DOI: 10.4408/IJEGE.2017-01.O-02

CHARACTERIZATION OF CALCARENITIC STONES IN MONUMENTAL MASONRY BUILDINGS OF COSENZA (ITALY)

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EXTENDED ABSTRACT

Lo scopo della presente ricerca è quello di offrire un contributo al corretto impiego di materiali lapidei come materiale da costruzione attraverso l'utilizzo di nuovi dati. Secondo tale ottica, questa ricerca è stata orientata verso lo studio di rocce locali calabresi, utilizzate come materiali da costruzione, appartenenti al patrimonio architettonico regionale. In particolare, l'attenzione è focalizzata sulla provincia di Cosenza dove, sin dal XV secolo fino ai giorni nostri, la varietà litologica, l'abilità delle scuole di scalpellini calabresi e la notevole presenza di cave ha da sempre influenzato la storia dell'economia locale contribuendo alla realizzazione del vasto patrimonio architettonico dei centri storici regionali.

Il presente articolo si occupa, come casi studio, di due portali appartenenti ad importanti edifici del centro storico della Città di Cosenza, realizzati mediante la pietra locale di "Mendicino". Questo litotipo, largamente impiegato in passato per la realizzazione della maggior parte dei monumenti della città e non solo, è costituito da una calcarenite compatta, dal color biancastro a volte giallo-rossastro, conosciuto dagli scalpellini con il nome di "biancolella" e noto commercialmente come "tufo di Mendicino", in merito alla sua facile lavorabilità. Questo materiale è presente in affioramento in numerosi siti estrattivi della Valle del Fiume Crati (San Lucido, Rogliano, Altilia, Mendicino ed altri) ed è stato principalmente impiegato per la realizzazione di elementi strutturali e costruttivi, quali murature, pavimenti, portali, molti dei quali risultano esposti agli agenti atmosferici.

Lo scopo principale del presente studio è stato quello di migliorare la diagnosi sui processi di degrado, finalizzandola al corretto intervento di manutenzione ordinaria e straordinaria dei manufatti analizzati. La ricerca è stata sviluppata in due fasi: la prima riguardante la caratterizzazione e la seconda la durabilità dei materiali costruttivi. La caratterizzazione è stata eseguita mediante diverse tecniche non distruttive (TND) le quali hanno permesso di mettere in evidenza, in situ, processi di alterazione, nonché di ricavare indirettamente le caratteristiche petrofisiche e meccaniche dei materiali analizzati. La durabilità è stata valutata mediante test di invecchiamento accelerato, in particolare attraverso il test di cristallizzazione dei sali, poiché l'azione dei sali è risultata essere il principale fattore di degrado per le costruzioni esaminate. Grazie a queste tecniche di indagine è stato possibile costruire delle mappe dettagliate di degrado dei casi studio analizzati, al fine di individuare i necessari interventi di conservazione di cui gli stessi necessitano.

I casi studio analizzati sono i portali della Chiesa di San Francesco di Paola, del XVI secolo, e di Palazzo Bombini, del XVII secolo. In seguito ad un accurato rilevamento geometrico, con il quale sono state localizzate le forme di degrado, sono stati eseguiti test sia in situ che in laboratorio. In particolare, l'analisi architettonica è stata condotta mediante rilievi celerimetrici diretti e sopralluoghi, durante i quali sono state valutate le caratteristiche meccaniche del materiale litico dei due portali esaminati ricorrendo a battute sclerometriche mediante il martello di Schmidt. L'analisi chimica e morfologica è stata condotta in laboratorio mediante analisi al SEM, allo scopo di identificare lo stato di alterazione dei campioni analizzati e di confrontare i campioni degradati con quelli inalterati prelevati in cava. I campioni di cava provengono dalla cava attiva di San Lucido, appartenente alla Successione Miocenica della Valle del Crati. Ai fini della valutazione della durabilità dei campioni sono stati inoltre condotti test di invecchiamento accelerato. L'obiettivo di confrontare campioni degradati con quelli di cava è quello di promuovere l'uso dei materiali lapidei locali, con proprietà petrofisiche, chimiche e meccaniche simili a quelle dei materiali impiegati in passato per la realizzazione delle costruzioni storiche.

I risultati ottenuti mostrano la suscettibilità del "tufo di Mendicino" al degrado, in particolare all'azione dei sali. Nei punti in cui l'azione dei sali è maggiore sono stati registrati ridotti valori di resistenza meccanica. Un possibile intervento suggerito è quello che prevede la sostituzione del materiale originario con un materiale con caratteristiche simili in modo da non provocare processi di degrado differenziale. Infine, i risultati attesi sono utili per la costruzione di Linee-guida da seguire per la caratterizzazione petrofisica, chimica e meccanica di questi materiali, e per il corretto impiego delle rocce lapidee nei progetti di recupero architettonico, con particolare riferimento alla cosiddetta "edilizia di base" dei centri storici calabresi.

ABSTRACT

The aim of this study is to analyze the deterioration of the stone commercially known as "Mendicino calcarenite", used for the building of two important portals in Cosenza (Italy), belonging to the Church of "San Francesco di Paola" (XVI century) and "Palazzo Bombini" (XVII century), evaluating, by means of site and laboratory tests, changes in petrophysical and mechanical properties.

Building type analysis of stone decay was obtained through a field survey and direct measurements. Mechanical properties have been assessed on site by means of Schmidt Hammer Hardness Test. Chemical and morphological SEM analyses have been performed in laboratory in order to identify anomalies in rock structure, as well as to compare unweathered and deteriorated specimens. Unweathered calcarenitic samples come from the active quarry of San Lucido, belonging to the geological Unit of the Tortonian-Messinian sedimentary succession of the High Crati Valley. Furthermore accelarated ageing test by salt crystallization have been performed on quarry samples in order to assess durability of this material.

Tests results have provided a preliminary comprehensive understanding of the level of deterioration of the examined case studies, how deterioration can affect physical and mechanical properties of the building stone and an evaluation of the compatibility to restore the most deteriorated parts with a similar quarried lithotype.

Keywords: *deterioration, NDT, laboratory tests, Mendicino calcarenite, characterization, durability*

INTRODUCTION

Mendicino calcarenite, commonly named as "tuff" (Rodolico, 1995) due to its easy workability, was utilized as building material by the most important Calabrian schools of stonemasons to realize structural and ornamental elements, such as mamposteries, arches and portals of many Calabrian historical centres of the Coastal Thyrrenian area and the central area of the Crati River (Italy). The outcrops of this building material, quarried in the past, are situated near the town of Cosenza, in an area including the southern part of the Coastal Thyrrenian Range, from San Lucido to Domanico, and the right side of the Crati River, from Laurignano to Altilia (Crisci *et alii*, 2003). The ancient quarries were situated in Mendicino, Altilia and San Lucido (Lico, 2015). Mendicino and Altilia quarries were exploited until the last century, but nowadays are not active. San Lucido quarries were situated in the area of the "Deuda stream" and the "Torbido stream", where there was one of the ancient quarries. Since the 50s of the last century has started the quarry activity in the northern area of San Lucido with three new quarries that are still in use (Forestieri *et alii*, 2016).

