

Gravestone Guardians Technical Note No. 1

Biofilms on Historic Marble: Cyanobacteria, Gloeocapsa, and the Myth of Harmless Biological Growth

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A 501(c)(3) nonprofit organization dedicated to the preservation, documentation, restoration, and interpretation of historic cemeteries through education, research, and hands-on conservation.

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Abstract

Biological growth on historic marble is often described either as harmless staining or as an organism that “eats” calcium carbonate. Both descriptions are incomplete. Cyanobacteria, algae, fungi, bacteria, and other organisms can form biofilms in which cells are embedded in extracellular polymeric substances (EPS) that promote adhesion, retain moisture and particulates, and create a chemically active microenvironment at the stone surface. These effects may contribute to deterioration, particularly where marble is already roughened, microfractured, granular, or persistently damp. Cyanobacteria are significant because they can colonize nutrient-poor mineral surfaces and support more complex microbial communities. The organism commonly called *Gloeocapsa magma*—now accepted as *Gloeocapsopsis magma*—is frequently associated with dark exterior staining, but visual appearance alone cannot establish species identity. This technical note explains the conservation significance of cyanobacterial biofilms, rejects the oversimplified “eating stone” model, and presents a condition-based approach to treatment, prevention, and maintenance. Its central premise is that biological control should be pursued only when warranted and with the least possible loss of historic marble.

Keywords: historic marble; gravestone conservation; cyanobacteria; *Gloeocapsa*; *Gloeocapsopsis magma*; biofilm; extracellular polymeric substances; biodeterioration; biological growth; stone conservation

Disclaimer

This technical note supports informed care of historic marble gravestones and monuments. It summarizes scientific and conservation literature but does not replace monument-specific assessment by a qualified conservator or other appropriate specialist. Marble that is actively sugaring, flaking, delaminating, structurally unstable, or losing surface material may require stabilization or professional evaluation before cleaning. Product references are included for technical discussion only; current manufacturer instructions, site permissions, safety requirements, and accepted conservation practice should govern use.

1. Introduction: When “Dirty” Is Actually Biological

Historic marble gravestones are continuously altered by weather, atmospheric deposits, soil splash, vegetation, soluble salts, and repeated wetting and drying. Among the most visible changes is the development of green, gray, brown, or black biological growth. In everyday cemetery language this material may be called dirt, mold, mildew, algae, or lichen, but some darkened surfaces are better understood as biologically active communities rather than simple deposits.

Microorganisms on stone can form biofilms: attached communities containing cyanobacteria, algae, fungi, bacteria, and other organisms embedded in extracellular material. Such films can obscure inscriptions, retain moisture and particulates, and modify chemistry immediately adjacent to the stone. Their conservation significance is not uniform. A heavily stained but cohesive marble tablet may be less vulnerable than a lightly colonized stone already undergoing granular disaggregation. Likewise, a visible film may be largely aesthetic in one setting but persistent and moisture-associated in another (Scheerer et al., 2009; Li et al., 2018).

Two simplifications should therefore be avoided. The first is that biological growth is always harmless because it is natural. The second is that cyanobacteria directly “eat” marble as food. Research instead supports a coupled stone-environment-microorganism model in which biological activity interacts with pre-existing weathering, water availability, carbonate chemistry, and the physical condition of the substrate (Crispim & Gaylarde, 2005; Banerjee & Singh, 2026).

This note focuses on three practical questions: what cyanobacterial biofilms are, how they may affect historic marble, and how they can be managed without causing greater damage through cleaning. The governing conservation principle is straightforward: biological growth should be controlled when it presents a meaningful material or legibility concern, but treatment should sacrifice as little historic fabric as possible.

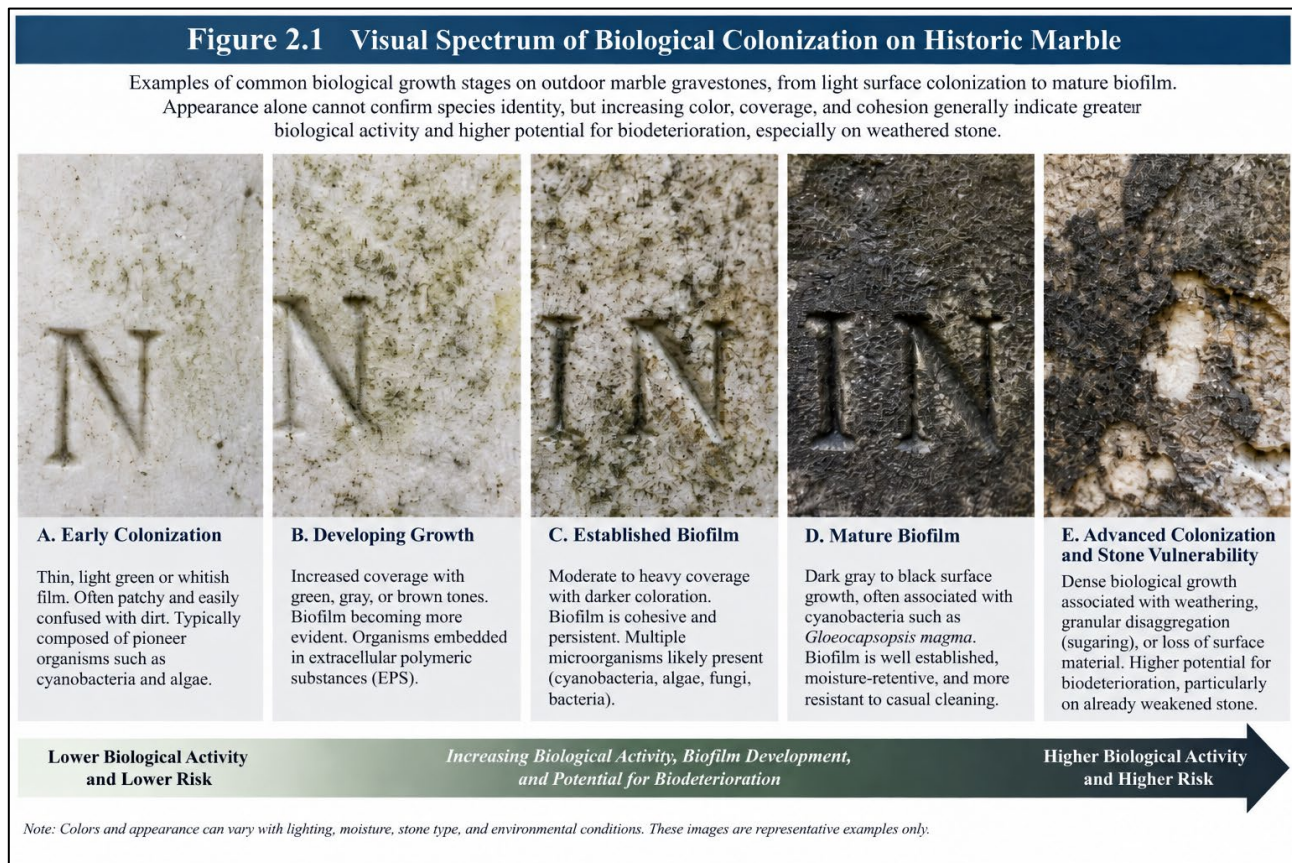
2. What Is a Biofilm?

