

# Study of the bryological flora at the archaeological site of Chellah, Morocco

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**Abstract**—The Chellah archaeological site in Rabat, listed as a cultural asset since 2012 on UNESCO's World Heritage List, is subject to significant biodeterioration. The aim of this study is to identify the bryophytes that have an important impact on the destruction of the substrate. For this purpose, three prospections were carried out in autumn 2014, spring 2015 and winter 2016. The systematic sampling carried out allowed us to identify 20 species of bryophytes belonging to 10 botanical families, of which 4 are dominant with 13 species equivalent to 65% of the total. The four families are Pottiaceae, Brachyeciaceae, Funariaceae and Bryaceae; they belong to the class of Muscinae. The liverworts are represented by only 6 species, representing 30% of the total population.

Among the 20 species inventoried, 3 are newly observed in the region of Rabat: *Entosthodon pulchellus* (H. Philib.) Brugués; *Dydimodon Fallax* Hedw. and *Trichostomum crispulum* Bruch.

When bryophytes settle on substrates, a preliminary soilis initiated to the detriment of the quality of materials and their durability.

**Keywords**—Biodeterioration, bryophytes, historical site, Chellah, Morocco.

## I. INTRODUCTION

Like other historical sites in Rabat such as the Hassan tower or the Kasbah of the Udayas, the Chellah archaeological site, a melting pot of several civilizations (Phoenician, Carthaginian, Roman and finally Islamic) is one of the highlights of the capital's history.

The site of Chellah, also known as Chellah necropolis due to its transformation into a royal necropolis by the Marinids sultans, has undergone several archaeological excavations since 1917 that allowed uncovering the different occupations of the site (Basset H. & Levi-

Provençal E., 1929, Basset H. & Terrasse H., 1932, Boube J., 1966).

Regarding the state of conservation of sites, a preliminary diagnosis by Benharbit M. in 2017, identified the main factors degrading the historical monuments of Rabat, including Chellah. These are climatic, dynamic, biological and anthropic factors. Among the biological factors, Benharbit M. (2017), cite lichens, plant roots and bird droppings. Nettekoven et al. (2015) worked more particularly on the lichens installed on the construction stones of Chellah. They identified six encrusting species, known as important agents of biodeterioration of building materials: *Aspicilia calcarea*, *Verrucaria nigrescens*, *Toninia aromatica*, *Verrucaria calciseda* (syn. *Bagliettoa calciseda*), *Placidium squamulosum* and *Lecania spadicea*. With regard to weeds, 91 species have been recorded in Chellah; their presence on buildings generally indicates the presence of moisture in the joints of materials (Taleb et al., 2005). However, no investigation has yet been carried out on bryophytes, but it is agreed that these plants are pioneer plants that initiate plant succession by participating in pedogenesis; their installation on old masonry participates in their biodeterioration. The aim of this study is thus to draw up a list of bryophytes species that are in the necropolis of Chellah and to see up to what extent they take part in the biodeterioration of the substrates.

## II. MATERIAL AND METHOD

The archaeological site of Chellah is located within Rabat at 4 km from the Atlantic coast; it overhangs the Bouregreg valley and occupies an intramural area of about 7 hectares.

Carthaginian had occupied the site in the 12th century BC and Phoenician in the 6th century BC. Later, Romans settled there and founded a city, mentioned by the Greek

astrologer and astronomer Ptolemy under the name of Sala, and a river port serving as a Mediterranean counter. The site was then deserted and given up before being again occupied by the Marinids sultans who built there a necropolis named Al-Ribat Al Mubarak. An inscription in kufic script on the front gate indicates that the work was completed in 739 after hijri (AD 1339).

The Marinids wall, which encircles the site, currently contains characteristic vestiges of the Roman city, including in particular the capitol, the forum, the thermal baths, a nymphaeum and a triumphal arch. From the

Marinids occupation, there remain a mosque, a madrasah (Islamic school), a mausoleum, halls for ablutions and several funerary rooms (Fig. 1).

The site, state-owned property, is protected since november 19, 1920 by the royal decree that defines as national historical monument all the complex of Chellah. Since 2012, Chellah is part of the sites of Rabat inscribed in the list of World Heritage of UNESCO as cultural asset.



Fig.1: Location of the studied samples in the site of Chellah, Rabat

### III. METHODOLOGY

We carried out prospections in the Chellah archaeological site during three seasons: autumn 2014, spring 2015 and winter 2016. These prospections allowed us to follow the biological cycle of the encountered bryophytes, in particular their sporulation. Further investigations were concentrated on the spring season, which is the most favorable period for observing the species with the sporophyte that is necessary for identification. The sampling is systematic and the harvest is therefore carried out at each encountered bryophyte population taking care not to pick up the entire population in order to preserve the species.

We sorted and identified the collected samples in the laboratory. The bryophytes are reviscent plants that

preserve very well after dehydration. Therefore, they are moisturized progressively for the identification.

Species recognition was done using the following identification keys: Augier (1966), Boulay (1884 and 1904), Casas et al., 2006, Coudreuse (2005), Pierrot and 2004). For each sample, morphological and histological characteristics were studied.

### IV. RESULTS AND DISCUSSION

Based on the three prospections carried out in Chellah (fall 2014, spring 2015 and winter 2016), 20 species have been inventoried relating to 18 genera, 10 families and 8 orders and belonging to two classes: Muscinae and liverworts.

Muscinae are dominant with 14 species (70%) grouped in 5 orders: Bryales, Fissidentales, Funariales, Pottiales and

Hypnales. On the other hand, liverworts are represented by only 6 species (30%) grouped in 3 orders: Marchantiales, fossombroniales and sphaerocarpaceales.

Over the 10 encountered families, 4 clearly dominate the site (Figures 2 and 3): Pottiaceae with 5 genera and 6

species, Brachytheciaceae with 3 genera and 3 species, Funariaceae and Bryaceae with 2 genera and 2 species each. These families alone account for 13 species, or 65% of the total. The other 6 families contribute only by 35%.