The main objective of the present study is to determine the effect of deterioration on the durability of selected calcarenitics in the area of the historical centre of Cosenza (Italy) and in particular the effect of modifications to the physical and mechanical characteristics. Specimens representative of two important portals (Molezzi, 2015) were selected and the deteriorated calcarenitics samples examined were compared to unweathered quarry specimens of the same lithology, in order to establish possible relationships.

The study area (Fig. 1) belongs to the old town of Cosenza. The historical centre of Cosenza is situated on seven hills and in a valley at the junction of the Crati and Busento rivers, and has always been known for its rich history. Cosenza is an ancient town, being the capital of the Bruttii people, and later came under the influence of the Greek civilization. In 204 BC it was conquered by the Romans, and became an important communication centre along the Via Popilia connecting Rome to Reggio and Sicily. The morphology of its old town follows the topography of its hills on which it is located and the prevalent building material employed for the construction of its historic building is the "Mendicino calcarenite", a whitish-reddish calcarenitic limestone that has been the raw material employed by the most significant and representative Calabrian stonemasons.

GEOLOGICAL AND PETROGRAPHICAL CHARACTERISTICS

The Mendicino calcarenite belongs to the Tortonian-Messinian sedimentary succession that represents the infilling of the basins opened during the Lower Tortonian in the western area

Fig. 1 - Map of the old town of Cosenza with the two case studies: Portal of the church of "San Francesco di Paola" XVI century (1); Portal of the Palace "Palazzo Bombini", XVII century (2)

of the Calabrian Arc. The area belongs to the high Crati Valley, between the Coastal Range in the west and the Sila Massif in the east (Mastandrea *et alii*, 2002). According to many authors the succession can be divided into four units and the "Calcare di Mendicino" belongs to the second one, made up of mixed carbonate and terrigenous sediments (Colella, 1995).

Regarding petrographical characteristics of calcarenite, showing a carbonate matrix, it can be defined as biocalcarenite/calcirudite (Mastandrea *et alii*, 2002) or biolitite/boundstone (Crisci *et alii*, 2003), with a presence of fossils like microfossils and shells fragments. It's a porous material, almost resistant, with a colour ranging from whitish to reddish, variable for the presence or not of iron minerals. The Altilia calcarenite, belonging to the same "Calcare di Mendicino", can be defined as a calcarenite with a high content of calcium carbonate and it is partially dolomitized (Forestieri *et alii*, 2016).The San Lucido calcarenite can be classified as biocalcarenite. From the petrographic analysis of samples belonging to the active quarry of "Motta Lupo" in San Lucido and analyzed by a microscope in transmitted polarized light (UNI EN 12407, 2007), it can be said that the material is a carbonate rock composed by bioclasts and peloids and it can be classified as a "biopelmicrite" (Folk, 1959) or "packstone" (Dunham, 1962). It contains many fossils like macroforaminiferas, corals, microforaminiferas and algaes (Forestieri *et alii*, 2016). According to the geological map of the Fig. 2, the Miocenic succession in San Lucido is composed by whitish and dark-reddish limestones, mainly calcarenites; sandstones and sands, well stratified; conglomerates, made of rounded to sub-angular pebbles of igneous and metamorphic rocks.

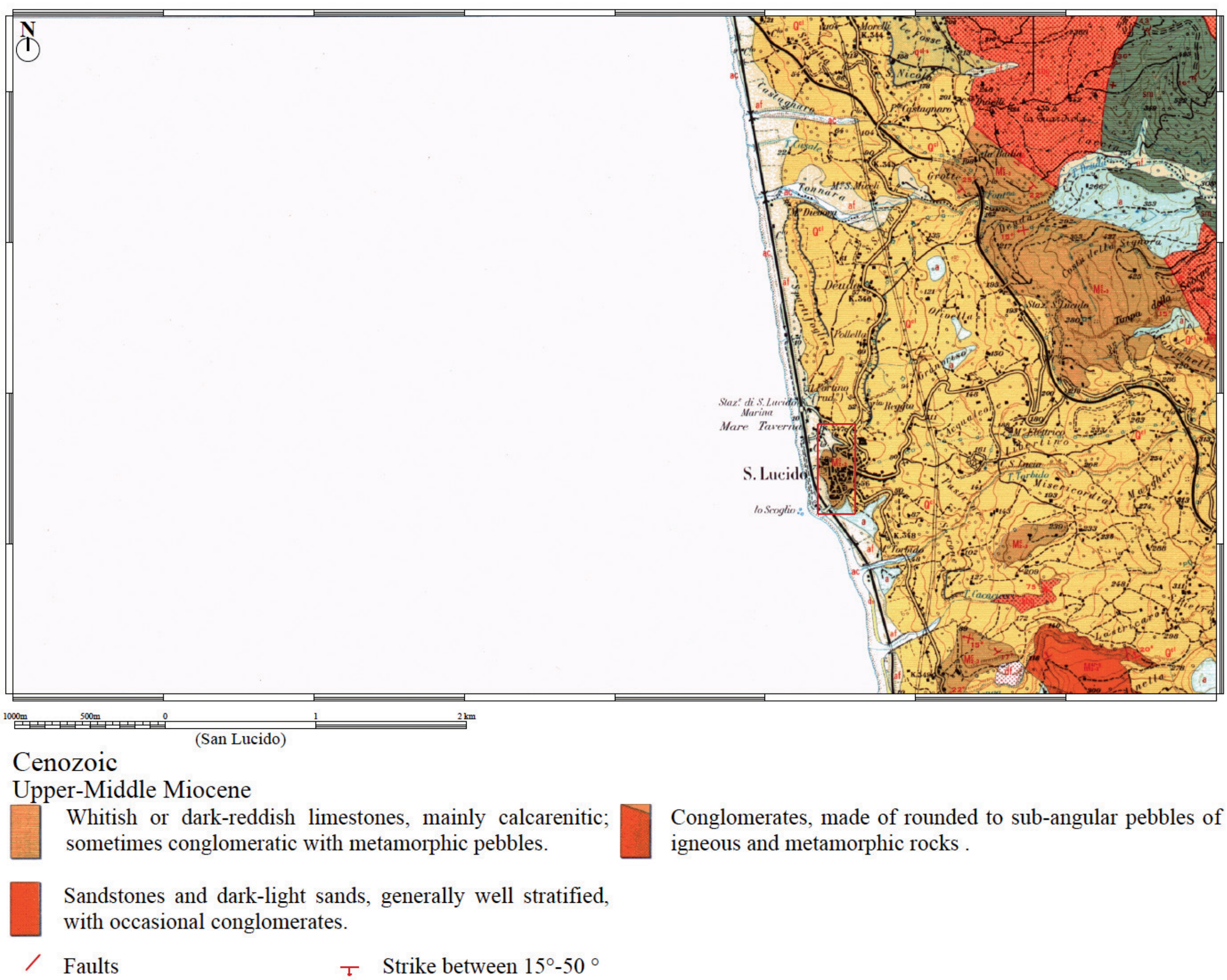

Fig. 2 - Geological sketch map of the "Motta Lupo" quarry of San Lucido (red rectangle shows the studied area and the quarry of "Motta Lupo") (CASMEZ, 1967)