A biofilm is not merely a group of microorganisms resting on a surface. It is an organized community in which cells adhere to a substrate and become associated with a self-produced matrix of extracellular polymeric substances, or EPS. On stone, EPS commonly includes polysaccharides, proteins, lipids, nucleic acids, and incorporated inorganic material. For cyanobacteria, this matrix improves attachment, reduces desiccation, and helps cells survive cycles of rainfall, drying, intense sunlight, and nutrient limitation (Crispim & Gaylarde, 2005; Li et al., 2018).

The same properties that benefit the organisms can matter to the stone. EPS can retain water and dissolved ions, bind particles and cellular debris, and prolong contact among organisms, mineral surfaces, and environmental deposits. A colonized microdepression may therefore remain chemically and biologically active longer after wetting than an adjacent bare surface. The significance is not that EPS behaves as a permanently saturated sponge, but that the

biofilm can create a local microenvironment whose moisture, pH, ion concentrations, and metabolic products differ from those measured in the surrounding air.

Biofilms are also mixed communities. Photosynthetic organisms such as cyanobacteria and green algae can colonize relatively nutrient-poor surfaces and contribute organic material that supports heterotrophic bacteria and fungi. What appears visually to be a uniform black or green film may therefore include multiple organisms, dead cells, mineral particles, soil, pollen, and atmospheric pollution. This complexity is one reason biological growth cannot be diagnosed reliably by color alone.



Note. Conceptual cross-section showing microorganisms embedded within an EPS matrix containing retained moisture and particulates at the interface with a weathered marble surface. Biofilm thickness, composition, and penetration vary with organism, substrate condition, environment, and time.

3. Cyanobacteria and Gloeocapsa

Cyanobacteria are photosynthetic bacteria historically called “blue-green algae.” Their ability to use light as an energy source, tolerate nutrient-poor conditions, produce protective extracellular material, and recover after periods of desiccation makes them successful colonizers of exposed mineral surfaces. Reviews of cultural-heritage stone report cyanobacteria on marble, limestone, sandstone, granite, travertine, and other substrates, with *Gloeocapsa* among the genera frequently identified (Macedo et al., 2009).

The species commonly discussed in popular exterior-cleaning literature as *Gloeocapsa magma* presents a taxonomic complication. Current taxonomic authorities treat *Gloeocapsa magma* as a synonym of *Gloeocapsopsis magma*. This note therefore uses *Gloeocapsopsis magma* when referring specifically to the accepted species and retains *Gloeocapsa magma* only when discussing older or popular usage (Integrated Taxonomic Information System, n.d.).

The more important conservation caution is diagnostic. Dark staining on a gravestone should not automatically be identified as *G. magma*. Mature stone biofilms may contain several cyanobacterial taxa together with algae, fungi, bacteria, lichens, and nonbiological deposits. Reliable species identification may require microscopy or molecular analysis, and conservation decisions generally do not depend on proving the identity of a single species (Crispim & Gaylarde, 2005; Li et al., 2018).

Field documentation should therefore distinguish observation from identification. Terms such as dark biological film, green biological growth, suspected cyanobacterial biofilm, or mixed biological colonization are appropriate when laboratory identification has not been performed. This restraint strengthens the technical argument: the conservation concern is the behavior of the biofilm and the vulnerability of the stone, not whether a familiar species name can be assigned from appearance.