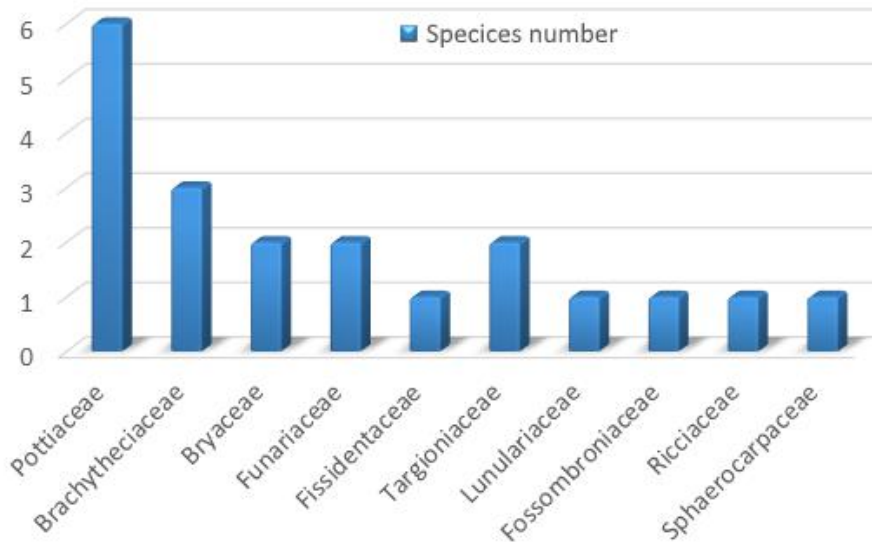


Fig.2: Specific richness per family

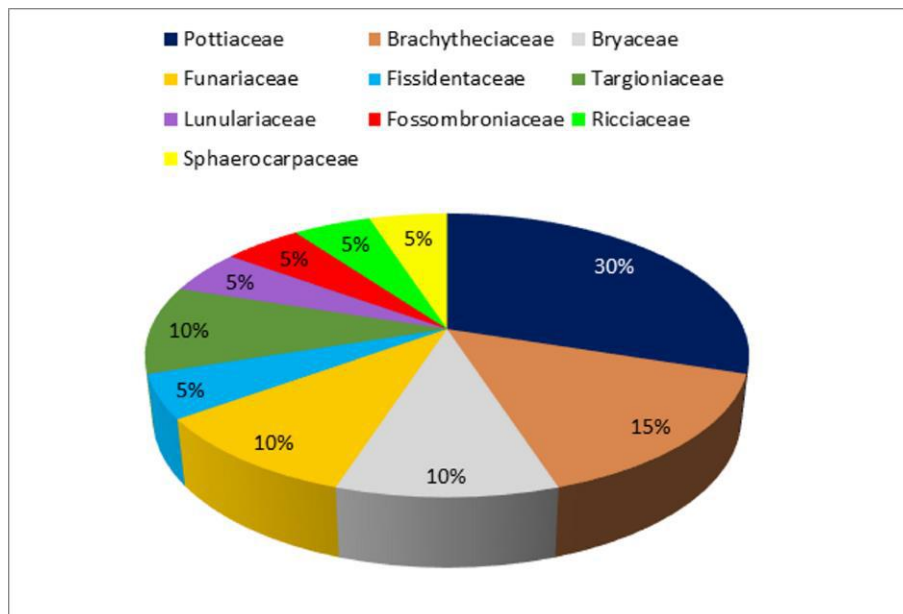
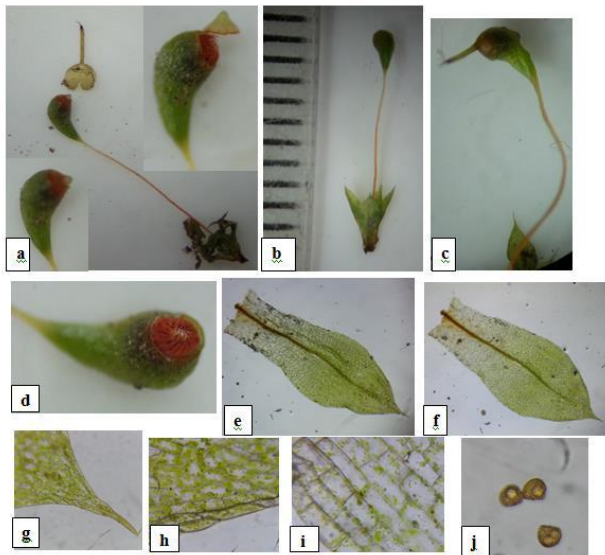


Fig.3: Spectrum of encountered families

Among the 20 inventoried species, 3 are newly described in Rabat region: *Entosthodon pulchellus* (H. Philib.) Brugués; *Didymodon fallax* (Hedw.) R.H. Zander and *Trichostomum crispulum* Bruch. They are illustrated in figures 4 to 6.



**Fig.4.** a, b and c: individual of *Entosthodon pulchellus* x10; d: capsule showing a double peristome x40; e and f: microscopic observations of the leaves x40; g, h and i: respectively microscopic observations of the apical, median and basal cells of the leaves x400; j: microscopic observation of spores x400.



**Fig.5.** a: observation of a dry tuft of *Didymodon fallax* x10; b, c, d: observations of leafy stems in a wet state x15; e: observation of a leaf x40; f, g, h: respectively observations of the apical, median and basal cells x400; i: observation of the cross sections of a leaf x400.



**Fig.6:** a, b and c: *Trichostomum crispulum* plant in a dry state x15; d: plant in a wet state x15, e: x10, f, g and h: x 5; i and j: observation of cross sections of a leaf x400; k and l: observation of leaves x40; m and n: basilar cell observations with the margin (m) and apical cells (n) x 400

#### 4.1. Phylum of Muscinae (Bryophyta)

This phylum contains 14 species that will be presented per family.

