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Biological Deterioration of Calcarenite by *Caloplaca* Lichens at Sabratha Archaeological Site, NW Libya

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Abstract: This study investigates the impact of biological weathering on Roman and Byzantine calcarenite monuments at the Sabratha archaeological site in Libya, specifically focusing on colonization by *Caloplaca* lichen species. Comparative analysis of total carbonate content between fresh and weathered stone samples was conducted using insoluble acid residue experiments. The results revealed a significant reduction in calcite content in weathered samples compared to fresh ones. Furthermore, petrographic observations of thin sections indicated that fresh calcarenite building stones are characterized by dominant calcite cement, whereas weathered samples show substantial degradation of the stone fabric. These findings highlight the critical role of lichen-induced biodeterioration in the irreversible loss of Mediterranean cultural heritage.

Keywords: Calcarenite, Gargaresh formation, Sabratha, biological weathering, lichens, *Caloplaca*.

1-Introduction.

The preservation of cultural heritage constructed from natural stone is a global challenge, as these materials are subject to slow but irreversible degradation. In the ancient city of Sabratha, a UNESCO World Heritage site on the Mediterranean coast of Libya, the predominant building material is porous calcarenite from the Quaternary Gargaresh Formation [1]. This stone is particularly susceptible to weathering due to its high porosity, low structural strength, and high carbonate content [2].

Biological deterioration, or biodeterioration, plays a pivotal role in the degradation of such historic structures. Microorganisms, including bacteria, cyanobacteria, algae, fungi, and lichens, act as primary agents of stone decay [3]. Lichens, which represent a symbiotic association between a fungus (mycobiont) and one or more photobionts (algae or cyanobacteria), are among the most successful and persistent colonizers of stone surfaces [4]. Recent studies have emphasized that biological activity, coupled with fluctuating climatic conditions and environmental pollution, accelerates the weathering of limestone monuments [5][6]. In Sabratha, the Mediterranean climate—characterized by humid winters and hot, dry summers—provides an ideal environment for lichen colonization, particularly in areas exposed to marine aerosols and high humidity [7].

2. Mechanisms of Lichen-Induced Biodeterioration

Lichens affect stone durability through both physical (mechanical) and chemical processes.

2.1 Physical Mechanisms

The physical impact is primarily driven by the penetration of fungal hyphae into the stone pores and cracks. The expansion and contraction of the lichen thallus during hydration and dehydration cycles exert significant pressure on the mineral grains, leading to micro-fracturing and surface exfoliation [8]. Recent research using advanced monitoring techniques has confirmed that these moisture dynamics are critical drivers of long-term stone deterioration [9]. Lichens can be classified based on their growth relationship with the substrate:

- **Epilithic:** Growing on the stone surface.
- **Endolithic:** Penetrating several millimeters into the stone structure.
- **Chasmolithic:** Occupying existing cracks and fissures for protection [10].

2.2 Chemical Mechanisms

Chemically, lichens modify the mineral substrate by secreting organic acids, most notably oxalic acid. These metabolites act as chelating agents, reacting with calcium carbonate (calcite) to form calcium oxalates, which can either form a protective patina or lead to the dissolution and removal of the cementing material [11]. This process is particularly aggressive in calcareous stones like the calcarenite found in Sabratha, where the loss of calcite cement leads to the loss of structural integrity [12].

3. Materials and Methods

The study focused on the *Caloplaca* genus, one of the most common lichen groups found on Mediterranean archaeological sites [13].

3.1 Study area

Sabratha is a coastal city overlooking the Mediterranean Sea in the far west of the "three ancient cities" Sabratha, Oea and Leptis at coordinates32°47′32"N 12°29′3"E

Figure (1-a) Sabratha old city location   Figure (1-b) collected sample location

3.2 Sample Collection

Due to the study area is archaeological site only Five fresh calcarenite samples and five weathered samples (colonized by *Caloplaca* colonies) were collected from Roman villa, the Theater within the Sabratha ruins (Fig1-b). Care was taken to ensure that sampling did not aesthetically damage the site (Fig-2).