4. Why Historic Marble Becomes Biologically Receptive

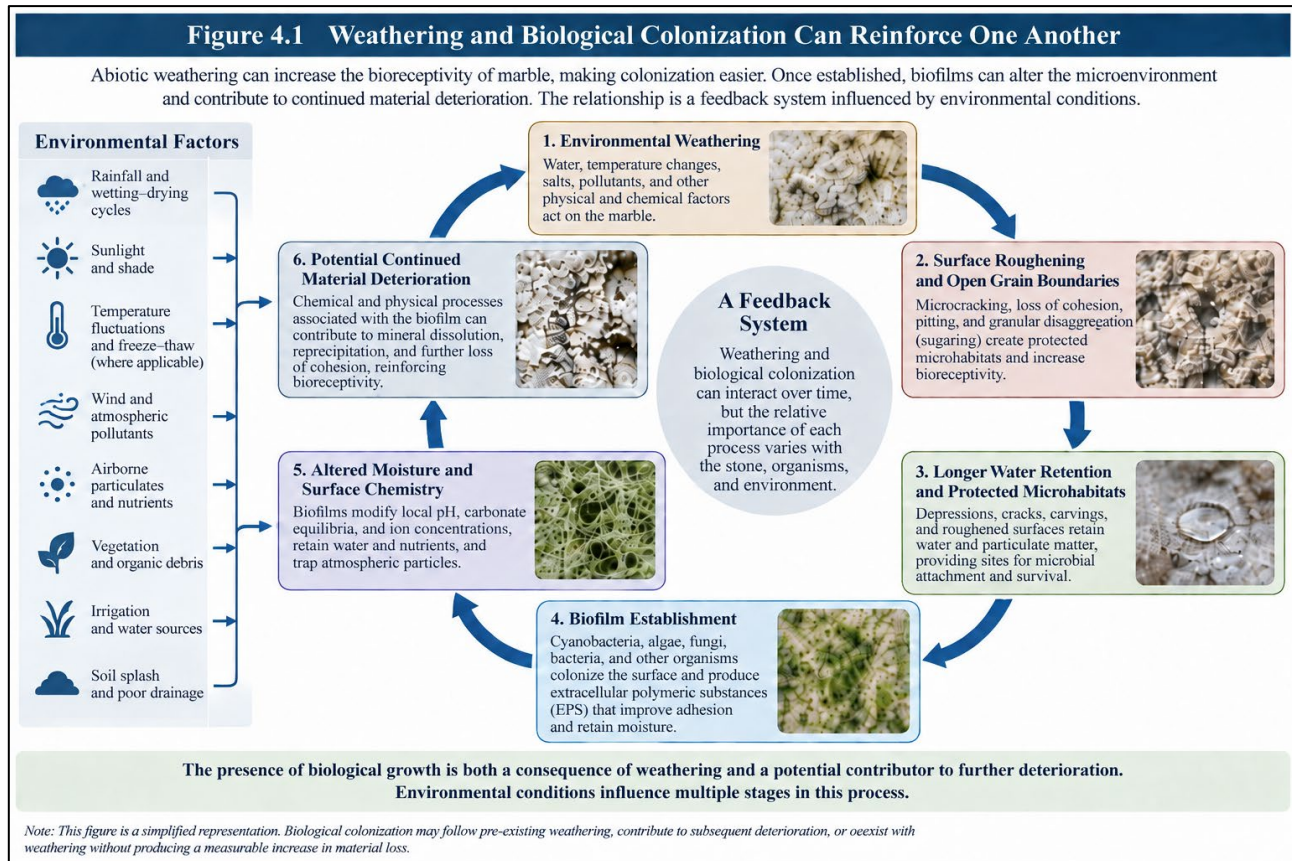
The capacity of a material to support colonization is often described as bioreceptivity. It is influenced by surface roughness, water availability, pore structure, mineral composition, and local microclimate. Weathering can change those properties, so a century-old marble surface may provide a very different habitat from the one originally produced by the stonecutter (Miller et al., 2012).

Historic marble undergoes substantial abiotic weathering before biology is considered. Thermal cycling is especially relevant because calcite crystals expand differently along different crystallographic directions. Repeated heating and cooling can generate stresses at grain boundaries, contributing to microcracking and loss of cohesion. In advanced cases, granular disaggregation or “sugaring” releases individual grains and threatens the carved surface itself (Shushakova et al., 2013).

Such deterioration may increase secondary bioreceptivity by creating pits, fissures, opened grain boundaries, roughened lettering, and protected locations that hold water and particles. Yet the relationship is not simply “rougher stone equals more biology.” Experimental work indicates that roughness, water-accessible pore structure, lithology, and the specific weathering mechanism interact in complex ways (Cubero et al., 2025). The defensible conclusion is that deterioration can alter a stone’s receptivity to colonization, not that all weathered marble will support more growth under all conditions.

Cause and effect should also be assigned cautiously. Microorganisms found in a crack may have created it, enlarged it, or merely occupied a pre-existing defect. In many historic stones, abiotic deterioration and biological colonization form a feedback relationship: weathering

creates sheltered microhabitats, while an established biofilm may retain moisture and alter chemistry within them. Recent microscopy of cyanobacterial biofilms on weathered marble at the Taj Mahal documented biological material within pits, pores, micro voids, and intergranular areas together with localized mineral alteration (Banerjee & Singh, 2026). The study demonstrates intimate association, not proof that biology initiated every defect.

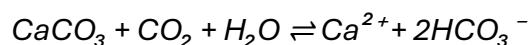


Note. Conceptual feedback loop linking environmental weathering, altered surface properties, moisture retention, biofilm establishment, and potential continued deterioration. The relationship is conditional rather than inevitable.

5. The Myth: “It Eats the Marble”

The common statement that cyanobacteria “eat limestone” or “feed on the calcium carbonate” in marble is memorable but scientifically inadequate. Calcium carbonate is an inorganic mineral, not an organic food source in the conventional sense. Cyanobacteria obtain energy through photosynthesis and fix inorganic carbon; their survival does not require consuming a gravestone as an animal consumes food. The conservation concern instead lies in the chemical and physical conditions created at the biofilm-stone interface.

Calcite already participates in aqueous carbonate equilibria. A simplified reaction is:



Whether calcium carbonate dissolves or precipitates depends on pH, carbon dioxide, temperature, water chemistry, saturation state, and other conditions. A biofilm can alter those conditions at microscopic scale. Photosynthesis consumes inorganic carbon and can

raise local pH, while respiration and metabolites may shift chemistry in other directions. EPS can bind ions and retain dissolved substances close to the surface. Calcium may therefore dissolve, migrate, bind to extracellular material, or reprecipitate without the organisms “eating” the stone (Crispim & Gaylarde, 2005; Li et al., 2018).