##### 4.1.1. Family of Brachytheciaceae

*Rhynchostegium megapolitanum* (Bland. ex F. Weber & D. Mohr) Schimp. (*Brachythecium cardotii* Winter; *Eurhynchium megapolitanum* (Bland ex F. Weber & D. Mohr) Milde; *Hypnum confertum* var. *megapolitanum* (Blandow ex. H. Weber & D. Mohr) Hampe; *Hypnum megapolitanum* Blandow ex F. Weber & D. Mohr; *Hypnum megapolitanum* var. *meridionale* Schimp.; *Hypnum megapolitanum* var. *septentrionale* Boulay; *Rhynchostegium megapolitanum* f. *julaceum*

Brizi; *Rhynchostegium megapolitanum* var. *julaceum* (Brizi) Latzel; *Rhynchostegium megapolitanum* subsp. *meridionale* (Schimp.) Giacom.; *Rhynchostegium megapolitanum* var. *meridionale* Schimp.)

In Morocco, the brachytheciaceae was reported on limestone substrates (Braun-Blanquet, 1954, Jelenc, 1955a, 1955b, 1967, Braun-Blanquet, 1954, cited by Ros et al., 1999). Elsewhere, it was reported on gravel and coastal sand by Augier (1966), and on sandy soil, or on old walls according to Boulay (1884). Smith, (2004) described it as a calcic species. In the studied site, it was harvested on clay-sandy soil.

*Rhynchostegium megapolitanum* (Bland, ex F. Weber & D. Mohr) Schimp. is a lying stemmed moss harvested in a vegetative state, with unequally spaced branches of irregular length. The horizontal stem, spread out, carries branches of different thickness. The leaves are spread, drawn up, sharp, dentate and slightly concave with a relatively sharp and long pointed tip and with a simple or bifid vein that extends to about the middle of the leaf blade. The cells of the leaf blade measure 8/1 and have membranes of the same thickness.

*Rhynchostegiella curviseta* (Brid.) Limpr. (*Eurhynchium curvisetum* (Brid.) Delogne; *Hypnum curvisetum* Brid.; *Hypnum rigidulum* Bruch; *Rhynchostegiella curviseta* var. *laeviseta* (W.E. Nicholson & Dixon) Podp.; *Rhynchostegiella letourneuxii* (Besch.) Broth.; *Rhynchostegium curvisetum* (Brid.) Schimp.; *Rhynchostegium curvisetum* var. *fastigiatum* Bott.; *Rhynchostegium letourneuxii* Besch.; *Rhynchostegium curvisetum* Schimp.).

It has been reported on limestone rocks of streams and on wet walls (Hamada et al., 2002); Which is in agreement with Augier (1966) who also observed it on calcareous stones. Smith (2004) noticed it on rocks, wet stones, top of trees, walls, streams, rivers, canals, lakes, and shady shores. At Chellah, it was harvested on limestone rocks.

*Rhynchostegiella curviseta* (Brid.) Limpr. is a Pleurocarpus moss with a creeping stem, irregularly ramified by more or less drawn up branches from 5 to 10 mm length and unequally spaced. The drawn up leaves, lanceolate, narrow, and gradually narrowed leaves in the upper half are weakly toothed and have a vein that reaches the middle of the leaf blade. The middle limb cells are more than 10 fold longer than broad. The silk is red, rough and slightly curved in S. The actinomorphic capsule is more or less inclined.

*Scorpiurium circinatum* (Bruch) M. Fleisch. & Loeske (*Hypnum circinatum* Brid.; *Scorpiurium circinatum* (Brid.) Fleisch. & Loeske; *Eurhynchium circinatum* (Brid.) Schimp.; *Alsia circinata* (Brid.) Kindb. illeg. hom.; *Hypnum leskea* Grev.; *Hypnum mediterraneum* Sendtn.; *Hypnum strigosum* var. *circinatum*

Brid.; *Rhynchostegium circinatum* (Bruch) De Not.; *Scorpiurium circinatum* var. *runderale* (Brizi) M. Fleisch. & Loeske; *Thamnium cossyrense* var. *melitense* Bott.).

It has been described as a terricole by Ros et al. (2001); It was observed on rocks and tree trunks, at an altitude ranging from 1500 to 2000 m a.s.l. (Maire & Werner, 1934; Jelenc, 1955a, 1967; Ros et al., 1990; Rauh, 1952, cited by Ros et al., 1999); like on vertical limestones and in overhang, sometimes under very shady conditions (Jiménez et al., 2002b). It has also been encountered on sand or on sunny rocks of nature rather limestone (Augier, 1966); Smith, (2004) cites very diversified substrates and insists on the fact that these substrates are not exclusively limestone. It was collected on ground and on the sunny limestone rocks of the studied site.

*Scorpiurium circinatum* (Bruch) M. Fleisch. & Loeske is a Pleurocarpus moss with a reeded stem with twigs in a dry state not reaching 1 mm wide, arched at their end. It occurs in thick tufts of about 2 cm, olive green and faded on the surface. The leaves are oval, about 1 mm in length, revolved only at the base, and denticulate in the upper part of the limb. The middle limb cells are relatively short (3 to 4 out of 1). It was harvested in a vegetative state.

#### 4.1.2. Family of Bryaceae

*Ptychostomum capillare* (Hedw.) Holyoak & N. Pedersen (*Bryum capillare* Hedw.; *Bryum aschersonii* Müll. Hal.; *Bryum capillare* var. *platyloma* (Schwägr.) Schimp.; *Bryum capillare* var. *rufifolium* (Dixon) Podp.; *Bryum capillare* var. *meridionale* Schimp.; *Bryum capillare* var. *macrocarpum* Huebener; *Bryum capillare* var. *tectorum* Warnst.; *Bryum capillare* var. *triste* (De Not.) Limpr.; *Bryum capillare* var. *ustulatum* G. Roth.; *Bryum capillare* var. *majus* Bruch & Schimp. illeg. nom. incl. var. *prior*; *Bryum capillare* subsp. *meridionale* (Schimp.) Podp.; *Bryum cochlearifolium* (Brid.) Hartm.; *Bryum rufifolium* (Dixon) Demaret & R. Wilczek; *Bryum torquescens* var. *gracile* Besch.; *Bryum validicostatum* Cardot & Dixon; *Mnium capillare* (Hedw.) With.).

