries; oolithic limestone named:Pierre de Lens (Lens stone), Pierre de Caen (Caen stone), Comblanchien and Larrys. Their petrophysics properties are compelled in the following (Table 1).

The Comblanchien and Larrys are from Burgundy, Comblanchien is a famous building stone used in France in many architectural buildings both historic (e.g. The Opéra de Paris).

Lens stone also is a famous limestone in the Gard in south of France whose exploitation dates back to Roman. Used in Nimes, Carcassonne, Montpellier, Perpignan, etc. It has become a benchmark for sculptors and stonemasons.

Caen Stone is used in the rehabilitation of cultural heritage and restoration; it will be used also for renovation, decoration and furnishings.

Table 1: Properties of different limestones used for the experiments in quasi-static and dynamic alteration mode.

Limestones	Porosity (%)	Shape for Alteration in quasi static mode.	Shape for Alteration in dynamic mode
Comblanchien	<1	cylindrical	rectangular box
Pierre de Caen (Caen stone)	~20	cylindrical	rectangular box
Pierre de Lens (Lens stone)	~15	cylindrical	rectangular box
Larrys	~4	cylindrical	rectangular box

2.1 Materials for the experience on static mode alteration :

These different limestones are cored whose dimensions are known :100 mm in length and 12 mm in diameter.

- Water : pH 2 (acidified with sulfuric acid (H_2SO_4)).
- weight accuracy ± 0.0001g
- Beakers (100 ml)
- SEM (Scanning Electron Microscope)
- Calcium test JBL

Jbl calcium test instructions: 5 mL of water in the tank in the test tube add 5 drops of reagent (1) mix then wait one minute; 1 dose of the powder (2) stir until dissolved then the number of drops needed to change the color of the reagent (3) (transition from pink to purple and blue).the number of drops multiplied by 20 and gives your value of Ca.

2.2 Materials for the experience on dynamic mode alteration:

These different limestones are sawed whose dimensions are known :100 mm high and the base is 50 mm square edge.

- Water : pH 2 (acidified with sulfuric acid (H_2SO_4)).
- weight accuracy ± 0.0001g
- SEM (Scanning Electron Microscope)
- Rugosimetry Laser

2.3 Experiments:

The experiment one: Alteration in quasi-static mode, and the second : Alteration in dynamic mode are made in order to describe the phenomena : alteration of rock bridge (defined as a continuity between a unstable block and the massif) (2.4) and the alteration of the porous matrix (2.5).

2.4 Alteration in quasi-static mode:

The goal of the experiment is to simulate the behavior of a rock bridge in a gap filled with stagnant (none flowing) water: alteration is called quasi-static regime (without forced fluid convection).

The experiment consists in the observation and measurement of the degree of limestone sample alteration subjected to acid baths without forced convection of the solution.

Approach: This experiment was carried out initially with several types of limestone (4) different in porosity (1% to 22%) to identify the role of the microstructure. This is to make cycles of alteration with pencil shaped to represent the geometry of a rock bridge. Note that in this experiment there is a natural convection due to gradient density. The velocity induced in the solution remains very small in comparison to the flow phenomena in a discontinuity where the water does not stagnate. The specimens are soaked and left 5 days in beakers containing the acid solution, and left to dry in an oven at 60°C during 2 days, this period of "*soaking + drying*" constituting a *cycle* of deterioration. These specimens will undergo several cycles in order to monitor temporal alteration.

2.5 Alteration in dynamic mode:

The goal of the experiment is to “reproduce” the alteration in wall surface of a discontinuity where the water flows and a rock bridge: named: alteration in dynamic mode (with pseudo forced convection).

The experiment is to replicate the alteration of hangingwall and to observe and measure the degree of alteration.

Approach: This alteration is caused by an acid water flow through an artificial discontinuity created by sawing a block of limestone at an angle to define a rock bridge and secured to the lower block. This experiment is being developed, especially regarding the shaping of the specimens.

3 Results:

3.1 Alteration in static mode:

3.1.1 Petrography

In this section we compare by SEM (Scanning Electronic Microscopy) Lens stone (Figure 1) which has a high porosity (15%) and Larrys (Figure 2) which has a small porosity. In order to compare the intensity of the alteration by acid water, we observe by SEM, a first sample unaltered and a second one which underwent 4 cycles of alteration for each type of limestone.