This also complicates the claim that cyanobacteria simply attack marble by secreting acid. Acid-mediated dissolution is one possible mechanism within a mixed community, but photosynthetic activity can also favor carbonate precipitation. Heterotrophic bacteria and fungi associated with the biofilm may produce organic acids and chelating compounds, while fungal activity can also produce secondary minerals such as calcium oxalates. The net effect depends on the organisms present and the environmental conditions under which they are active.

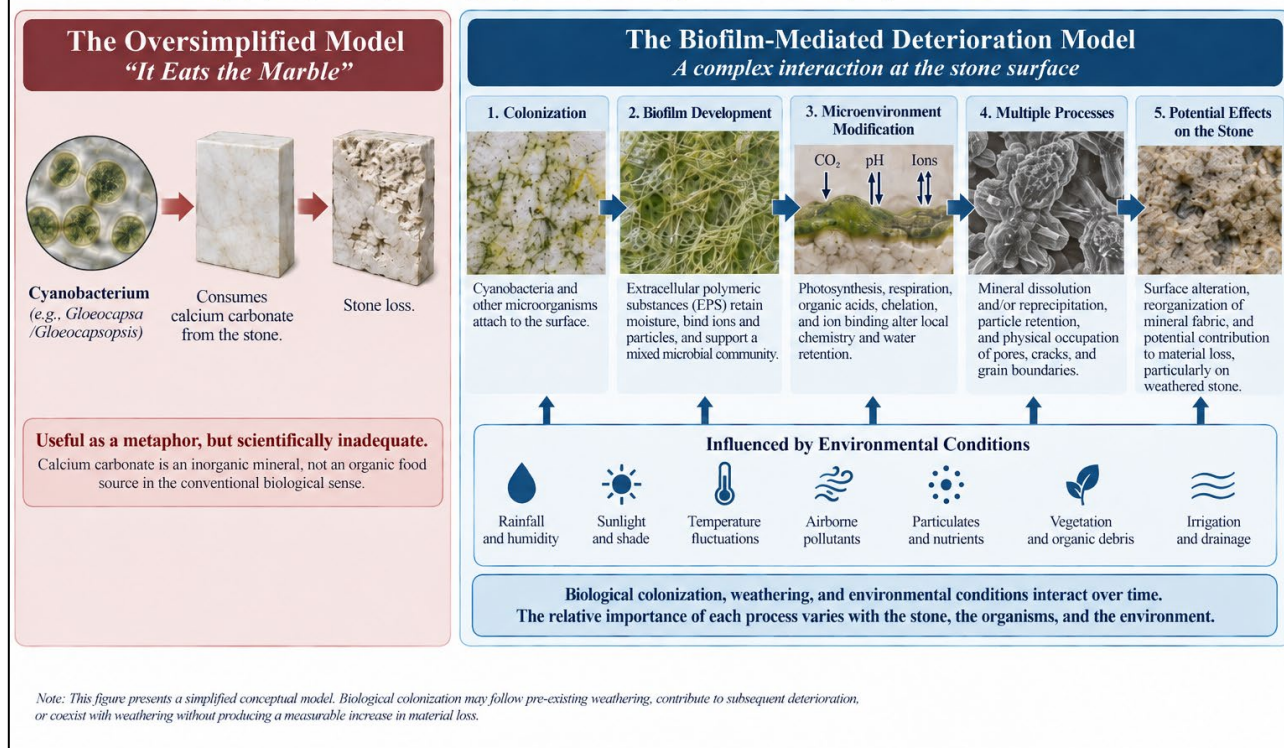
EPS is central to this process because it is more than biological glue. Its chemical groups can bind ions, incorporate mineral particles, and maintain prolonged contact among water, organisms, and the substrate. Repeated wetting and drying can therefore reorganize the stone-biofilm interface through cycles of dissolution, ion movement, and precipitation. Persistent moisture extends the period during which both microbial metabolism and aqueous mineral reactions can occur.

Physical colonization adds another layer. Cyanobacterial cells and filaments may occupy surface depressions, pores, fissures, and intergranular spaces, while fungal hyphae can penetrate existing discontinuities more deeply. Microscopy showing organisms within a defect does not establish whether they caused that defect, but it demonstrates that mature biofilms can become integrated with already weakened surface zones. This has direct treatment implications: mechanical effort sufficient to remove every visible trace may also remove friable marble.

The better deterioration model is therefore biofilm-mediated rather than organism-centered. A photosynthetic colonizer establishes on a receptive surface; EPS improves adhesion and moisture retention; additional organisms join the community; local chemistry changes; ions are mobilized or reprecipitated; and organisms occupy existing defects while abiotic weathering continues. No single mechanism must dominate every case.

Figure 5.1 From “Eating Stone” to Biofilm-Mediated Deterioration

Cyanobacteria do not need to consume marble for their colonization to matter. Biological communities can modify the stone’s microenvironment through physical, chemical, and biological processes, influencing both dissolution and precipitation of calcium carbonate.



Note. Contrast the oversimplified sequence “cyanobacterium → consumes calcium carbonate → stone loss” with a multi-pathway model incorporating EPS, moisture, mixed microbial communities, carbonate chemistry, mineral mobilization/precipitation, and occupation of weathered defects.

Cyanobacteria therefore do not need to “eat” marble for their colonization to matter. Their conservation significance lies in the biologically active microenvironment created at the surface and in the larger community that develops within it.

6. Cosmetic Growth Versus Conservation Concern

Recognizing that biofilms can participate in deterioration does not mean that all biological growth is inherently destructive. Reviews of lithobiontic communities describe both biodeteriorative and, under particular conditions, potentially protective effects. Some surface communities or mineralized patinas may moderate rainfall impact, thermal fluctuations, or direct exposure of the substrate (Favero-Longo & Viles, 2020; Liu et al., 2022). This does not justify encouraging biological growth on gravestones; it does mean that intervention should be based on observed conditions rather than an assumption that biology is always harmful.