METHODOLOGY AND SAMPLING

The quarry samples which have been analyzed in this study belong to the active quarry of San Lucido. In particular, eight cubic specimens (C1-C8) have been exploited in order to carry out “in situ” and laboratory tests.

The “in situ” mechanical tests included strength measurement of calcarenite surfaces and weathered parts by the Schmidt hammer Geohammer (L-type), according to ASTM D5873 standards (2014), to assess hardness characteristics of rocks. The rebound test hammer housing was held firmly by hand in a position aligned horizontally downward (~0 degrees) so that the impact plunger striked at an angle perpendicular to the test surface of the portals (Fig. 3). Eight points were examinated, four for each portal, the portal of “San Francesco di Paola” and of “Palazzo Bombini”. For each point twelve impact readings were recorded. After the plunger impact for each reading, the surface of the rock was examined. Readings were rejected if any individual impact test resulted in cracking or any other visible damage. The correlation between the uniaxial compressive strength and Schmidt hammer rebound values was determined by the relationship of Singh *et alii* (1983), that according to literature and empirical studies it is suggested to estimate the uniaxial compressive strength of rock on the basis of Schmidt hammer rebound as: $\sigma c=2Hs$ (Eq.1), where σc is the uniaxial compressive strength in MPa and Hs the Schmidt hammer rebound. The relationship has been employed in this study (Eq.1) because in other empirical studies have been obtained strong correlations between unconfined compressive strength and Schmidt values for different lithological units from samples of sandstone, siltstone, limestone and anhydrite (Sharma *et alii*, 2011; Forestieri & Ponte, 2016).

The chemical composition of the samples was determined by electron probe micro-analyzer (EPMA) - JEOL JXA 8230, while the morphological composition was obtained by scanning electron microscopy with energy-dispersive X-ray spectroscopy microanalysis (SEM–EDS) on a FEI Quanta 200 instrument, equipped with an EDAX Si (Li detector). A total of 4 samples were analyzed by chemical-morphological analysis: the sample “San Francesco_01” was taken from the lower part of the portal of the church of “San Francesco di Paola” (Fig. 4), affected by higher grade of deterioration than the other parts of the Portal; the sample “Bombini” was taken from the right abutment of the Portal at 1.80 m height above ground (Fig. 5); two quarry samples, the sample “C24” unaltered and the sample “C16” altered by salt crystallization test (Fig. 6). Accelerated ageing tests by salt crystallization (UNI EN 12370, 2001) were performed on eight cubic specimens (C15-C22) (5x5x5 cm) which underwent fifteen 2-h cycles at 20°C of total immersion in an aqueous solution of decahydrate sodium sulphate (Na_2SO_4*10 H_2O) at 14% v/v and subsequent drying for 16 h at 105°C. At the end of each cycle, the results were expressed as percentage weight loss (ΔM%) due to degradation by salts crystallization.

RESULTS

In situ surveys of all calcarenites show a markedly different behaviour when exposed to weathering agents. The observed morphologies of decay were classified according to the current

Fig. 3 - Operative phases about: the Schmidt hammer test (Fig.3); the sample “San Francesco_01” belonging to lower part of the left portal's pilaster of the Church of “San Francesco di Paola” (Fig.4); the sample “Bombini” belonging to the right abutment of the Portal of “Palazzo Bombini” (Fig.5). All the samples have been in-situ tested through the Schmidt Hammer Hardness Test and analyzed by chemical-morphological laboratory analysis

standard recommendation (UNI EN11182, 2006). A spectrum of different weathering forms with a range in intensity were identified from monument mapping. Maps of weathering forms are presented as examples for the south façade of the Church of San Francesco di Paola (Fig. 7), for its main portal (Fig. 8) and for one of the Portal of the east façade of Palazzo Bombini (Fig. 9). The findings overall evidence a diversity of weathering forms on these monuments. The weathering forms found are: back weathering due to the loss of scale (uniform loss of stone material parallel to the original stone surface); alveolar weathering (formation, on the stone surface, of cavities); missing parts (morphological change of the stone surface due to the partial or selective loss of stone pieces); missing parts due to the break out (loss of compact stone pieces); efflorescence

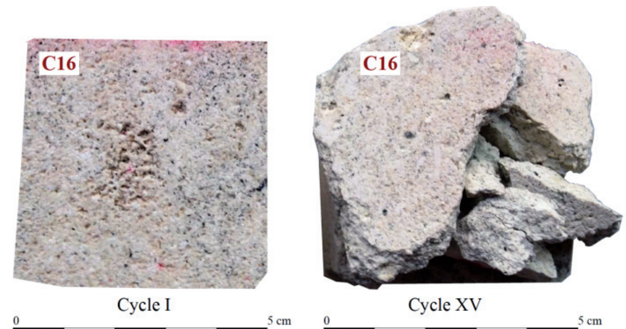

Fig. 6 - Specimens of "Calcare di Mendicino" , belonging to the active quarry of San Lucido (CS), before and after the salt crystallization test