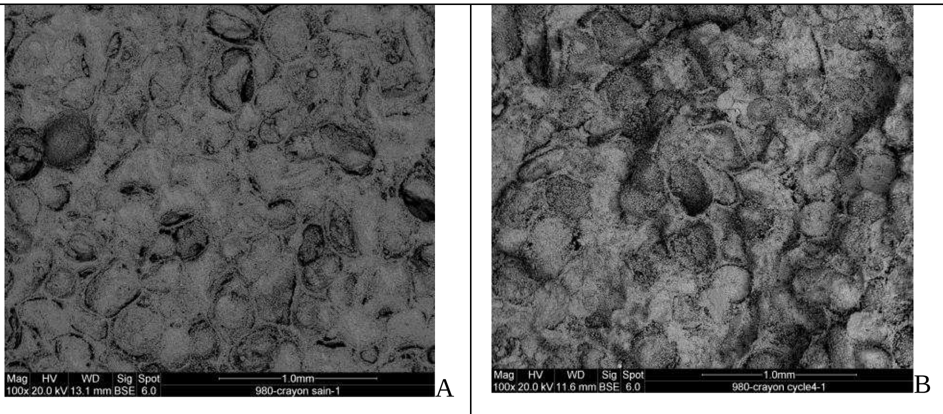

Figure 1: A. SEM image of Pierre de Lens unaltered sample. B SEM image of Pierre de Lens after 4 cycles of alteration.

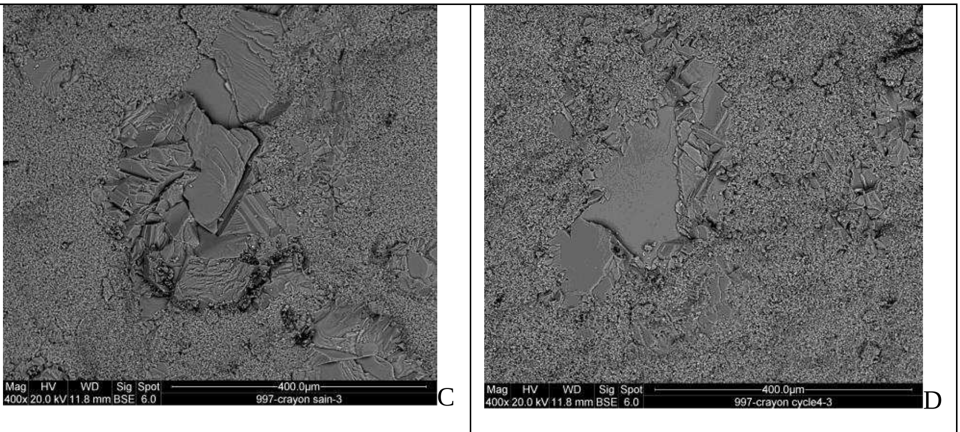

Figure 2: C: SEM image of Larrys unaltered sample. D: SEM image of Larrys after 4 cycles of alteration.

We can observe on figure 1B that oolites in Lens stone are altered, they seem to be unstructured, whereas the Comblanchien is not altered as we can see on figure 2. C-D.

In addition of SEM observations, we observe the sample with binocular. Saad [SAA11], showed appearance of small black spot on the surface of the sample of Pierre de Lens, due to an accumulation of particles of manganese. This kind of black spot are already seen on the Pierre de Caen, but not on Larrys and Comblanchien.

3.1.2 pH and Calcium rate

pH measurement is linked to the concentration of oxonium ion. This concentration allowed us to have a quantification of the calcium dissolved after acid bath as formula explains [1].

$$CaCO_3 + 2\ H_3O^+ \rightarrow Ca^{2+} + CO_2 + 3\ H_2O \quad [1]$$

During the period of imbibitions an increase of the pH is observed, which is linked to an increase of concentration of calcium. This pH increase during the period of imbibitions until it reaches saturation at about 7.3.