In Morocco, this species was found on siliceous substrates (High-Atlas) (Werner, 1932; Gattefossé, 1932); on granite (Zaian) (Gattefossé, 1931-1932, cited by Gattefossé & Werner, 1932) and on granitic and porphyritic rocks (Mayor, 1924). It has been reported on sandstones in Tangier; on sands in the Mamora forest near Rabat and on quartzites near Benslimane (Maire & Werner, 1934). Outside Morocco, (Ros et al., 2000) observed it on the edges and cracks of granitic and quartzitic rocks and on peats between 2100 and 3300 m. It was collected on the shady limestone rocks of the studied site.

*Ptychostomum capillare* (Hedw.) Holyoak & N. Pedersen, is a 4 cm Acrocarpus moss with a circular to

slightly polygonal stem. The twig has a helical shape. Leaves are spatulate, twisted in the dry state, drawn up and spread apart in the wet state. They are cogged at the apex with an excurrent vein, margined on most of their length and mainly on the upper part of the limb where two rows of longer elongated cells are observed, the other cells are less elongated (2-3 of 1 at least), of hexagonal-losangic shape, having tips at the ends of their major axis. The middle of the limb has a large and loose areolation with cells of 2 to 3 on 1 in general. The sporophyte is well developed with an orange smooth silk of 2.5 cm and a rust-colored capsule of 4 mm, hanging with a double peristome.

***Bryum radiculosum*** Brid (*Bryum duriaei* Schimp. ex Besch.; *Bryum murorum* (Schimp.) Berk; *Bryum erythrocarpum* var. *murorum* Schimp.; *Bryum atrovirens* var. *radiculosum* (Brid.) Wijk & Margad.; *Bryum erythrocarpum* var. *limbatum* Berth.; *Bryum erythrocarpum* var. *murale* Wils. ex Hunt. err. pro *B. erythrocarpum* var. *murorum* Schimp.; *Bryum erythrocarpum* var. *radiculosum* (Brid.) Bruch & Schimp.; *Bryum murale* Wilson ex Hunt. illeg. hom.).

In Morocco, it was observed on land in the Oued El Abid gorges at Bin El Ouidane (Mayor & Werner, 1934, Mayor and Werner, 1932, quoted by Gattefossé & Werner, 1932); (Jelenc, 1967, Jelenc, 1955b, cited by Ros et al., 1999); on the edges of the granitic rocks, between 2210 and 2400 m (Ros et al., 2000). It was first described in the Anti Atlas by Cano et al. in 2002. Elsewhere, it was reported on stony soils or on the wall mortar by Augier (1966) and Smith (2004) who considered it as a calcareous species. On the site of Chellah, it was harvested on limestone rocks.

*Bryum radiculosum* Brid is a yellowish-green acrocarpus moss, dioecious in compact tufts 4-10 mm high, with well-differentiated stem, oval-lanceolate leaves of about 2 mm, acuminate, denticulate at apex, the brown-russet-red veins excurrent, the limb is smooth with a narrow and tightly bounded area around the middle (cells measure 6/1 at least). This plant was harvested in a vegetative state during the three inspections.

#### 4.1.3. Family of Fissidentaceae

***Fissidens bryoides*** Hedw (*Dicranum bryoides* (Hedw.) Sw. (*Fissidens arcticus* Bryhn, *hypnum bryoides* Linn.).

It was seen on the walls of Rabat (Braun-Blanquet & Maire, 1924), on non-calcareous shallow ground by Augier (1966), on slopes, along the paths, on wet stones, Boulay (1884). Smith (2004), found it on neutral to acid soils or more rarely on wood or stones in open areas. At Chellah, it was harvested on concrete and wet soil.

*Fissidens bryoides* Hedw (*Dicranum bryoides* (Hedw.) Sw.) is a small acrocarpus moss of 1 cm of length, with a short, drawn up and simple stem fixed on the substrate by

fine and dense rhizoids. The leaves are spread out, inserted over two rows on both sides of the stem. They are oblong to lanceolate, acute, with a dorsal blade (sheath) shorter than the limb measuring about 1/3 of the length of this one and margined by very narrow cells that are lengthened and hyaline. The cells of the limb are isodiametric and short, square almost round. The vein is simple, excurrent in a small mucron. (5 mm). The silk is short (5 mm), red, the capsule is ellipsoidal, drawn up and green with a simple peristome made up by red teeth divided up to the middle.

#### 4.1.4. Family of Funariaceae

***Funariella curviseta*** (Schwägr.) Sérgio (*Funaria curviseta* (Schwägr.) Milde, *Gymnostomum curvisetum* Schwägr., *Physcomitrium curvisetum* (Schwägr.) Bruch & Schimp., *Entosthodon curvisetus* (Schwägr.) Müll. Hal.)

It was reported on limestone (Braun-Blanquet, 1954, Jelenc, 1955a, 1967, Braun-Blanquet, 1954, quoted by Ros et al., 1999); in the cracks and crevices of limestone rocks on wet sites with maritime influence. It was collected between the cracks of the limestone rocks of the studied site.

*Funariella curviseta* (Schwägr.) Sérgio, is a small acrocarpic moss of 5 mm of height, forming grass between the cracks of limestone rocks, with toothed leaves in the upper part, acuminate and without clear margin. The isolation is smooth in the upper part of the limb, is more or less translucent with rectangular cells and a vein finishing close to the top. The silk is about 2 mm long. The mature capsule is brown, symmetrical, pyriform, sloping at pendulum before dehiscence and drawn up at maturity with reticulated spores of 20 µm in diameter. The capsule well developed, swollen and has a long beak. The peristome is absent. It forms a stand in association with *Targionia hypophylla* in the studied site.

\****Entosthodon pulchellus*** (H. Philib.) Brugués (*Funaria pulchella* H. Philib.)

It has been reported on the cracks of granitic rocks at 2100 m a.s.l. (Ros et al., 2000). It was observed on basic soils in meadow and between rocks, and referred to as calcicole by Smith, (2004). It was picked up on rocks and limestone ground of the studied site.

*Entosthodon pulchellus* (H. Philib.) Brugués is an 8 to 12 mm acrocarpus moss, forming loose turf on moist soil, the apical leaves, being larger than the others, form oval and whole rosettes. The limb is more or less translucent and terminated in a long filiform point; the areolation is smooth in the upper part, comprises rectangular cells more or less elongated from 2 to 3 in 1 at least. The vein does not reach the top of the limb. The silk is rectilinear; the capsule is oblique, and the urn is smooth. The spores are finely papillose and are about 20 µm in diameter.

