WEATHERING OF BUILDING MATERIALS OF THE GIRALDA (SEVILLE, SPAIN) BY LICHENS

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ABSTRACT

The weathering of stones and bricks of the Giralda (a Moorish tower) of Seville caused by lichen action has been studied. The most abundant lichens are *Lecania erysibe*, *Caloplaca decipiens*, *Lecanora albescens* and *Xanthoria parietina*. The moss *Tortula muralis* is also present. The role of these organisms in the weathering of urban monuments is discussed.

The most outstanding monument of Seville is without any doubt the Giralda, a Moorish tower with a Christian superstructure. This tower was originally the minaret of the largest Mosque in Seville; it was built between 1184 and 1196 using Roman building stones for the foundations and bricks for the edifice. In 1565-68 the architect Hernan Ruiz added a belfry with 25 bells, with an enormous bronze statue on the top, which serves as a weather vane. The height of the Giralda is 94 metres.

In past centuries the tower suffered from several earthquakes but the greatest damage to it today is caused by weathering of the building stones of the belfry. The belfry walls show evident signs of deterioration, being almost covered with a dark, compact, homogeneous crust, detached in many areas leaving the original yellow limestone exposed to subsequent attacks. A detailed study of this crust is the subject of another communication (Saiz-Jimenez and Bernier, 1981). This paper advances preliminary results on the lichens involved in the deterioration of the belfry.

Centres of urban and old industrial towns support very few lichen species and in the areas of highest pollution buildings, walls and monuments of acid stone, and trees, remain completely uncolonized. Calcareous substrates are more favourable than non-calcareous substrates to bryophyte and lichen colonization. The high pH of such substrates as mortar, asbestos-cement and limestone provides a buffering effect on the toxicity of the urban environment (Seaward, 1975). Thus, the behaviour of lichens in polluted areas is to some extent governed by the nature of the substrate. Species occupying acidic substrates are usually far more sensitive to sulphur dioxide than those present on basic substrates. Sensitive species disappear first from trees and then sandstone walls, while calcareous stones and asbestos-cement roofs retain their flora longest. The urban climate reduces species diversity, and the limited number of lower plants to be found in urban areas have a high reproductive capacity and a tenacious hold on the substrates they colonize (Gilbert, 1973; Seaward, 1979).

Stambolov and van Asperen de Boer (1972) stated that lichens cannot tolerate soot or sulphate and are therefore unlikely to attack buildings and monuments in urban and industrial areas. However, LeBlanc and Rao (1975) reported that the different species of lichens and bryophytes show considerable variations in their susceptibility to injury by air pollution, especially sulphur dioxide. Characteristically, a few species are toxitolerant, taking advantage of the reduced competition, or they may be actually stimulated metabolically by certain pollutants present in the urban and industrial environments.

According to Hueck-van der Plas (1968), lichens are involved in stone weathering in different ways:

(a) through increase of their mass as they grow;
(b) through changes in volume in wet and dry periods resulting in repeated relaxation and shrinking of the colony - this is particularly important for organisms with a strong adhesion to the surface;
(c) through their water-binding capacity, whereby they can exert considerable force in winter frosts;
(d) and finally through the excretion of organic acids.

However, the effectiveness of lichens as agents for rock weathering has been discussed for many years and opinions have varied widely. On the one hand, it has been claimed that both the physical and chemical action of lichen on bare rock surfaces are of great significance and, on the other, that such action has been grossly exaggerated. There is certainly no doubt that lichens are involved in the mineral weathering and the rock/lichen interface is, in fact, an ideal location for the study of the microbiological weathering of minerals since, unlike the situation in soil, the influence of a single organism on any one mineral, or on a variety of minerals, can be easily investigated (Jones et al., 1980).

Syers and Iskandar (1973) have reviewed the ways by which lichens are able to decompose minerals. They concluded that rhizine penetration and thallus expansion and contraction cause mechanical disintegration on the substrate. The significance in biogeochemical weathering of hydrogen ions furnished by the dissolution of carbon dioxide in water is unknown but is expected to be small. Similarly, oxalic acid produced by lichens is probably of minor importance in biogeochemical weathering. Soluble metal complexes are formed when lichen compounds are allowed to react with minerals and rocks in the laboratory. This provides a satisfactory explanation for mineral degradation under experimental conditions but does not appear to have been demonstrated in the field, although chemical and mineralogical changes in the substrate below lichen thalli indicate that this weathering could occur under field conditions.

According to Seaward (1979) information relating to the colonization of algae, bryophytes and lichens on urban buildings is fragmentary and widely scattered in scientific literature, and detailed surveys on the cryptogamic flora have unfortunately not been undertaken in urban areas. Therefore, it appears of interest to investigate the colonization of fresh surfaces by lichens and mosses and specifically their role in the deterioration of the belfry limestone and bricks of the Giralda. Scanning electron microscopy which permits detailed analysis of the structures of these organisms was used (Hale, 1976).