Figure(2) Sample collection

3.3 Laboratory Analysis

- **Petrographic Analysis:** Thin sections (0.003 mm thickness) were prepared and examined under a polarized microscope to describe texture, mineral composition, and porosity.
- **Carbonate Content Determination:** The insoluble acid residue method was employed using 10% dilute hydrochloric acid (HCl) to quantify the difference in calcium carbonate content between fresh and weathered samples (Fig 3)

Figure (3) Laboratory analysis

4. Results and Discussion

The comparative analysis of fresh and weathered calcarenite samples from the Sabratha archaeological site reveals a significant reduction in calcium carbonate ($CaCO_3$) content associated with lichen colonization. Fresh samples exhibited an average carbonate content of approximately **88.8%** (table 1), whereas weathered samples showed a reduced value of about **69%** (table 2), indicating a decline of nearly **20%**. This substantial loss is consistent with previous studies highlighting the role of biological agents in carbonate dissolution and transformation [11,14].

This reduction cannot be attributed solely to simple chemical dissolution. Lichens, particularly those of the genus *Caloplaca*, produce organic acids such as oxalic acid that chelate calcium ions and promote the formation of secondary biominerals like calcium oxalates [11]. While these compounds may form superficial protective crusts, their formation typically occurs at the expense of the original calcitic cement, thereby weakening the stone structure and reducing its mechanical integrity [14].

Table (1) Results of the experiment of the residual of the 10% dilute hydrochloric acid reaction for fresh samples.

Sample	Original weight(gm)	Remaining weight(gm)	Dissolved calcium carbonate	Residual minerals
1	50	5	%90	%10
2	50	4	%92	%8
3	50	6	%88	%12
4	50	5	%90	%10
5	50	8	%84	%16
		Average	%88.8	%11.2

Table (2) Results of the experiment of the residual of the 10% dilute hydrochloric acid reaction for weathered samples.

Sample	Original weight(gm)	Remaining Weight(gm)	Dissolved calcium carbonate	Residual minerals
1	10	4	60%	40%
2	10	2.5	75%	25%
3	10	2.8	72%	28%
4	10	3	70%	30%
5	10	3.2	68%	32%
		Average	69%	31%

Petrographic observations strongly support these findings. Fresh calcarenite samples display a well-cemented fabric dominated by calcite cement, providing strong structural cohesion (Fig 4) In contrast, weathered samples exhibit clear evidence of microstructural deterioration, including increased porosity, grain detachment, and partial dissolution of the cementing material(Fig 5). This reflects a progressive transition from a cement-supported framework to a grain-supported structure, ultimately leading to granular disintegration, as reported in similar studies [8,15].

The physical properties of the Gargaresh Formation calcarenite play a crucial role in its vulnerability to biodeterioration. Its high primary porosity and relatively low mechanical strength facilitate deeper penetration of fungal hyphae into the stone matrix. This allows lichens to act not only as surface colonizers but also as endolithic agents, enhancing subsurface deterioration processes and accelerating the breakdown of the internal structure [10,12].