#### 4.1.5. Family of Pottiaceae

*Barbula unguiculata* Hedw. (*Barbula apiculata* Hedw.; *Barbula fastigiata* Schultz; *Barbula gattefossei* P. de la Varde; *Barbula microcarpa* Schultz; *Barbula obtusifolia* Schultz illeg.hom.; *Barbula unguiculata* var. *apiculata* (Hedw.) Bruch & Schimp.; *Barbula unguiculata* var. *apiculata* (Hedw.) Mönk.; *Barbula unguiculata* var. *cuspidata* (Schultz) Mönk.; *Barbula unguiculata* var. *cuspidata* (Schultz) Brid.; *Barbula unguiculata* var. *fastigiata* (Schultz) Huebener; *Barbula unguiculata* var. *latifolia* Bréb.; *Barbula unguiculata* var. *microcarpa* (Schultz) Huebener; *Barbula unguiculata* var. *minus* Hillier; *Barbula unguiculata* var. *obtusifolia* Mönk.; *Barbula unguiculata* var. *robusta* Lindb.; *Bryum unguiculatum* (Hedw.) With.; *Dialytrichia canariensis* Bryhn; *Streblotrichum unguiculatum* (Hedw.) Loeske.; *Tortula unguiculata* (Hedw.) P. Beauv. illeg. nom.)

It was seen on the edges of granitic rocks, on quartzic soils near streams (Ros et al., 2000); as well as on the bases and trunks of *Quercus rotundifolia* (Draper et al., 2006). It was described as a messicole by Augier (1966), which described it as a pioneer plant on clay soil and limestone sand. It was seen on very diversified substrates by Boulay, (1884), who observed it particularly on disturbed soils or on landfills. It was collected on limestone rocks and on clay-sandy soil of the studied site.

*Barbula unguiculata* Hedw. is an acrocarpus moss of 1.5 to 2 cm of length. The leafed stem is about 1 cm of length. The basal leaves are revolved and measure 1.5 to 3 mm, with an excurrent vein with two stereids bands. The leaves are helically and strongly twisted in a dry state. The top of the limb is flat and obtuse and has numerous C-shaped papillae. The sporophyte is made up of a red silk and a 1.5 mm capsule. The spores are smooth, yellowish green and 10 to 12 µm in diameter. The teeth of the peristome describe 2 to 3 spiral turns.

\**Didymodon fallax* (Hedw.) R.H. Zander (*Barbula acuminata* Hedw.; *Barbula adriatica* Baumgartner; *Barbula brevicaulis* Schwägr.; *Barbula brevifolia* (Dicks. ex With.) Brid.; *Barbula fallax* var. *brevicaulis* (Schwägr.) Podp.; *Barbula fallax* var. *brevicaulis* (Schwägr.) Huebener; *Barbula fallax* var. *brevifolia* (Dicks. ex With.) Schultz; *Didymodon fallax* var. *adriatica* (Baumgartner) Düll; *Didymodon fallax* var. *brevifolius* (Dicks. ex With.) Ochyra; *Tortula fallax* (Hedw.) Schrad. ex Turner; *Barbula Fallax* Hedw.).

It has been seen on fresh rocks in a sterile state (Jahandiez, 1923); at the bottom of limestone rocks, on damp ground; on porphyritic rocks (Maire & Werner, 1934); on limestone (Braun-Blanquet, 1954); Ros et al., 2001 describe it as a terricole species; and according to Jiménez et al., (2002b), it would develop on cracks of

rock and on sandy soils. Smith, (2004) noticed that it can be present on clay-rich soils and on sand dunes at altitudes ranging from 0 to 490 m. It was collected on clay-sandy soil of the studied site.

*Didymodon fallax* (Hedw.) R.H. Zander is an acrocarpus moss harvested in a vegetative state from 1 to 3 cm in height; It is rust-colored. The stem is ramified, with a differentiated axial beam. Partially revolved leaves are acute and lanceolate 2-3 mm in length, spread-arched, more or less squarrose, in the wet state. The top of the limb is plane and acute with conical papillae that make areolation quite distinct. The base of the limb shows some rectangular and elongated cells whereas others are a little longer than the cells of the higher half of the limb, with thick membranes.

*Timmiella barbuloidea* (Brid.) Mönk (*Barbula cirrhata* Arn.; *Timmiella barbula* Limpr illeg. nom.; *Timmiella barbula* var. *minor* Schimp. ex Luisier; *Trichostomum Barbula* Schwaegr. illeg. nom.; *Trichostomum barbuloidea* Brid.).

It develops on limestone rocks (Mayor, 1924) and (Augier, 1966); at the bottom of walls and maritime cliffs of Rabat, as well as on travertines at Taza (Braun-Blanquet and Maire, 1924). It has been reported on siliceous ground wet places (Maire & Werner, 1934); in tufa caves at Zalagh Mount near Fez and in Taza Gorges (Braun-Blanquet, 1954, Jelenc, 1955a, 1955b, 1967, Ros et al., 1990, Braun-Blanquet, ., 1999).; on clay soil, at the bottom of rocks and walls and in ravines according to Boulay, 1884. At Chellah, it was collected on limestone rocks.

*Timmiella barbuloidea* (Brid.) Mönk, is a 3cm acrocarpus moss. The tuft is of a dark green shining in the dry state. The stem, of 5 mm, is not ramified. The sheathing leaves, involute, of hooked form in the dry state, carry on the upper face high projections each formed by a cell. The limb is largely bistratified with a vein including two bands of stereids. The capsule presents a rudimentary ring with a very little twisted peristome with 32 long and fine teeth.

*Tortula marginata* (Bruch & Schimp.) Spruce (*Barbula marginata* Bruch & Schimp.; *Desmatodon meridionalis* Luisier; *Tortula limbata* auct.).

It has been described as calcicole by Augier (1966) and has been observed on limestone rocks (Ahayoun et al., 2007). Boulay, 1884, observed it on the walls, the rocks and in the shaded and little covered places. Smith (2004), noticed it on wet and shaded basic rocks as well as on the walls of natural and artificial habitats. It was taken from the limestone rocks at Chellah.