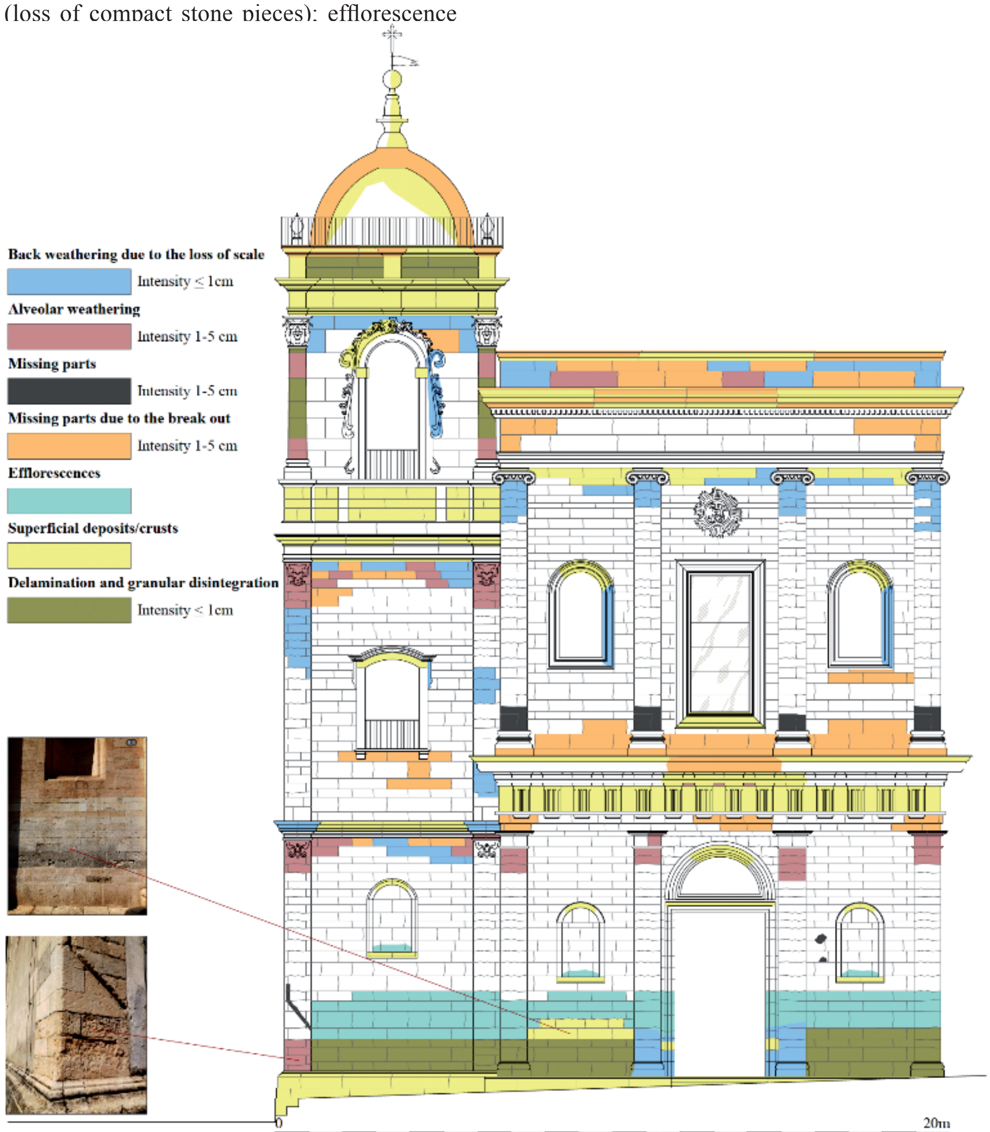

Fig. 7 - Map of weathering forms – South façade of the Church of San Francesco di Paola (CS)

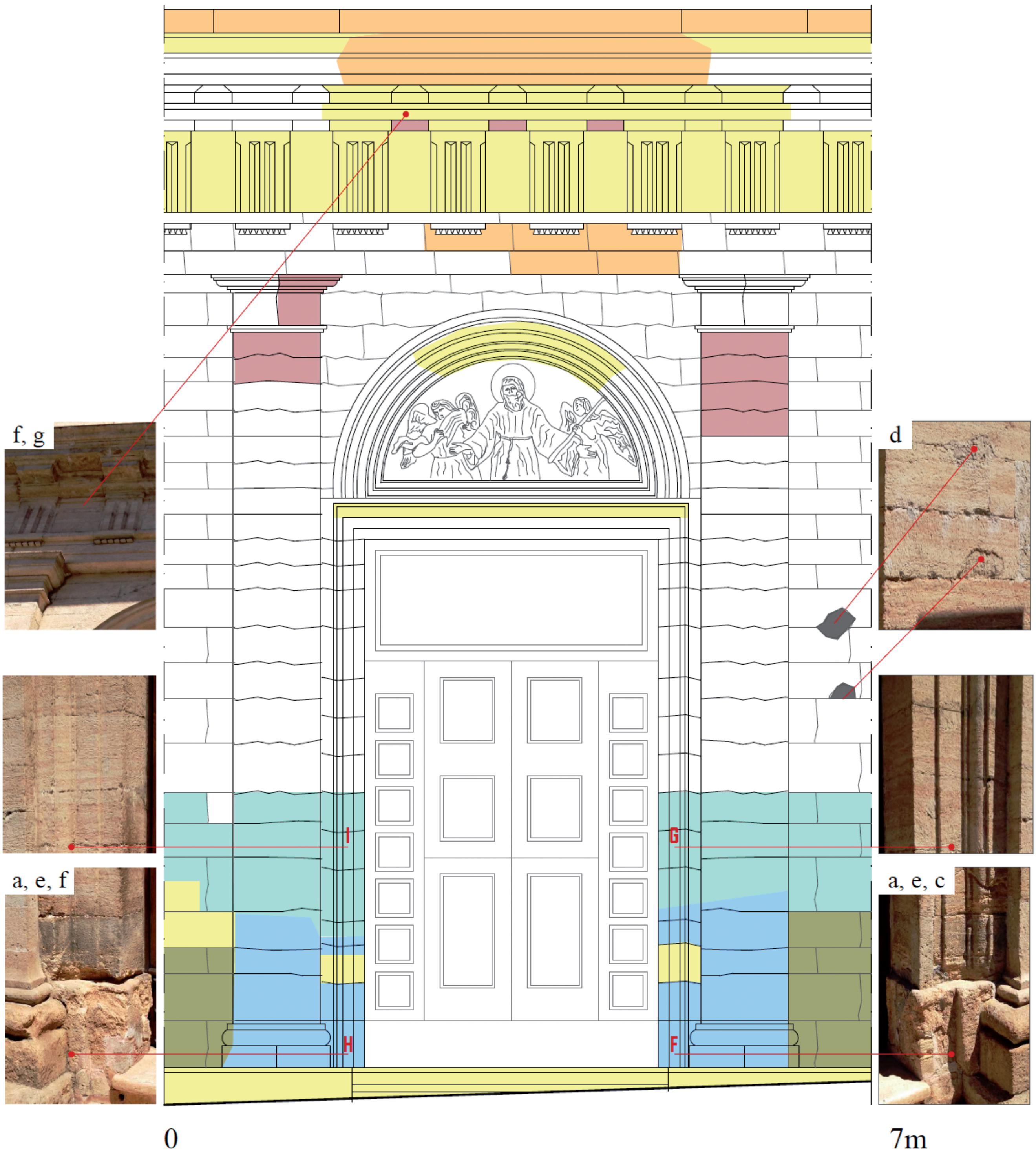

Fig. 8 - Portal of the Church of San Francesco di Paola with the deteriorated parts. F, G, H and I points have been analyzed by Schmidt hardness test. The point F (at 0.30 m of height) has been also tested by morphological analysis by SEM and the sample has been called "San Francesco_01"