Aesthetic alteration should also be distinguished from material deterioration. Biological growth may obscure names, dates, carving, or tooling without producing demonstrable structural damage. Loss of legibility can itself justify treatment, but it should not be described as proof that the marble is being chemically destroyed. Conversely, a thin film on a

persistently damp, friable surface may deserve greater concern than a conspicuous film on sound marble.

The vulnerability of the substrate should therefore determine the permissible aggressiveness of treatment. A heavily blackened but cohesive tablet may tolerate careful cleaning better than a lightly colonized stone that is actively sugaring. High conservation concern should trigger greater diagnostic care, not greater cleaning force.

Table 6.1 — Condition-Based Interpretation of Biological Growth

Concern	Typical Condition	Recommended Response
Low	Light or discontinuous growth on sound, rapidly drying marble; inscriptions remain legible.	Document and monitor.
Moderate	Established or recurring biofilm, prolonged dampness, trapped debris, or obscured inscriptions.	Controlled treatment where the substrate permits; investigate environmental causes.
High	Significant colonization with sugaring, scaling, friability, cracking, or severe surface loss.	Limit handling; assess stability; consider specialist evaluation or stabilization before cleaning.

The treatment threshold is therefore condition-based rather than appearance-based. The relevant question is not simply whether organisms are present, but whether the biofilm is creating a meaningful material, legibility, or moisture-management concern and whether intervention can reduce that concern without disproportionate loss of original stone.

7. Treatment: Control the Biofilm Without Removing the Marble

Once treatment is justified, the objective is to control the biofilm while preserving the marble beneath it. This differs from cosmetic cleaning. A treatment can create a dramatic visual improvement and still be poor conservation if it removes grains, roughens the surface, leaves damaging residues, or establishes a cycle of unnecessary repeated cleaning.

Assessment comes first. Marble should be examined for sugaring, scaling, flaking, delamination, cracks, friable carving, unstable repairs, and active material loss. If grains release under very light contact or gentle wetting, routine brushing is difficult to justify. Cleaning conditions also matter: water-based treatment should be avoided when freezing is possible, while excessive heat or direct sun can cause cleaners to dry prematurely (National Park Service [NPS], 2025a).

Where established biological growth warrants chemical control, selection should be based on the performance of the complete formulation rather than the generic name of an active ingredient. NPS/NCPTT comparative testing found specific quaternary-ammonium-based biocidal formulations, including D/2 Biological Solution, effective for biological growth on marble headstones. That evidence does not mean that all quaternary ammonium products are interchangeable; concentration, buffers, surfactants, residue behavior, and compatibility differ among formulations (NPS, 2025b).

Treatment protocols should also be distinguished clearly. NPS guidance recommends thoroughly pre-wetting marble, applying a compatible cleaner, using gentle agitation where the stone permits, and thoroughly rinsing. Current D/2 manufacturer instructions provide an immediate-result method with dwell time, agitation, water misting, rinsing, and light reapplication, as well as a no-scrub/no-rinse method intended to act over time (D/2 Biological Solutions, Inc., 2026). These procedures should not be blended into one supposedly universal method. Manufacturer instructions, conservation guidance, and monument-specific judgment serve related but distinct purposes.

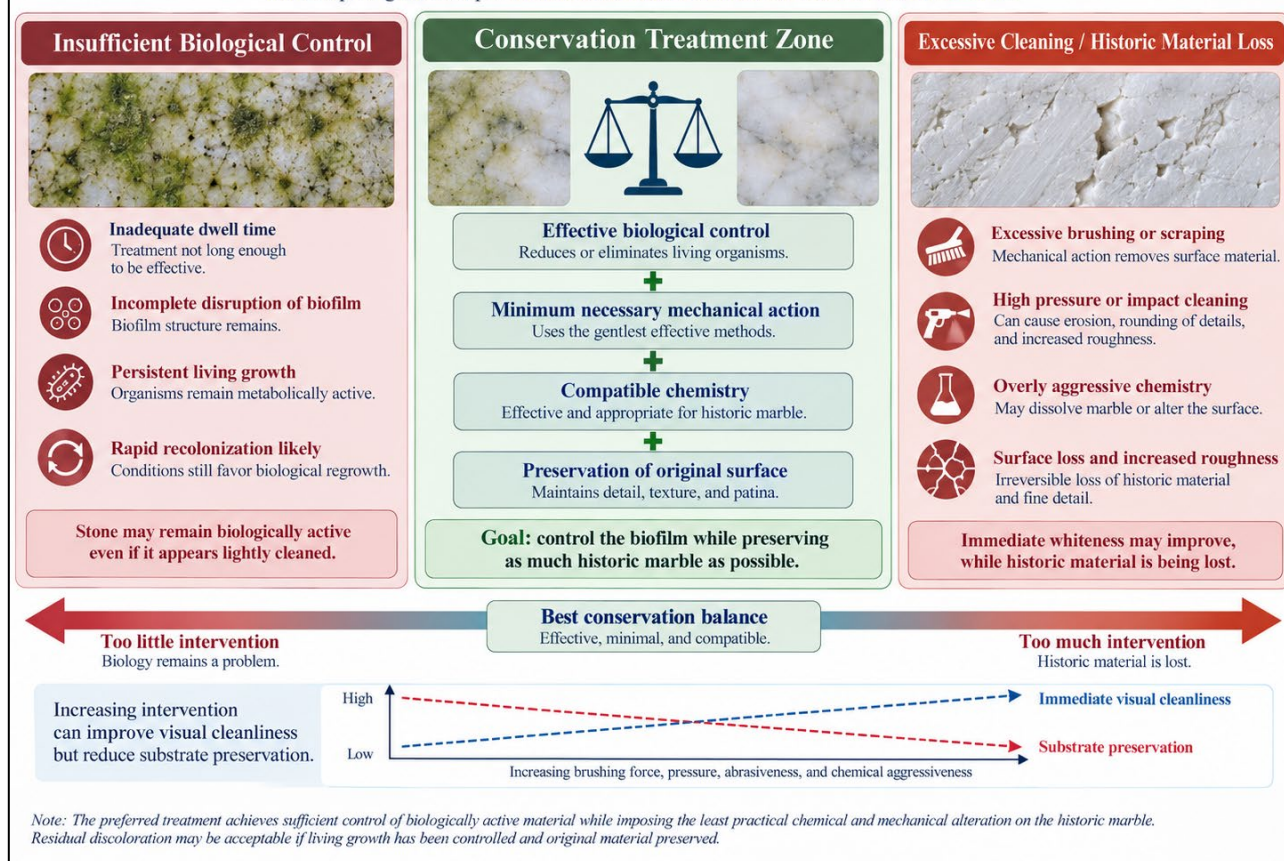
Dwell time should replace unnecessary scrubbing force. If a compatible biocide is doing the chemical work, mechanical action can often be reduced. Soft natural or appropriate synthetic bristles may be used where the marble remains cohesive, but cleaning should stop if grains or powder are released. Wire brushes, abrasive pads, powered brushes, and forceful scraping are inappropriate for historic marble.

