Geophysical Research Abstracts,
Vol. 10, EGU2008-A-08961, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-08961
EGU General Assembly 2008

The effects on ornamental stone consolidation by the growth of the bacteria that inhabit the stone

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Progressive deterioration of the built and sculptural heritage represents a problem that considerable resources have attempted to address and manage. There are numerous treatments based on the application of a consolidating agent to the substrate that result in the organic and/or inorganic precipitation of new cement within the porous system of deteriorated ornamental stone. However, the effects of such treatments have not been as encouraging as expected because of the compositional and textural complexities encountered. The observed incompatibility of most organic consolidants has prompted the search for more compatible (inorganic) and effective conservation treatments in recent years. Among such new conservation treatments, there is a new promising procedure to consolidate ornamental stone that makes use of bacterially induced mineralization (Castanier et al., 2000; Rodriguez-Navarro et al., 2003; Jimenez-Lopez et al., 2007). Despite the success of the restoration procedures which involve the application of a bacterial-inoculated culture medium to improve the degree of stone consolidation, these procedures, nevertheless, are technically problematic since they require a specialized person/equipment to manipulate the product so that the conditions for bacterial growth are optimal. Because the stones being treated are not sterile and may contain microorganisms that can induce calcium carbonate precipitation (Urzi et al., 1999), a simpler, more user-friendly restoration procedure would be to apply a non-inoculated culture medium that could activate, from within the microbial community of the stone, only those bacteria that induce the extracellular formation of

calcium carbonate.

The present study describes a new method, specially oriented to protect and to increase the consolidation of new pieces of stone that are going to replace damaged ones in restoration procedures, in order to make the new piece more resistant to deterioration. Specifically, this study determines the effects on the consolidation of quarry and non-degraded porous limestone following the application of a culture medium to the stone whose natural microbial community has not been eliminated.

Quarry, non-degraded calcarenite stone slabs were introduced in Erlenmeyer flasks containing culture medium and incubated at 28ºC for 30 days. Several of these Erlenmeyer flasks were incoculted with *Myxococcus xanthus*, a non-pathogenic, common soil bacteria. Aliquots of the culture medium were taken under aseptic conditions at different time intervals during the time course experiment. At the end of the experiment, stone slabs were collected, rinsed and dried. Then, the mineralogy of the new precipitate was analyzed by XRD. Also, Scanning Electron Microscopy analyses were performed on both the surfaces and cross-sections of the non-treated and treated stones, to determine homogeneity and depth penetration of the newly formed calcium carbonate. Consolidation tests and measurements of the porosity of the treated stone were carried out and compared to those of the non-treated samples.

Our results show that the tested culture media were able to activate, among the microbial community of the stone, those bateria that are able to induce the precipitation of calcium carbonate. This occurred because the culture media used in our experiments enhanced the growth of chemoorganotrophic bacteria that use amino acids as a source of carbon, nitrogen and energy, thus inducing the alkalinization of the culture media by the oxidative deamination of such amino acids. The newly formed calcium carbonate was compatible with the substrate and consolidated the stone with no pore plugging. These results were enhanced were *M. xanthus* was present in the culture media. Since the bacteria activated in our experiments have been commonly found in natural environments and in other ornamental rocks from different locations and being calcarenite one of the most common and widely used ornamental stone (particularly in the Mediterranean Basin) the proposed method to consolidate calcarenite seems to have the potential to be used in a broad range of locations. This is the first study to propose the use of a bacterial non-inoculated culture medium in the consolidation of newly-quarried stone.

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