Another test has been performed; a simple test usually used monitoring of corals in the aquarium; on water after imbibitions cycle. This test showed an increase of calcium concentration with the porosity. Smaller the porosity is, smaller the rate of calcium is.

3.1.3 Mass evolution

We measure the weight of the different rock sample after the drying period. We could notice a loss of weight for each type of limestone and each sample (Figure 3). Both types of limestone have the same behavior between the beginning and Cycle 3. From Cycle 4, we see a difference. The less porous limestone seems to lose less mass than the other one.

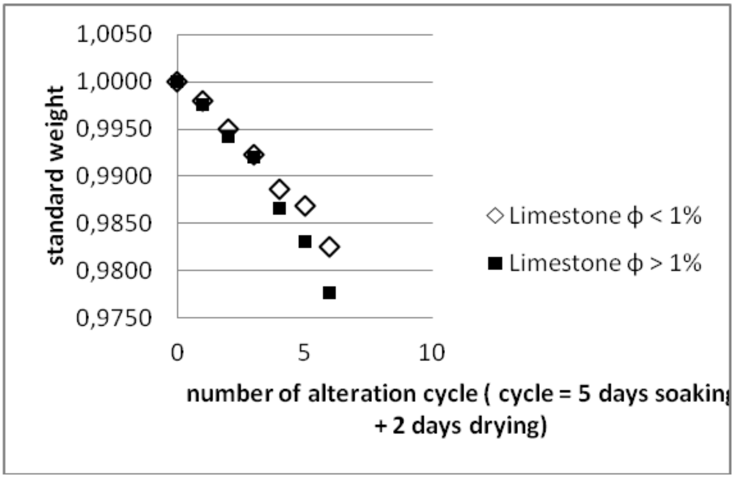

Figure 3: Evolution of the sample weight after drying period between each cycle for two type of limestone (high and low porosity).

3.2 Alteration in dynamic mode:

The experience and particularly the shaping of specimens does not allow us until now to have the back and the results corresponding to the experiment.

4 Discussion:

The reduction in the mass of rock bridges due to weathering poses questions about the implications on the interlocking of the stones. It is expected that the reduced mass and changed shape of single rocks has a detrimental effect on the stability of the rocks and leads to an increased degree of hangingwall's mobility. The more the single rock elements become degraded, the more movement is allowed and the more the rock is prone to rock-to-rock abrasion and hence degradation.

The lake of time to realize the experiment 2 named Alteration in dynamic mode, let us to think about the improvement of the method that we want to develop which is profilometry by laser. We want to observe the influence of water on the surface, and specific ways taken by the fluid.

5 Concluding remarks:

To conclude this paper, even if we have increased the rate of the phenomenon, the rock alteration is a quite long process. The observed phenomena appeared late.

However it should be noted that lower porosity lost less weight than the high porosity. We can say that porosity influence the degradation. We also note that the measurement of pH is alternative way to measure the calcium concentration. We are at a crossroads on this measure, because we choose a simple and inexpensive, such as classic aquarium test. This calcium concentration measurement should be more efficient with a water analyse by *ICP mass spectrometry*.

The previous experiments showed important aspects of the alteration of the rock bridge, the discontinuity and also the massif. The following experiment will take into account the previous results in order to improve it.

According to Kupper [KUP85], the weathering is greater in low temperatures, hence the idea is to set up an experiment that will seek to alter in quasi-static regime at a temperature of 5°C.This temperature can be an in situ temperature reported in temperate countries (autumn to winter period) [BOS08].

The large-scale component (in-situ, ground) was naturally considered to validate the observations from laboratory experimentation. Several sites are under investigation in Isère and Savoie (France). Laboratory experiments are performed attempting to replicate the best reality on the ground where possible using blocks of the site will be chosen [HAN07].

Mainly of cultural heritage monument are weathered because of the environment condition (e.g. pollution by exhaust gas of cars.). All experiments conducted here could be easily applicable on cultural heritage, indeed the size of the simple are quite small. The acid used could simulate an acid rain which replaces the study in a configuration of urban environment.

6 Acknowledgment:

This work has been performed thanks to the INERIS National Institute for Industrial Environment and Risks, and the IFSTTAR French institute of science and technology for transport, development and networks.

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