Where a rinse-based protocol is used, rinsing is part of the treatment rather than an incidental final step. Adequate clean water should be available before work begins, and pressure should remain low enough to avoid erosion. The purpose of water is wetting and transport, not impact cleaning.

Finally, immediate whiteness is not a valid measure of success. Biological death, pigment change, and visual clearing do not occur simultaneously. NPS and D/2 both note that treated surfaces may continue to lighten after cleaning. Continuing to scrub solely to accelerate that change can remove historic material for no conservation benefit (NPS, 2025a; D/2 Biological Solutions, Inc., 2026).

Figure 7.1 Treatment Must Control Biology Without Removing Marble

Visual cleanliness and conservation performance are not equivalent. The preferred treatment achieves sufficient biological control while imposing the least practical chemical and mechanical alteration on historic marble.



Note. The preferred treatment zone balances effective biological control with compatible chemistry, adequate dwell time, minimal mechanical action, and preservation of the original surface.

8. Treatments That Create a Greater Conservation Problem

A cleaning method should not be judged successful merely because it kills microorganisms or produces a white surface. The relevant question is whether it controls biology without creating a more serious deterioration mechanism.

Sodium hypochlorite bleach is an effective oxidizing disinfectant, but NPS/NCPTT guidance advises against bleach-based products for marble headstones because of concerns about soluble residues and subsequent material damage. Bleach should not be mislabeled as an acid—household sodium hypochlorite is typically alkaline—but its biocidal effectiveness does not make it conservation-compatible (NPS, 2025a, 2025b).

Acidic cleaners pose a more direct chemical problem because hydrogen ions react with calcite. Vinegar, acidic bathroom cleaners, and acidic rust removers can dissolve the same calcium carbonate that forms inscriptions and carved detail. A brightened surface may therefore reflect microscopic material removal rather than safe cleaning.

Strong bases and poorly characterized household detergents are likewise inappropriate default choices. Familiarity does not establish compatibility with historic stone, and proprietary products may contain surfactants, salts, fragrances, chelators, or other additives not evaluated for marble conservation.

Aggressive mechanical methods create a different but equally serious risk. Wire brushes, abrasive pads, sanding devices, grinders, powered brushes, and forceful scraping clean by abrading the substrate. Freshly abraded white marble may look impressively clean while having lost original polish, tooling, edges, and weakened grains. Increased roughness can also change subsequent soiling and bioreceptivity.

High-pressure washing presents similar concerns. NPS distinguishes low-pressure wetting and rinsing from commercial pressure washing and warns that high pressures can damage marble. No pressure value should be treated as universally safe for weathered gravestones; stone condition governs what the surface can tolerate (NPS, 2025a).

Finally, biological prevention does not justify indiscriminate coatings or sealers. Water repellents and polymer films can alter wetting, drying, vapor transport, appearance, and future retreatability, while recolonization may still occur. Environmental moisture management should be considered before permanent alteration of the historic surface (Pinna, 2023).

9. Can Biological Regrowth Be Prevented?

Permanent biological prevention on an outdoor gravestone is generally unrealistic. Microorganisms are continually introduced by air, rain, soil splash, vegetation, insects, birds, and adjacent surfaces. A cleaned stone therefore becomes a newly available substrate within the same environment that supported colonization before treatment.

The most useful preventive variable is often water. Cyanobacteria require moisture for active metabolism, and studies of stone bioreceptivity repeatedly identify water availability, humidity, drying behavior, porosity, roughness, and shade as important controls on colonization (Miller et al., 2012). For cemetery monuments, moisture may come from irrigation, soil contact, splash back, dense vegetation, poor drainage, horizontal ledges, or shaded surfaces that dry slowly.

Preventive conservation should therefore ask why a particular portion of a monument remains wet. Where appropriate, irrigation can be redirected, organic debris removed, vegetation kept from direct contact with stone, and drainage problems investigated. Such measures should remain proportionate to the historic landscape; removing significant trees or radically changing cemetery character simply to keep marble brighter may sacrifice one heritage value for another.

A weathered surface cannot safely be made biologically unreceptive by grinding, polishing, or coating it back to a new appearance. Historic roughness and porosity are part of the surviving fabric. Prevention should modify avoidable environmental stressors before it modifies original stone.