(mass of salt deposits); superficial deposits/crusts (due to the soil, salts and to strongly adhesive deposits); delamination and granular disintegration (detachment of individual grains or small grain aggregates). For the façade of the Church of San Francesco di Paola (Fig. 7), the main detected weathering forms have been back weathering due to the loss of scale with an intensity less than a 1cm, efflorescence and superficial deposits. Regarding the first weathering form found, the most deteriorated parts are concentrated in the high part of the façade, in particular at the terminal part of the second level and in the lower part of the pilasters of the main portal. The dimension of missing parts, concentrated in the lower stone blocks of the columns of the second level and due to break-out—often along joints—ranges up to 5 cm. Parts affected by alveolar weathering are concentrated in the higher portions of the columns of the first level and in the higher and in the left part of the façade. A consistent part of the façade, the low-medium portion of the first level, is affected by efflorescence, prevantly concentrated about 2.60 m of height. The most salt-deteriorated part is the lower one of the main portal (Fig. 8). Three kinds of superficial deposits have been detected: soiling in the form of deposits of dust; soil or mud particles on the stone surface; loose salt deposits and crusts. Loose salt deposits are more than the soiling ones and are concentrated near the floor and in the terminal part of the second level. Crusts include whitish and brownish crusts. The brownish crusts are widespread on the frame separating the two levels and especially on surfaces that are still in an early phase of weathering (Heinrichs, 2008). With respect to detachment of stone material, individuated in the lower part of the façade, along the parapets of the last level and on the external surface of the dome, two weathering forms have been detected: delamination as detachment of layers of stone surface and granular disintegration as detachment of individual grains or small grain aggregates.

Generally, the observations about weathering forms of the two monuments reveal that the Portal of San Francesco di Paola shows a lower decay intensity than the other case study. The main degradation forms which occur in the main Portal of the Church

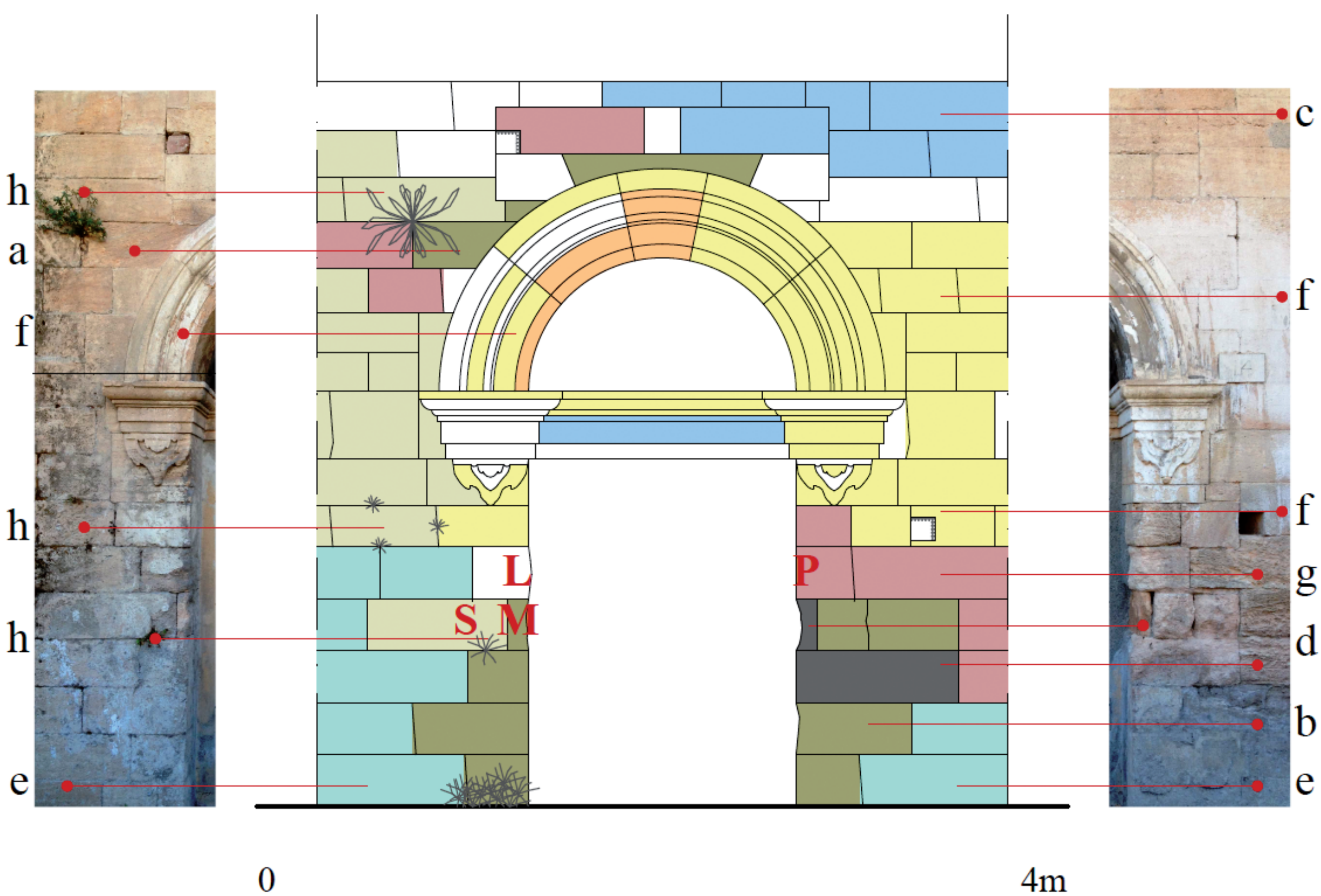

Fig. 9 - Portal of Palazzo Bombini with the deteriorated parts. L, S and M points have been analyzed by Schmidt hardness test. The point S (at 1.80 m of height) has been also tested by morphological analysis by SEM and the sample has been called "Bombini"

of San Francesco di Paola (Fig. 8) include: differential erosion (a); exfoliation (c); micro-cracks and missing parts (d); efflorescence (e); superficial deposits and crusts (f); alveolization (g). Instead, the portal of "Palazzo Bombini" exhibits a higher degree of deterioration than the other portal, especially concentrated in its right part, most exposed to weathering agents, rainfall and wind. The detected forms of degradation (Fig. 9) are: differential erosion (a); delamination and granular disintegration (b); exfoliation (c); micro-cracks and missing parts (d); efflorescence (e); superficial deposits and crusts (f); alveolization (g); biological colonization (h).