Two differentiated zones can be discerned in the area studied at a height of 50 to 85 metres, which corresponds with the belfry floor to the bronze statue base. One of them comprises the balustrades of four balconies and their limestone ornamentations; the other is made up of the brick and mortar outer walls of these floors.

The limestone supports a species-poor lichen flora, especially when compared with other monuments, as for example the Notre-Dame de l'Epine basilica (Deruelle et al., 1979), composed of Lecania erysibe (Ach.) Mudd, Caloplaca decipiens (Arn.) Jatta, Lecanora albescens (Hoffm.) Floerke, Xanthoria parietina (L.) Betr., Candelariella medians (Nyl.) A.L. Sm., Lecanora dispersa (Pers.) Rohl., Phaeophyscia orbicularis (Neck.) Poetsch, Caloplaca cf. flavovirescens (Wulf.) DT and Sarnth., and Caloplaca dolomiticola (Hue) Zahlbr.

These lichens occur on exposed surfaces, where the supply of water and nutrients is sporadic and, consequently, they may have to withstand periods of desiccation as in summer, when no water is available either as rain or fog. They are located on the front stones oriented to all the four cardinal points. On the southern front Lecanora muralis (Schreb.) Rabenh. is also found.

All the above mentioned species are usually found on flat, perpendicular and sloping surfaces, in the upper parts of the balustrade and its ornamentations, whereas the lower parts were mostly bare, with small and patchy colonies of Lecania erysibe.

The distribution of species is not very homogeneous, due to environmental gradients which favours dispersion. Differential distribution of nutrients and minerals also play an important role in lichen colonization, because the action of rain on stones causes absorption of water depending on their porosity and density. Acid rain (common in urban and industrial sites) leaches out the calcium ions from the surface, causing it to crumble away, generating channels and cracks. The water dissolves and bring with it salts in solution to the interior of stones. The drying out of the stone results in the formation of saline deposits on the surface. This creates favourable niches for microbial growth which enrich the stones in nitrogeneous compounds. However, in this investigation lichen establishment was encouraged by pigeon excrement, high in nitrogen and phosphorous, widely distributed all over the belfry. In this connection, the lichens reported here are considered as ornithocoprophilous (Brodo, 1973; James et al. 1977) and are often associated with limestone, bone and neutral-barked trees.

The bricks and mortar from the belfry outer walls support a few lichen species with a scanty and diffuse distribution. Species identified were Lecania erysibe, Candelariella medians, Lecanora dispersa, Caloplaca aurantia (Pers.) Hellb., Caloplaca teicholyta (Ach.) Steiner and Acarospora sp. (subgenus Acarospora). In this case, the perpendicular wall surfaces may afford the lichens some measure of protection against mechanical wear, and the pigeons' influence on colonization cannot be as important as in exposed belfry stones. This and the distinct substrate constitution may explain the differences in lichen species.

Also the moss Tortula muralis (L.) Hedw. was observed. This is adapted to shallow or primitive soils formed at the junction between stones, and in holes, cavities and protected places where dust and particulate matter is deposited by the wind. It was found that small rhizoids penetrate the limestone where they extend like a net, probably through pores and microfissures. In some cases, Phaeophyscia orbicularis was found growing on Tortula muralis.

Most man-made substrates tend to be rather alkaline and this exerts a neutralizing effect on sulphurous pollutants and enables lichens to extend further into towns on asbestos-cement, concrete and limestone (Seaward, 1975). Xanthoria parietina appears on these materials at mean winter sulphur dioxide levels of about 125 ug/m^3. In Britain common urban lichens include Lecanora dispersa, Candelariella aurella and Lecania erysibe, all on asbestos-cement or similar calcareous substrates. These species show an enhanced resistance to air pollution, as does the moss Tortula muralis (Gilbert, 1973). Other species (Caloplaca aurantia, Caloplaca teicholyta, Candelariella medians) were also reported to be of interest in air pollution survey works (Hawksworth and Rose, 1976).

The range of lichen species observed leads to believe that the atmosphere is not highly polluted, but probably moderately polluted (mean year 1976-80 sulphur dioxide level of about 90 ug/m^3) and the flora is more-or-less representative of "semi-natural" calcareous substrates influenced by bird excrement (Seaward, personal communication).The community is a Caloplacion decipientis Klem. near to Caloplacetum murorum (DR.) Kaiser. The association occurs on a soft, decayed calcareous substrate enriched by bird excrement, is very nitrophilous, photophilous, xerophilous and sulphur dioxide-air pollution tolerant.