*Tortula marginata* (Bruch & Schimp.) Spruce is a 10 mm acrocarpus moss. It organizes small stands with lichen in the studied site. The leafed stem is about 2 mm high. The leaves are very little revolved, lingulate and narrow from

2 to 3 mm length with an excurrent vein in a rather long point. They are margined on almost all their contour by two strata of cells. The latter are more elongated and narrower than those of the rest of the limb. The areolation is papillose and opaque in the upper part of the limb, where the cells are quadrangular, almost square; it is smooth and translucent in the lower part of the limb, where the cells are rectangular and elongated. The capsule, of about 2 mm, is without cover and contains yellowish smooth spores of 10 µm in diameter.

*Tortula muralis* Hedw. (*Barbula heribaudii* Corb.; *Barbula muralis* (Hedw.) Crom.; *Barbula muralis* var. *incana* Bruch & Schimp.; *Barbula muralis* var. *obcordata* Schimp.; *Barbula muralis* var. *rupestris* Schultz; *Bryum murale* (Hedw.) With.; *Syntrichia muralis* (Hedw.) Raab; *Tortula aestiva* var. *vulcanicola* Schiffn.; *Tortula muralis* f. *incana* (Bruch & Schimp.) Sapjegin; *Tortula muralis* var. *incana* (Bruch & Schimp.) Wilson; *Tortula muralis* f. *obcordata* (Schimp.) Mönk.; *Tortula muralis* var. *obcordata* (Schimp.) Limpr.; *Tortula muralis* f. *rupestris* (A. Chev.) Sapjegin; *Tortula muralis* var. *rupestris* A. Chev.)

It has been reported on granite (Gattefossé, 1931-1932, quoted by Gattefossé & Werner, 1932); On the Roman ruins of Volubilis (Braun-Blanquet, 1954, Jelenc, 1955a, 1955b, 1967, Braun-Blanquet, 1954, cited by Ros et al., 1999). Cano et al. (2002) described it for the first time in the Anti Atlas on bare soils. Its presence was also noted on the banks of the BouRegregriver; on granite; on limestone rocks; as well as on limestone slopes (Ahayoun et al., 2007). Boulay, (1884) and Smith (2004) cite very diverse substrates such as walls, roof tiles and cracks in rocks. Smith, (2004) argues that *Tortula muralis* tends to prefer basic substrates and is found more rarely on acidic substrates and is more common in urban areas where it is able to resist atmospheric pollution. At Chellah, it was harvested on limestone rocks.

*Tortula muralis* Hedw is an acrocarpus moss about 2cm. The leaves are more or less drawn up-isolated in the wet state, contracted and twisted in the dry state, with a strong vein all along the leaf, showing in cross-section a single band of stereids, dorsal, excurrent in one hair smooth or slightly dentil, often flexuous hyaline, long; formed hyaline point, partly at least, by the vein itself. The limb is very papillose at the top, and revolute up to near the summit. The cells of the upper part of the leaf are furnished with many papillae, they are square-subarounded, very chlorophyllian, elongated towards the middle. The basal cells are hyaline, rectangular and longer. The drawn up cylindrical capsule takes on a blackish color at maturity with a long beak opercula (1/4 length of the capsule), and a cupped headress. The peristome has completely divided teeth up to the basilar membrane; it

then appears formed of 32 bristles, twisted in whorl with 1-3 turns. The spores are spherical with a smooth wall about 10 µm in diameter.

*Tortula muralis* var. *aestiva* Brid. ex Hedw. (*Barbula aestiva* (Brid. ex Hedw.) Schultz; *Barbula muralis* var. *aestiva* (Brid. ex Hedw.) Röhl.; *Tortula aestiva* (Brid. ex Hedw.) P. Beauv.; *Tortula muralis* subsp. *aestiva* (Brid ex Hedw.) Meyl.).

It is a bright green plant with the same characteristics as *Tortula muralis* Hedw except in the shape of the leaf, which is tightly lingulate, spatulate with an excurrent vein in a yellowish green tip.

*Trichostomum crispulum* Bruch. (*Mollia crispula* (Bruch) Lindb., *Trichostomum brevifolium* Sendtn. ex Müll. Hal.; *Trichostomum crispulum* var. *acuminatum* Meyl.; *Trichostomum crispulum* var. *angustifolium* Bruch & Schimp.; *Trichostomum crispulum* subsp. *brevifolium* (Sendtn. ex Müll. Hal.) Giacom.; *Trichostomum crispulum* var. *brevifolium* (Sendtn. ex Müll. Hal.) Bruch & Schimp.; *Trichostomum crispulum* var. *cucullatum* (Cardot ex G. Roth) Podp.; *Trichostomum crispulum* var. *elatum* Schimp.; *Trichostomum crispulum* f. *longifolium* Bouvet; *Trichostomum crispulum* var. *pseudoweisia* Schimp.; *Trichostomum crispulum* var. *viridulum* (Bruch) Dixon; *Trichostomum hammerschmidii* Loeske & H.K.G. Paul; *Trichostomum viridulum* Bruch)

It develops on the ground and in the cracks at the base of moist granitic rocks (Ros et al., 2000). It has been described as a pioneer on limestone rocks, on gravelly soil and on coastal dunes by Augier (1966). Boulay, (1884), notes its presence on the sandy or marly soil of the hills, in the hollows of the rocks, on the old walls and on the fixed sands of the old dunes. According to Smith 2004, it is found in shaded or exposed basic habitats, on the ground, rocks, rocky banks, cliffs, old wall mortar, and sandy dunes. It was collected on limestone rocks of the studied site.

*Trichostomum crispulum* Bruch. is an acrocarpus moss, harvested in a vegetative state, light green to yellowish on surface, brown inside. The leafed stem is 1 to 1.5 cm long with mucronate acute leaves at the apex and strongly tight in the dry state; they are lanceolate from 3 to 4 mm, very papillose-opaque in the upper 2/3 of the limb. The limb is a little curved at the edges, and terminates in small cap, more or less mucronate, with a vein that is not very excurrent; it has two bands of stereids. Cells in the upper limb have thin membranes and generally square cellular contours becoming rectangular and thick membrane towards the lower part.