Morphological analyses by SEM are reported in the Fig. 10. The sample "San Francesco_01" (Fig. 10 a,b) shows the presence of crystals of salts of Cl, Na and K of 5-10 x 5-10 µm. It is prevantly composed by a micritic and microcrystalline calcite. Are also visible crystals of dolomite and gypsum. The rock shows a medium level of porosity and the substrate is altered. The sample is also deteriorated by biological colonization by fungi and lichens. Lichens form a biological crust on the sample. Furthermore are visible fossils and the presence of salts is concentrated along deteriorated areas. The presence of gypsum has been confirmed by the chemical analysis. The electron probe micro analysis detect the content of CaO (44.39%), SO_3 (14.66%), SiO_2 (16.87%), MgO (11.25%), Al_2O_3 (6.85%), K_2O (2.92%), FeO (1.88%), Na_2O (1.00%), Cl_2O (0.19).

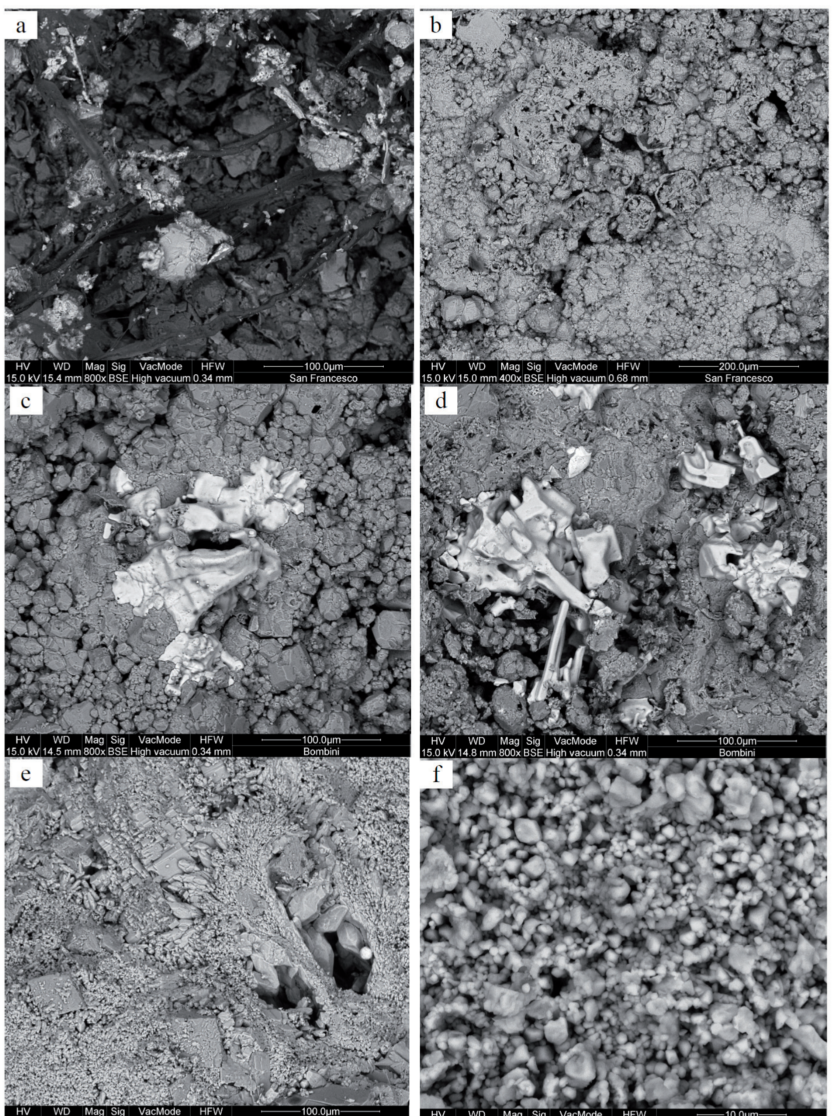

Fig. 10 - SEM analyses: (a), (b) sample "San Francesco_01"; (c), (d) sample "Bombini", (e) calcarenitic quarry sample "C24" ; (f) altered sample by salt crystallization test "C16"

The sample "Bombini" (Fig. 10 c,d) shows a high presence of crystals of salts of Na and Cl of 5-10 x 5-10 µm. The rock shows a high level of porosity and the substrate is very altered. Moreover are visible fossils and the presence of salts is concentrated along deteriorated areas and pores. From the chemical analysis performed is also present gypsum. The electron probe micro analysis detect the content of Na_2O (57.73%), Cl_2O (38.91%), CaO (1.59%), MgO (1.02%), SiO_2 (0.49%), Al_2O_3 (0.27%). The quarry sample C24 (fig. 10 e), reach in CaO, reveals the presence of a microcrystalline calcite and the presence of dolomite crystals. The surface of the altered sample C16 (Fig. 9 f) is entirely recovered by salts and salts are homogeneous and uniformly distributed.

Schmidt hammer rebound values and the uniaxial compressive strength values calculated are reported in Table 1. Calcarenite of both portals shows an average value of uniaxial compressive strength of 57.4-60.6 MPa and Schmidt hammer rebound value of 29-30. When this calcarenite is exposed, altered and rain-washed (points F, M), the rebound values show a decrease. On the contrary, when superficial deposits develop on this lithology, Schimdt hammer values slightly increase (points G, L). Major discrepancies between Schmidt hammer rebound values and related uniaxial compressive strength values were found for the portal of Palazzo Bombini, where the maximum value is 68.3+5.6 MPa for the point L (unaltered) and the minimum one is 49.2+6.2 MPa for the point M (affected by delamination and granular disintegration). Regarding the portal of the church of San Francesco di Paola the maximum value of uniaxial compressive strength has been recorded for the point G (altered by efflorescence) with a mean value of 68.7+7.6 MPa while the minimum value belongs to the point F (the most deteriorated with the presence of back weathering due to the loss of scale) with a mean value of 51.3+5.3 MPa.