Residual biocidal activity may delay recolonization, but it does not provide permanent immunity. NPS/NCPTT testing documented persistent antimicrobial activity from some products, while longer-term reviews show that recolonization varies with substrate, treatment, climate, and local ecology (NPS, 2025b; Prieto et al., 2024). The appropriate expectation is therefore suppression and longer treatment intervals, not permanent sterility.

10. Preventive Treatment Versus Condition-Based Maintenance

If recolonization is inevitable, maintenance should be based on condition rather than a fixed cleaning calendar. NPS guidance that historic headstones should, where possible, not be cleaned more frequently than once per year establishes an upper boundary for routine cleaning; it does not prescribe annual cleaning for every monument (NPS, 2025a). Manufacturer guidance may recommend periodic applications to maintain a stain-free appearance, but appearance maintenance and preservation-driven biological control are not identical objectives.

For historic marble, the preferred cycle is:

Inspect → Document → Compare → Diagnose → Treat only when warranted → Reassess

Inspection can occur on a regular schedule even when treatment does not. Consistent photographs and brief condition notes allow the practitioner to determine whether growth is increasing, whether the surface remains damp longer than before, whether inscriptions are becoming obscured, whether irrigation or vegetation has changed, and whether the marble itself is becoming less cohesive.

Rapid recolonization should be treated as diagnostic information. It may indicate chronic moisture, dense shade, accumulated organic material, ineffective treatment, or a highly receptive weathered surface. Simply shortening the cleaning interval can conceal these causes while increasing cumulative intervention.

The practical distinction is important: a monument may warrant annual inspection without annual chemical treatment. Scheduled observation preserves the benefits of regular maintenance while allowing stable stones to remain untreated.

11. A Practical Decision Framework

The preceding discussion can be reduced to a field decision sequence without turning conservation judgment into a rigid recipe.

First, confirm that the observed material is reasonably interpreted as biological. Mineral crusts, metallic staining, soil, coatings, and old treatment residues may mimic biological deposits. Species-level identification is usually unnecessary, but the treatment should address the actual condition present.

Second, assess substrate stability. If the marble is actively sugaring, flaking, delaminating, structurally unstable, or releasing grains, routine cleaning should stop pending stabilization or specialist assessment.

Third, determine whether the colonization creates a meaningful conservation or legibility concern. Light, stable growth on sound marble may warrant monitoring. Persistent growth

associated with dampness, trapped debris, obscured inscriptions, or vulnerable surface fabric provides a stronger treatment rationale.

Fourth, investigate avoidable environmental moisture sources such as irrigation, soil contact, vegetation, splash back, or poor drainage.

Fifth, when treatment is justified, select the least damaging effective system: test first; pre-wet where required by the chosen protocol; apply a documented compatible biocide; allow sufficient dwell time; use only the mechanical action the stone can tolerate; rinse where the protocol requires; and allow delayed visual clearing before deciding that additional treatment is necessary.

Finally, monitor the result. Recolonization rate, moisture pattern, and substrate condition are more informative than whether the stone remains visually white.

12. Conclusions

Biological growth on historic marble should be neither dismissed as harmless coloration nor described as a single organism consuming the monument. Cyanobacteria can establish biofilms in which EPS, retained moisture, associated microorganisms, and localized chemical processes create a microenvironment different from that of exposed marble. On weathered stone, these communities may interact with pits, fissures, and weakened grain boundaries, but the degree and direction of damage vary with substrate condition and environment.

The familiar name *Gloeocapsa magma* should also be used cautiously. *Gloeocapsa* and related cyanobacteria are well documented on cultural-heritage stone, but dark growth cannot reliably be identified as *Gloeocapsopsis magma* by appearance alone. Conservation decisions should be based on the observed biofilm, moisture environment, and condition of the marble rather than speculative species identification.

The same condition-based reasoning should govern treatment. A compatible biocide and adequate dwell time can reduce the need for abrasion, but no cleaner compensates for an unstable substrate. Conversely, not every colonized stone requires immediate intervention. Monitoring may be the least damaging choice when growth is light and the marble remains stable.

Long-term control is therefore a management problem rather than an eradication problem. Outdoor stone will recolonize. The most durable strategy is to reduce avoidable moisture, inspect regularly, treat only when conservation significance warrants it, and evaluate success by preservation of historic fabric rather than permanent whiteness.

A clean stone is not necessarily a conserved stone. Successful biofilm management controls biological growth when it presents a meaningful concern while sacrificing as little historic marble as possible.

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Appendix A

Field Identification and Documentation Guide

Use this guide to document observable biological conditions and the condition of the marble before deciding whether treatment is warranted. Field descriptions should remain observational unless organism identification is supported by microscopy or molecular analysis.

Documentation element	Record
Site and monument	Cemetery/site: _____ Monument/marker ID: _____ Name/inscription: _____ Date/time: _____ Observer(s): _____ Face/orientation: _____
Observed surface condition	Color(s): _____ Distribution: localized / patchy / widespread / uncertain Approximate coverage: <10% / 10–25% / 25–50% / >50% Field description: dark biological film / green biological growth / suspected cyanobacterial biofilm / mixed biological colonization / lichen or moss / uncertain deposit
Moisture and environment	Surface dry / damp / wet at inspection Shade: low / moderate / heavy Possible moisture sources: rainfall retention / irrigation / soil splash / soil or turf contact / vegetation contact / poor drainage / horizontal ledge or carving / other: _____ Does this area dry more slowly than adjacent stone? yes / no / unknown
Marble condition	Cohesive / minor weathering / granular or sugaring / scaling or flaking / delamination / cracking / open grain boundaries / friable carving / previous repair / coating or unknown treatment / structural instability Are grains released by very light contact or gentle wetting? yes / no / not tested
Conservation significance	Legibility affected? yes / no Surface detail obscured? yes / no Persistent or recurring growth? yes / no / unknown Trapped debris present? yes / no Evidence of repeated wetness? yes / no / unknown Rapid recolonization after prior treatment? yes / no / unknown
Photographic record	Capture: full monument; each affected face; close detail with scale; surrounding grade/vegetation; moisture source if present. For monitoring, repeat the same viewpoints and approximate lighting when practical.