The importance of lichens as protective or detrimental organisms for stone monuments has been pointed out by Lallement and Deruelle (1978). It is true that lichens often create a "living barrier" to acid rain water attack, but in our case the lichens are harmful. Epilithic crustose lichens such as Lecania erysibe have an outer cortex with a layer of closely packed cells, an algal layer (figure 4) and a medulla, consisting of loosely interwoven hyphae in periclinal arrangement (figure 5), which is attached directly to the substrate (figure 6) where the hyphae are involved in disintegration and decomposition of stone, either through contraction which creates a pulling strain during dry periods or through dissolution by excreted lichen acids. It seems probable that Lecania erysibe has some detrimental effects on the limestone, because removal of the lichen also detaches a thin film of about 1-2 mm of substrate. Furthermore, crystals of lichen acids,embedded on the medullary hyphae, may act as metal-complexing agents and this promotes biogeochemical weathering, as reported by Syers and Iskandar (1973). Caloplaca spp. have also been found firmly attached to the substrate, causing detachment of particles when removed from the limestone.

In addition to limestone weathering, the lichens thriving on the Giralda produce an unpleasant appearance which causes darkening of surfaces. It is recommended to the architect-restorer that a conservation treatment should be carried out, involving cleaning and removal of the organisms. Sterilization with appropriate biocides is suggested because, in addition to lichens and bryophytes, bacteria and fungi were found growing directly on the stone. Consolidation of weathered stones and a water-proofing treatment are also necessary as pointed out by Tiano (1978).

Acknowledgements

I am grateful to Dr. A. Jimenez and Mr. J.M. Cabeza, architect-restores, for the facilities to carry out this research. I wish to acknowledge Dr. Cruz Casas for moss identification, Dr. Ana Crespo and Dr. M.R.D. Seaward for lichen identifications and valuable comments, Mr. J. Garcia for assistance in lichen studies, Mr. C. Alonso for help with scanning electron microscope, and Mr. E. Filgueras for photographic work. Figure 1 is a courtesy of Mr. C. Ortega, photographer. I am indebted to Dr. Seaward for helpful critical review of this manuscript.

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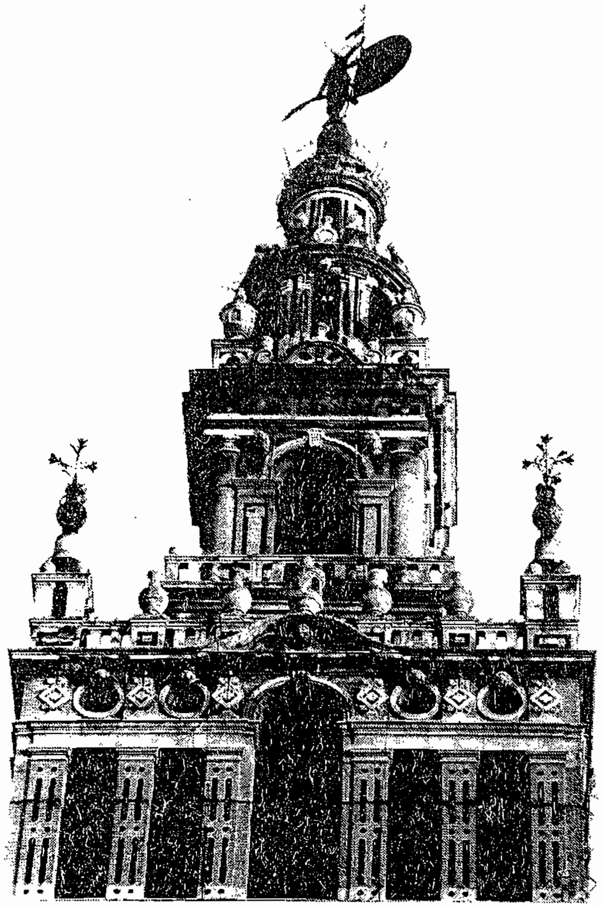

Figure 1. Detail of the Giralda belfry.

Figure 2. Detail of a weathered limestone by Lecania erysibe. Detached parts were also covered by the lichen.

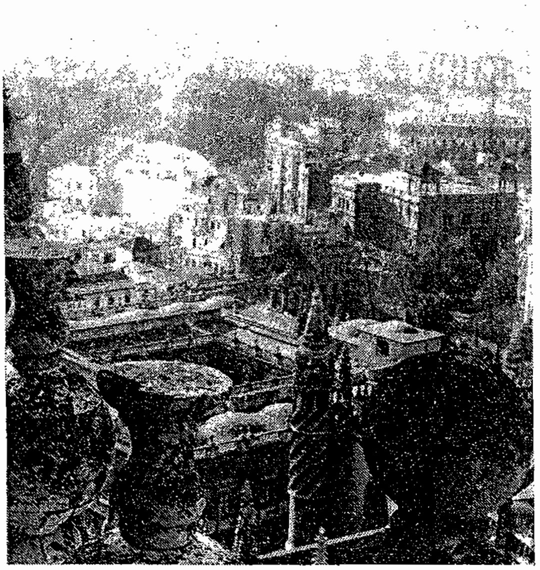

Figure 3. Stones colonized by Lecania erysibe and Xanthoria parietina.

Figure 4. Cross section of Lecania erysibe showing outer cortex and algal layer. x1800

Figure 5. Plectenchyma of interwoven hyphae of Lecania erysibe. x800

Figure 6. Attachment of hyphae of Lecania erysibe to the substrate. x1000