## 4.2. Phylum of liverworts (Marchantiophyta)

### 4.2.1. Family of Lunulariaceae

*Lunularia cruciata* (L.) Lindb. (*Dichominum cruciatum* (L.) Trevis.; *Lunularia cruciata* (L.) Dum.; *Marchantia*



*cruciata* L.; *Lunularia dillenii* Le Jol.; *Lunularia michelii* Le Jol.; *Lunularia vulgaris* Raddi illeg.nom.; *Lunularia vulgaris* Mich.; *Marchantia dillenii* Le Jolis; *Preissia cucullata* Nees & Mont.; *Staurophora pulchella* Willd. illeg.nom.).

In Morocco, it has been reported on walls, hollows of rocks, embankments, banks of wadis (Corbiere, 19132, Corbiere, 1923a, quoted by Gattefossé & Werner, 1932); on wet schistose and sandy rocks in the lower valley of Ourika (Mayor, 1924); on old walls in Rabat (Braun-Blanquet & Maire, 1924). It was also observed outside the immediate contact of warm water from the thermal spring of Lalla Aïa (Gattefossé, 1932); on siliceous substrates of Djebel Guedrouz (Werner, 1932, Gattefossé, 1932, Gattefossé & Werner, 1932); and on limestone rocks (Jovet-Ast, 1956c). Augier (1966), Coudreuse et al. (2005) and Boulay (1984) insist on the wet character of the substrate on which it is observed. It was collected on rocks and shaded and wet grounds of Chellah.

*Lunularia cruciata* (L.) Lindb. is a hepatic with thallus of 1.5 to 4 cm in length and 0.6 to 1.4 cm in width, dark green in color with crescent-shaped propagule baskets. The thallus is clearly differentiated, into two parts: that on the dorsal side is formed of a very green assimilative tissue, and that on the ventral side consists of a parenchyma little or not chlorophyllian, being used for retention or conduction of substances. The assimilative tissue is formed by chambers filled with chlorophyllous bristles (sometimes very short), and regularly drawn up on their floor, opening by pores.

#### 4.2.2. Family of Targioniaceae

*Targionia hypophylla* L. (*Targionia michelii* Corda; *Targionia convoluta* Lindenb. & Gottsche; *Targionia bifurca* Nees & Mont.; *Targionia germanica* Corda inval. nom.; *Targionia hypophylla* var. *fimbriata* (Müll. Frib.) Müll. Frib.).

In Morocco, it has been reported on fresh rocks (Braun-Blanquet & Wilczek, 1923); Schistose rocks (Braun-Blanquet & Maire, 1924); on the siliceous substrates of Djebel Guedrouz in Haut-Atlas, at 1850 m a.s.l. (Werner, 1932); as well as along cracks on limestone rocks at Adar-Ouaman in the Anti-Atlas (Mayor & Werner, 1934). This mesic species according to Augier, 1966, has been described as a pioneer on argillaceous soil and calcareous sand. According to Boulay, 1984, it is found on clay-sandy soil, on old walls owing to cracks and on limestone rocks. In Chellah, this species was collected on limerubble stone masonry or clay-sandy soil.

*Targionia hypophylla* L. is a hepatic with a dark green thallus of 10 to 15 mm long and 4 mm wide. The thallus is clearly differentiated, in two parts: that on the dorsal side contains a very green assimilative tissue, and that on the ventral side consists of a parenchyma little or not

chlorophyllian. The assimilative tissue is formed by chambers filled with chlorophyllous bristles regularly drawn up on their floor, closed or opening by pores. The ventral scales are large, and violet. The stomata are surrounded by 2 to 3 circles of cells very different from the epidermal cells. The capsule located on the ventral surface of the thallus is contained in a bivalve envelope. It contains elaters with 2-3 whorls and spores from 50 to 60 µm of diameter.

*Targionia lorbeeriana* Müller Frib. (*Targionia hypophylla* var. *lorbeeriana* (Müll. Frib.) Aleffi & Schumacker inval.nom.).

In Morocco, it has been reported on calcareous ground and rocks, siliceous ground, granite rocks (Jovet-Ast, 1956c). This species was harvested on limestone rocks in the studied site.

*Targionia lorbeeriana* Müller Frib., is a hepatic with glaucous thallus with some 4 mm wide lobes. Thallus is clearly differentiated, on a transverse section, into two parts like the previous species. The oval stomata are surrounded by 1 to 2 rings of about 7 large reniform cells. The capsule located on the ventral surface of the thallus is protected by a bivalve envelope. The spores are about 80 µm in diameter. It organizes dense stands on limestone rocks and between their cracks.

#### 4.2.2. Family of Ricciaceae

*Riccia crystallina* L. emend. Raddi (*Riccia crystallina* subsp. *austrigena* Schiffn., *Riccia crystallina* var. *major* Lindb., *Riccia crystallina* var. *vulgaris* Lindenb.).

In Morocco, it has been reported on mud (Corbiere, 1913a, Corbiere, 1913b, quoted by Gattefossé & Werner, 1932); on calcareous red ground, on ways (Jovet-Ast, 1955, Jelenc, 1955a, 1967, Jovet-Ast, 1965, quoted by Ros et al., 1999); on mud of dried marshes (Augier, 1966, Boulay, 1984, Hamada et al., 2002).

*Riccia crystallina* L. emend. Raddi, is a hepatic with radial sling thallus, with obtuse lobes, 1 to 4 mm wide, light green above, pale in lower part. The assimilative tissue is made of lacunary parenchyma. The thallus is one to two times dichotomous. The spores of 70 µm diameter on average carry on their convex face a network of alveoli. It is met with *Sphaerocarpos michelii* forming a same stand.

#### 4.2.3. Family of Fossombroniaceae

*Fossombronia angulosa* (Dicks.) Raddi (*Jungermannia angulosa* Dicks.).