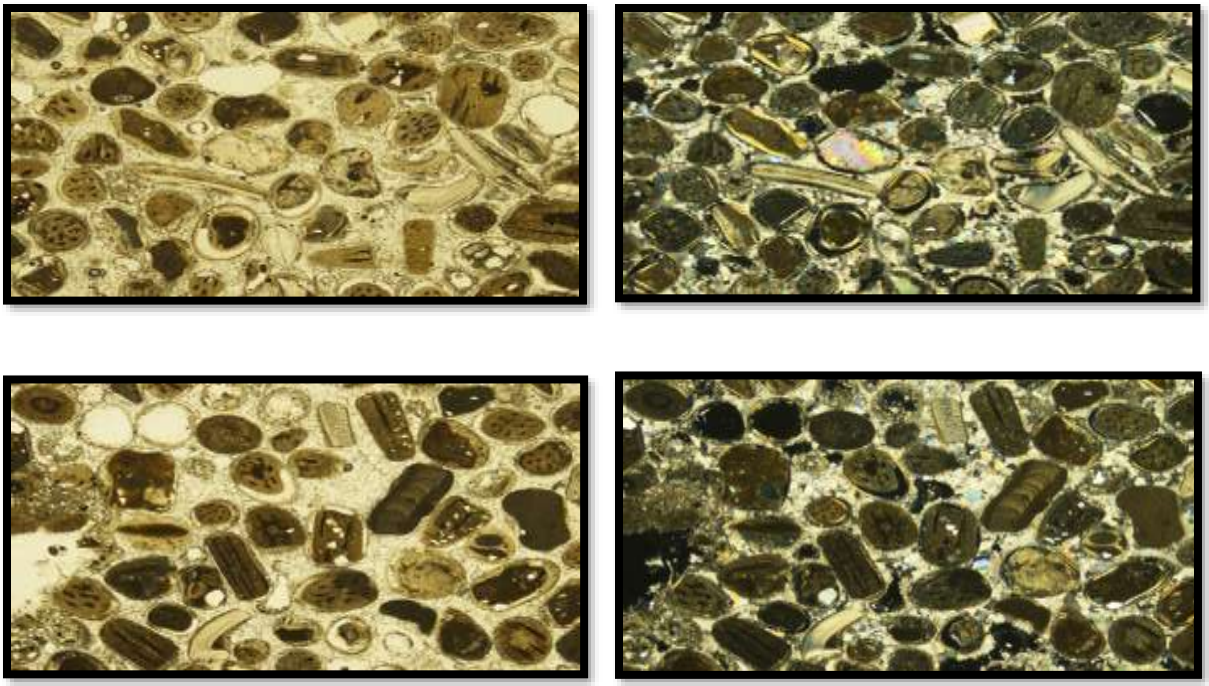

Figure (4) Photomicrograph showing fresh samples Calcarenite Biosparite calcite cement non affected by lichens with Rare dissolution

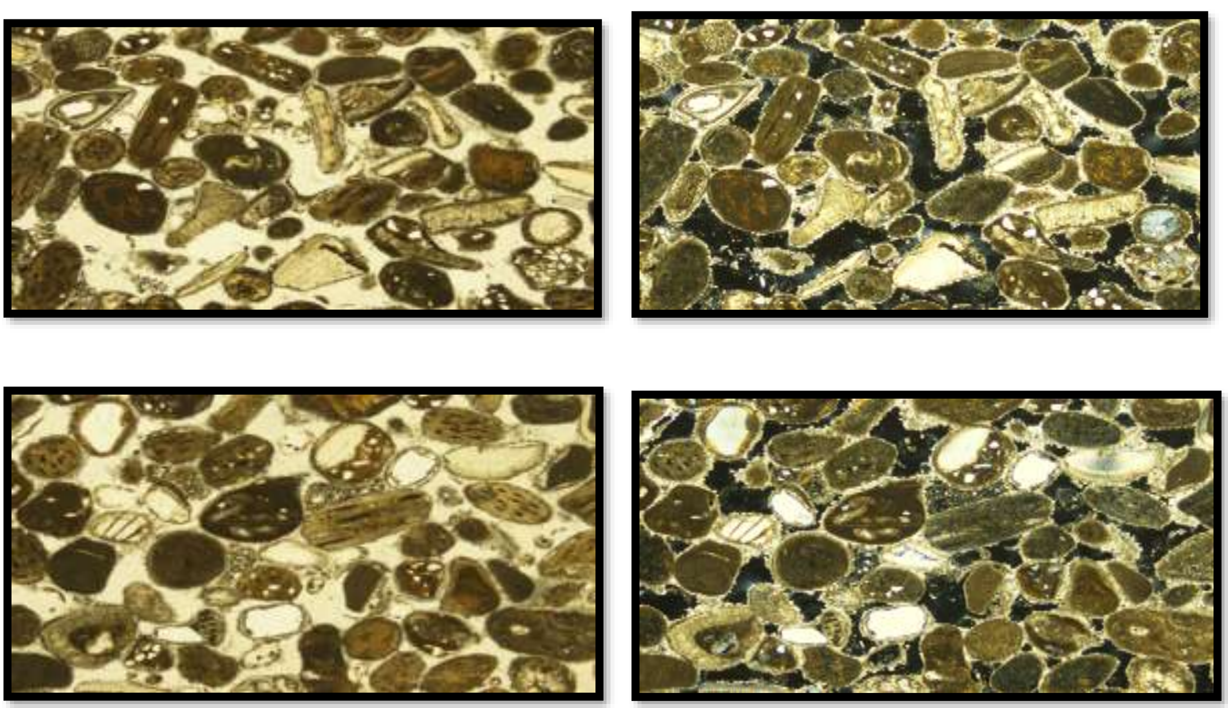

Figure (5) Photomicrograph showing weathered samples Calcarenite Biosparite calcite cement affected by lichens with intensive dissolution

In addition to biological activity, environmental factors significantly contribute to the observed deterioration. The coastal Mediterranean setting of Sabratha exposes the stone to marine aerosols, resulting in salt crystallization within pore spaces. This process, combined with cyclic fluctuations in moisture and temperature, intensifies internal stresses and accelerates stone decay [7,9]. The interaction between salt weathering and biological activity represents a synergistic mechanism, amplifying the overall degradation process beyond the effect of each factor individually.