Documentation element	Record
Initial disposition	Monitor only / environmental correction / small test treatment / controlled cleaning / specialist conservation assessment / stabilize before cleaning Reason for disposition:

Field identification note. Do not record a dark film as *Gloeocapsopsis magma* solely from color or gross appearance. Where species-level identification has not been performed, use descriptive terms such as “dark biological film,” “suspected cyanobacterial biofilm,” or “mixed biological colonization.”

Appendix B

Treatment Record

Use one record for each treatment event. The purpose is to document what was done, why it was done, how the stone responded, and what should be evaluated at follow-up.

Treatment element	Record
Identification	Cemetery/site: _____ Monument/marker ID: _____ Date: _____ Treatment team: _____
Conditions	Air temperature: _____ Stone/surface condition: dry / damp / wet Weather: overcast / sun / wind / recent rain / other: _____ Freezing conditions present or expected? yes / no
Pre-treatment assessment	Biological condition: _____ Marble condition: cohesive / weathered / sugaring / scaling / flaking / cracking / friable / other: _____ Reason treatment is warranted: legibility / persistent growth / moisture-holding biofilm / recurring growth / other: _____
Test area	Test location: _____ Result acceptable? yes / no Observed adverse response, if any: _____
Product and protocol	Product: _____ Manufacturer: _____ Concentration/dilution: _____ Lot/batch if recorded: _____ Protocol followed: NPS rinse-based / manufacturer immediate-result / manufacturer no-rinse / other documented protocol: _____
Application	Pre-wet performed? yes / no / not applicable Water source: _____ Application method: spray / brush / other: _____ Dwell time: _____ Surface kept wet during dwell where required? yes / no / not applicable
Mechanical action	Brush/tool type: _____ Agitation: none / very light / light / moderate Scraping used? no / limited after softening / other: _____ Any marble grains or powder released? yes / no If yes, treatment stopped? yes / no

Treatment element	Record
Rinsing and completion	Rinsed? yes / no / not required by protocol Rinse method/pressure: _____ Number of applications: _____ Residual staining intentionally left to avoid over-cleaning? yes / no Immediate observations: _____
Follow-up	Recommended reassessment date: _____ After drying/delayed clearing: biological reduction satisfactory / partial / uncertain Recolonization at follow-up: none / light / moderate / heavy Environmental issue requiring correction: _____
Documentation	Before photos: yes / no During-treatment photos: yes / no After photos: yes / no File/location or record number: _____

Stop criterion. If cleaning begins to release marble grains, soften carved edges, expose increasing friability, or otherwise remove historic material, additional visual improvement does not justify continued mechanical action.

Appendix C

Terminology

The following terms are used consistently throughout this technical note. Definitions are intentionally concise and oriented toward field interpretation and conservation decision-making.

Term	Working definition
Biofilm	A surface-associated microbial community embedded in a self-produced extracellular matrix. On stone, a biofilm may include cyanobacteria, algae, bacteria, fungi, cellular debris, trapped particulates, and mineral material.
Cyanobacteria	Photosynthetic bacteria historically called “blue-green algae.” Many species tolerate nutrient limitation, intense light, desiccation, and repeated wetting and drying.
<i>Gloeocapsa</i>	A cyanobacterial genus reported in cultural-heritage biofilms. Genus-level reports should not be assumed to identify <i>Gloeocapsopsis magma</i> .
<i>Gloeocapsopsis magma</i>	The currently accepted name for the species historically called <i>Gloeocapsa magma</i> . Dark staining alone is insufficient for species-level identification.
Extracellular polymeric substances (EPS)	The polymer-rich matrix surrounding many biofilm organisms. EPS promotes adhesion, can retain moisture and particulates, and can bind ions at the stone-biofilm interface.
Bioreceptivity	The capacity of a material to support biological colonization. It is influenced by properties such as surface condition, roughness, water availability, pore structure, and microclimate.
Primary / secondary / tertiary bioreceptivity	Primary bioreceptivity reflects inherent material properties; secondary bioreceptivity reflects changes caused by weathering or deterioration; tertiary bioreceptivity reflects changes caused by treatments or other human interventions.
Biodeterioration	Material alteration in which biological activity contributes to deterioration. The term does not imply that every biological film is actively or measurably damaging the stone.
Bioprotection	A condition in which a biological community or biologically influenced surface layer reduces a particular weathering process. Possible bioprotection does not mean biological growth should generally be encouraged on gravestones.
Colonization	Establishment and persistence of organisms on or within a material. Visible color or coverage alone does not determine the conservation significance of colonization.
Microhabitat	A small localized environment whose moisture, shade, geometry, or surface condition differs from surrounding areas and can favor biological persistence.

Term	Working definition
Recolonization	Return of biological growth after cleaning or treatment. Recolonization is expected outdoors and should be interpreted in relation to rate, location, moisture, substrate condition, and prior treatment.
Sugaring / granular disaggregation	Loss of cohesion among marble grains, causing the surface to feel granular or powdery and making original material vulnerable to removal during cleaning.
Dwell time	The period a treatment product remains in contact with the biological deposit before agitation, rinsing, or the next treatment step, as specified by the applicable protocol.
Condition-based maintenance	A management approach in which inspection may occur on a schedule but treatment is triggered by observed conservation need rather than by elapsed time alone.
Substrate	The historic stone surface or material beneath the biological growth or treatment layer.

Usage note. In field records, observation should be separated from taxonomic identification. Use the most specific term supported by the available evidence.