In Morocco, it has been reported on different substrates: on siliceous soil, on siliceous soil at the edge of a stream; on soil covering rocks of granite, on fresh ground in the shade, on shady rocks partially covered with soil; or on siliceous red soil at the edge of a runoff (Jovet-Ast, 1956c). According to Augier 1966, this species has been reported on non-calcareous wet soil, on the slopes of

hedges, paths and in rather dry places. It is cosmopolitan in the Mediterranean region according to Boulay, 1984. In Chellah, it is found between the rocks of the studied site.

*Fossombronia angulosa* (Dicks.) Raddi, is a hepatic with leaves of 1-3/0.5 cm with a creeping stem bearing succubus leaves and purple rhizoids. The silk is short with a round capsule containing spores of about 40  $\mu\text{m}$ . The spore has a hemispherical face and a pyramidal face.

#### 4.2.4. Family of Sphaerocarpaceae

*Sphaerocarpos michelii* Bellardi (*Sphaerocarpos terrestris* (Micheli) J.E.Sm.).

It has been reported on soil covering a granite rock (Jovet-Ast, 1956c); on sandy soil and on the granitic rock above the hot spring of Oulmès (Ahayoun et al., 2007). Augier, (1966) describes it as a mesicoleand indicates its presence on clay soil. It was harvested on the clay-sandy soil of the studied site.

*Sphaerocarpos michelii* Bellardi, is a dioecious hepatic with light green thallus with unistratified margins. Antheridia and archegones are located on the dorsal side of the thalli, each is surrounded by an involucre with the pyriform male and the globular female, tightened in the upper part and presenting a small opening. The dehiscence of the capsule is irregular. The spinous spores are united in tetrads of dark brown color measuring approximately 100  $\mu\text{m}$  in diameter.

#### 4.3. Bryophytes and Biodeterioration

Bryophytes are reviscent plants that settle as soon as the substrate is moistened (fig. 7 and 8); they can occupy very poor environments in organic matter. The samples were taken at different locations in Chellah site (Fig. 1). The obtained results show that bryophyte colonize both the moistened soil, the concrete of steps, the zellij, the terracotta brick made up essentially of calcarenite dating from antique and Islamic times (fig. 9, 10 and 11). This rock was extracted from the quarries of Sidi Bou-Knadel, about ten kilometers to the north of Salé, from plio-quadernary age and belonging to the dune cords that extend along the Atlantic coast between El Jadida and Larache. It is a compact, yellow-beige detritic sedimentary rock made up of two detrital fractions: a bioclastic fraction (shell fragments) and a terrigenous fraction composed of millimetric quartz grains bound by a limestone cement.

According to the bioreceptivity criteria described by Guillite (1995), Salé calcarenite offers a set of characteristics favorable to biocolonization. Indeed, the surface quality of Salé calcarenite has a large roughness allowing the anchoring of rhizoids. This surface roughness is also associated with a high porosity of about 24% and an estimated capillarity of 12.37 (El Amrani El Hassani & El Azhari, 2009), which is conducive to

retention of water and favorable for the installation and growth of bryophytes.

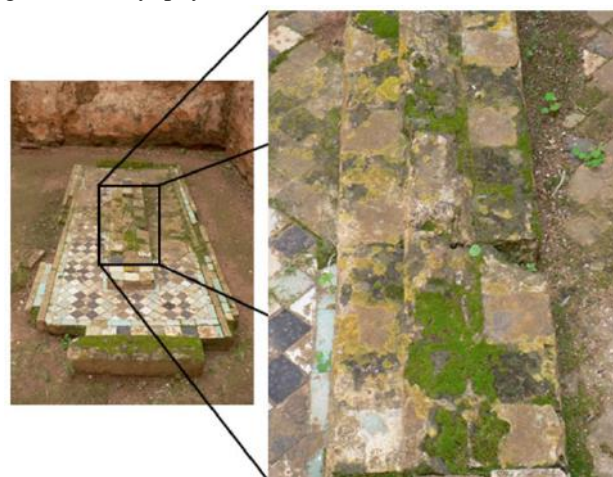


Fig.7: Development of bryophytes on zellij tiles of a tomb in Chellah necropolis contributing to the destruction of the enamel



Fig.8: Terracotta brick wall of the gate covered with bryophytes that maintain a high degree of moisture on the masonry



Fig.9: Colonization of the base of a calcarenite wall in Chellah by bryophytes thanks to the capillary rise that favors a high degree of moisture



Fig.10: Vertical edge of the calcarenite basin of ablution in Chellah covered by bryophytes



Fig.11: Total recovery by bryophytes of an architectonic element and loss of legibility

Once the supports have been colonized, the bryophytes cause initially a chromatic alteration and thus an aesthetic biodeterioration (Deruelle, 1991; Ortega-Calvo et al.,

1991; Warscheid & Braams, 2000; Gaylarde et al., 2003; Allsopp et al., 2004).

The bryophyte binding system will develop in the pores of material, exerting pressures inside the structure that may modify the porosity of the support and in the long term to make material to burst (Warscheid & Braams, 2000; Gaylarde et al., 2003). This is called physical biodeterioration.

Other chemical processes are involved: the dissolution of limestone substrate minerals by acidic secretions produced by plants as well as the assimilation of the substrate as a nutrient (Warscheid & Braams, 2000). This is referred to as a chemical biodeterioration.

## V. CONCLUSION

The archaeological site of Chellah has been subject to few scientific researches in botanical matter, in particular with regard to the bryophytes. Therefore, our objective consists in describing and identifying the species of bryophytes present in this site and then to establish a list of taxa of these species.

The harvest of the bryophytes allowed us to identify 20 species distributed as follows:

- Fourteen species belonging to the Moss class divided into 5 orders and families and 13 genera, the most widely represented order being the Pottiales with *Fissidens bryoides*, the most widespread species in the site;
- Six species belonging to the Hepatic class including one leaf hepatic. They are distributed in 3 orders, 5 families and genera, with *Lunularia cruciata*, the most encountered species.

The colonization of archaeological materials by bryophytes leads to their aesthetic, physical and chemical biodeterioration due to the acid secretions produced by these plants. All these processes have an important role in pedogenesis and thus in the initiation of plant succession. This fact, without gravity in the natural environment, becomes a source of issues when it concerns materials used in historical monuments whose durability is then threatened.

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