The magnitude of carbonate loss observed in this study is consistent with, and in some cases slightly higher than, values reported in comparable Mediterranean environments [5,6]. This suggests that the combined influence of coastal exposure conditions of low compaction calcarenite rocks and biological colonization at Sabratha creates a particularly aggressive weathering regime that accelerates both chemical and mechanical deterioration.

Although lichen-induced weathering is generally a slow process, its cumulative impact over time is highly significant. Continuous biochemical alteration, coupled with mechanical disruption, can lead to irreversible material loss and long-term structural weakening. Therefore, biodeterioration should be considered a critical factor in the degradation of stone cultural heritage rather than a superficial or secondary process [3].

It is also important to recognize that lichens may play a dual role in stone weathering. While they are commonly associated with deterioration, the formation of biomineral crusts may, in some cases, provide temporary protection against environmental exposure. This duality highlights the need for balanced and site-specific conservation strategies, rather than the indiscriminate removal of all biological colonization [16].

Overall, the deterioration of calcarenite at Sabratha reflects a complex geo-biological system in which chemical, physical, and biological processes are tightly interconnected. A comprehensive understanding of these interactions is essential for the development of effective, sustainable, and context-specific conservation strategies aimed at preserving Mediterranean archaeological heritage.

5. Conclusion

This study provides a preliminary yet critical assessment of the damage caused by *Caloplaca* lichens to the archaeological stones of Sabratha. The substantial loss of carbonate content and the disruption of the stone fabric demonstrate that biological weathering is major factor in the site's deterioration. Preserving this human cultural heritage requires a deeper understanding of these biological interactions to develop effective and sustainable conservation strategies.

6. References

1 Matthews, S., & Cook, J. P. (1975). *The Geology of the Sabratha Area*.
2 Ilich, M., & Smykatz-Kloss, W. (1980). *Weathering of Calcarenite in Archaeological Sites*.
3 Gorbushina, A. A., & Krumbein, W. E. (2004). *The Role of Microorganisms in the Deterioration of Cultural Heritage*.
4 Taylor, T. N., et al. (1995). *The History of Lichens*.
5 Reboah, P. (2024). The biological contribution to the weathering of limestone monuments in a vegetated urban area: results of a 5-year exposure. *Scientific Reports*, 14, 1388.
6 Sanjurjo-Sánchez, J. (2024). Biomineral deposits and coatings on stone monuments as products of biodeterioration. *Science of the Total Environment*, 906, 167475.
7 Abu-Ella, M. (2006). *Climatic Conditions of the Libyan Coast*.
8 De los Rios, A. (2014). *Physical Damage of Lichens on Stone Substrates*.
9 Canali, G. (2025). Lichen hydration, moisture dynamics and climate change. *Journal of Cultural Heritage*, 71, 100-115.
10 Tiano, P. (2016). *Biodeterioration of Stone Cultural Heritage*.
11 Jones, D., & Wilson, M. J. (1985). *Chemical Weathering of Minerals by Lichens*.
12 Zabihi, M. (2025). Lichen colonization and associated biodeterioration: Application of the lichen model to understanding mineral weathering. *PNAS*.
13 Alnnale, T. (2026). Predictive Governance in Digital Enterprises: An LSTM-Enhanced Deep Learning Framework for Economic Optimization of IT Incident Management Using Enriched Process Logs. *Al-Farooq Journal of Sciences*, *2*(3), 86-113.
14 Wilk, K. (2012). *The Genus Caloplaca in Mediterranean Environments*.
15 Adamo, P., & Violante, P. (2000). *Chemical Modification of Mineral Rocks by Lichens*.
16 Acquavia, M., Cardellicchio, F. & Curcio, M. (2025). XPS Monitoring of Calcarenite Building Walls Long-term Deterioration. *Applied Sciences*, 15(14), 7741.
17 Cicardi, M. (2025). Recolonization dynamics of lichens after innovative and traditional conservative treatments of archaeological stones. *International Biodeterioration & Biodegradation*, 198, 105962.