San Francesco di Paola				point	Palazzo Bombini		
point	H_s	σ_c (MPa)		point	H_s	σ_c (MPa)	
F	26 ± 2.7	51.3 ± 5.3		L	34.2 ± 2.8	68.3 ± 5.6	
G	34 ± 3.8	68.7 ± 7.6		M	24.6 ± 3.1	49.2 ± 6.2	
H	28 ± 3.9	56.2 ± 7.8		S	26.7 ± 4.8	53.3 ± 9.5	
I	33 ± 2.4	66.2 ± 4.9		P	29.3 ± 2.1	58.7 ± 4.3	
	30 ± 3.2	60.6 ± 1.5			29 ± 3.2	57.4 ± 2.2	

Tab. 1 - Schmidt hammer rebound values (Hs) and uniaxial compressive strength values σ_c (MPa) obtained by Singh et alii (1983) equation

The results of the salt crystallization test are reported into a graph (Fig. 11) showing the curves relative to the modification trend of specimens' weight within the fifteen cycles. The weight variations (ΔM%) for each cycle, at the end of the fifteenth cycle

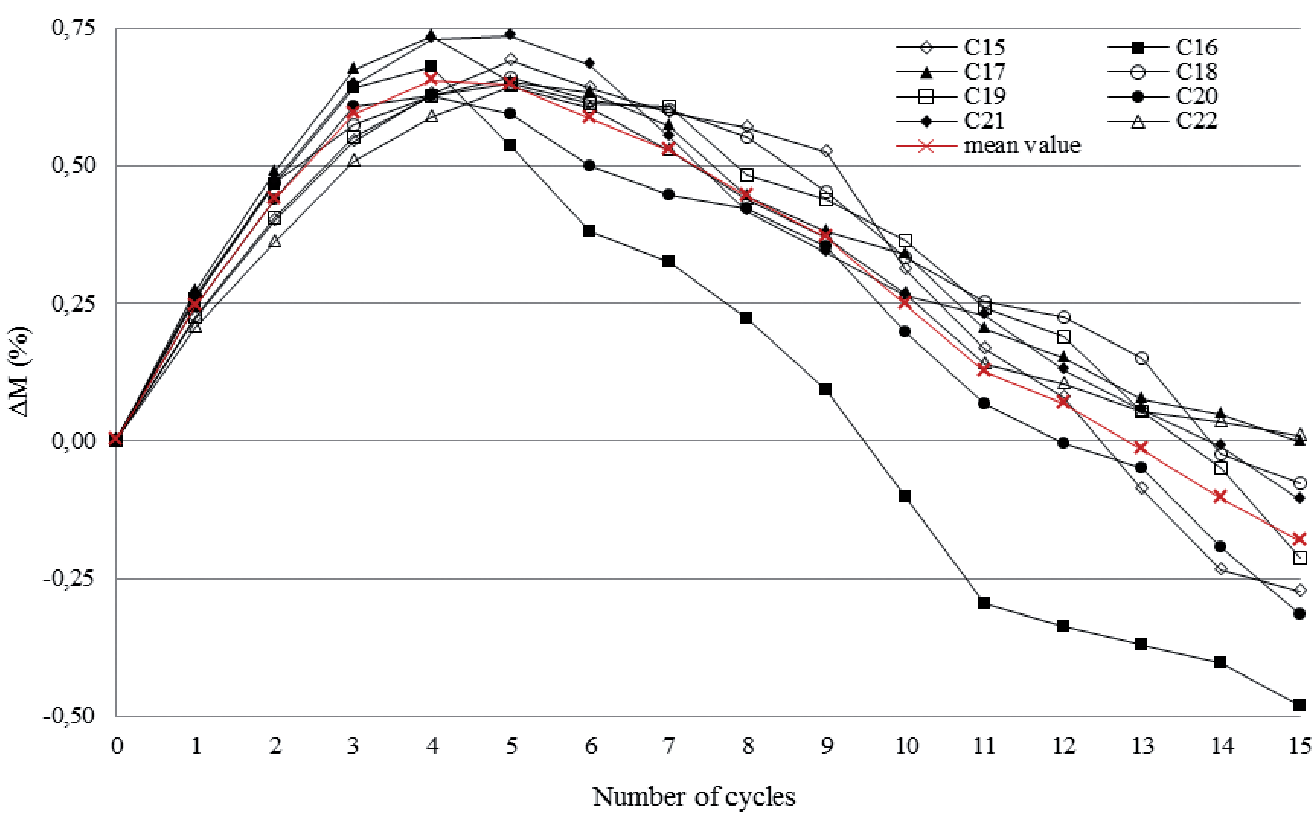

Fig. 11 - Binary diagram showing the weight variation (ΔM%) of specimens during salt crystallization test

Sample	ΔM_0	ΔM_1	ΔM_2	ΔM_3	ΔM_4	ΔM_5	ΔM_6	ΔM_7	ΔM_8	ΔM_9	ΔM_{10}	ΔM_{11}	ΔM_{12}	ΔM_{13}	ΔM_{14}	Δ_{15}	Δ_f
C15	0.00	0.22	0.40	0.55	0.63	0.69	0.64	0.60	0.57	0.53	0.31	0.17	0.08	-0.09	-0.23	-0.27	-0.29
C16	0.00	0.26	0.47	0.64	0.68	0.54	0.38	0.33	0.22	0.09	-0.10	-0.30	-0.34	-0.37	-0.40	-0.48	/
C17	0.00	0.27	0.49	0.67	0.73	0.65	0.63	0.57	0.45	0.38	0.34	0.20	0.15	0.07	0.05	0.00	-0.20
C18	0.00	0.26	0.47	0.58	0.63	0.66	0.62	0.60	0.55	0.45	0.33	0.25	0.23	0.15	-0.02	-0.08	-0.16
C19	0.00	0.23	0.40	0.55	0.63	0.65	0.61	0.61	0.48	0.44	0.36	0.24	0.19	0.05	-0.05	-0.21	-0.26
C20	0.00	0.24	0.44	0.61	0.63	0.59	0.50	0.45	0.42	0.35	0.20	0.07	0.00	-0.05	-0.19	-0.31	-0.43
C21	0.00	0.26	0.47	0.65	0.73	0.74	0.68	0.55	0.42	0.34	0.27	0.23	0.13	0.06	-0.01	-0.11	-0.27
C22	0.00	0.21	0.36	0.51	0.59	0.64	0.61	0.53	0.44	0.37	0.27	0.14	0.10	0.05	0.04	0.01	-0.09
me. val.	0.00	0.24	0.44	0.59	0.66	0.65	0.58	0.53	0.44	0.37	0.25	0.13	0.07	-0.01	-0.10	-0.18	-0.24
sta. dev.	0.00	0.02	0.04	0.06	0.05	0.06	0.10	0.10	0.11	0.13	0.15	0.18	0.18	0.16	0.16	0.17	0.11

Tab. 2 - Weight variations (ΔM%) of the "Mendicino calcarenite" specimens for each cycle, at the end of the 15th cycle and after water washing are listed

(Δ15) and after washing (Δf) are reported in the Table 2. During the first five cycle, all specimens are characterized by a slight mass increase, due to the crystallization of salts within the pore structure. The maximum value of mass increase from the initial weight is 0.74% for the sample C21. From the sixth cycle, can be observed a mass loss (which is particularly evident from the tenth cycle) and the specimens begin to degrade, mainly exhibiting smoothing of corners and edges, granular disaggregation and selective degradation dependent on fossil fragments. At the end of the fifteenth cycle the specimens display an average weight loss of -0.18% with maximum value of -0.48% for the sample C16. The final average weight loss after water washing is -0.24%. The sample C16 at the end of the test has broken. The Fig. 6 shows the sample C16 at the beginning and at the end of the salt crystallization test while the Fig. 10(f) displays the specimen C16, analyzed both by SEM analysis, at the end of the salt crystallization test.

DISCUSSION

Morphological observations coupled to chemical-mechanical investigations allowed to gain important information concerning the behavior of the "Mendicino calcarenite" in response to weathering and its durability.

The observed morphologies of decay in the two study cases were classified according to the current standard recommendation (UNI EN11182, 2006). Generally, the observations of monuments built with this building stone reveal an higher weathering intensity in the lower parts than the terminal portions, affected principally by efflorescence (Figg. 7, 8 and 9); the others main degradation forms which occur in this stone include selective weathering, delamination and granular disintegration. The case study of "Palazzo Bombini" exhibits a high degree of deterioration mainly consisting of delamination, granular disintegration and biological colonization by plants, that haven't been detected for the Church of "San Francesco di Paola". Additionally, results obtained by Schmidt Hammer test and the chemical-morphological analyses are in agreement with the above mentioned observations. Salts mostly accumulate on the lower parts of portals and most exposed to atmospheric decay agents (wind and rainfall). Both the monuments analyzed show a high presence of crystals of salts of Na, Cl and the presence of gypsum. The high amount of them has been individuated for Palazzo Bombini. Conversely, for the Church of San Francesco di Paola, have been also detected the presence of crystals of potassium.

Comparing SEM images of the sample "San Francesco_01", "Bombini" with salts and the quarry sample C24 (Figg. 10 a, b, c, d, e), it can be noticed the presence of cubic crystal of salts mainly concentrated into pores and into internal fracture lines.

Deterioration induced by salts, as shown in Figg. 10 (c,d), forms a continuum between the granular disintegration and delamination detected in the portal of Palazzo Bombini and according to literature (SNETHLAGE & WENDLER, 1997). Moreover, another factor of deterioration, detected in the case of the portal of San Francesco, is represented by lichens, responsible of the presence of the biological crust and superficial deposits on the façade.

Concerning to Schmidt rebound values, the weathering forms detected by the survey analysis have been also confirmed by this test. Tests carried out on the portal of "San Francesco di Paola" show considerable difference in the values of Schmidt rebound and the consequent uniaxial compressive strength between higher and lower parts. In particular, there is a loss of strength between the points I and G (higher part) and the points F and H (lower part) of 25%. These values are in agreement with the weathering analyses, which show that the most weathered parts are concentrated in the lower parts of the Portal due to the presence of salts. Moreover, it is evident that weathering decreases the strength of the rock. This is in agreement with several previous studies, on similar lithologies as limestones (CHRISTARAS, 1991) and Calabrian sandstones (FORESTIERI *et alii*, 2015 a). Schmidt rebound values obtained for the Portal of "Palazzo Bombini" from the left and its right part, are not comparable. The maximum value has been detected for the point L while for the other points

(M, S and P) altered by weathering forms have been recorded the lowest values, with a medium loss strength between the points L (the highest) and M (the lowest) of 33%.

Accelerated aging tests show that the studied calcarenite is sensitive to degradation induced by salt crystallization. The mass loss during the test mostly depends on the open porosity of 16.18+0.81% determined in a previous study (Forestieri *et alii*, 2015 b). As known, in fact, only the open pores are interested by salt crystallization so that the higher open porosity the higher amount of salts which crystallize causing the disaggregation of the sample and the consequent mass loss (Anania *et alii*, 2012). The calcarenite of this study is characterized not only by high porosity abut also by a chemical composition dominated by calcium carbonates, which, is kwown, gives the rock a high susceptibility to acid attack by gaseous atmospheric pollutants (Zaouia *et alii*, 2015).The result of the interaction between calcarenite and atmospheric pollutants is accompanied by structural degradation. The most frequent weathering minerals in our investigation are gypsum and salts of Na, Cl and K. It can be said that their crystallization is responsible for most of the damages in the monuments investigated as in the calcareous monumental stones of the Mediterranean region exposed to weathering agents (Zezza, 1993).

CONCLUSION

The study results demonstrate the susceptibility of the physical and mechanical properties of "Mendicino calcarenite" to weathering. The typical forms of decay for this building material are delamination, granular disintegrations and efflorescence. These are linked to the textural characteristics of this rock as the chemical carbonated composition of the calcarenite. Weathering agents, especially the action of salts, often lead to the total detachment after the process of salt crystallization, as seen during laboratory tests performed.

Salts detected by morphological-chemical analysis carried out, like sulfates and chlorides, affect the stone material by solution and crystallization mechanisms. This is due to the weathering process of this building stone in contact with pollutants atmospheric agents. The local climate, with characteristic humidity for the next presence of the Crati River to the monuments studied, probably is the important local factor contributing to the calcarenite weathering. The analysis of decay of the two case-studies investigated has shown that he less weathered samples exhibit, at the same porosity values, higher Schmidt rebound values and consequently higher uniaxial compressive strengths values. As a result of weathering, calcarenites exhibit a reduced durability due to the loss of strength within the rock following weakening by salts and other factors responsible of deterioration.

As a conclusive remark, this paper wants to highlight the importance of a correct approach in the restoration procedures of monuments which must provide for a diagnostic study. This type of investigation should start with the knowledge of the characteristics of building materials as the textural, physical–mechanical properties and its durability. Moreover, it is very important take in account the compatibility and the similarity between replacing and replaced materials. Furthermore, the factors and process of alteration must be considered in order to provide specific techniques of prevention, restoration, and optimal use of calcarenite, which has been widely used in the area of Cosenza as building stone and that could be still used as ornamental and structural material, due to the active presence of quarries in the area, especially concentrated in the area of San Lucido.

ACKNOWLEDGEMENTS

This research was carried out through laboratory tests at the DiBEST Laboratory of the University of Calabria, Cosenza, Italy and thanks to the techniques learnt at the IGEO Petrophysic Laboratory (CSIC-UCM) of Madrid, Spain. This study was supported by "Programa de Geomateriales 2 (S2013/MIT-2914)" and by "Fondi 5 per mille D.P.C.M. 23/04/2010".

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Received July 2016 - Accepted December 2016