ENVIRONMENTAL QUALITY AND ECOSYSTEM STABILITY - Volume V/B, Eds.: A. Gasith, A. Adin, Y. Steinberger & J. Garty, ISEEQS Publication, 1992

BIOGENIC WEATHERING OF MARBLE MONUMENTS IN DIDIM, TURKEY AND IN TRAJAN'S COLUMN, ROME

Avinoam Danin
Department of Evolution, Systematics, and Ecology
The Hebrew University of Jerusalem, Israel 91904

ABSTRACT

The Temple of Apollo in Didim, Turkey, was built in 560-550 B.C. with marble. Mean annual rainfall there is 656 mm. Much of the marble surface is covered by a black crust of microorganisms. Weathering patterns, associated mainly with cyanobacteria, observed there were: 1. Exfoliation with pleurocapsalean cyanobacteria in fissures. 2. Gradual removal, by splashing rain drops, of marble crystals, the coherence of which is reduced as a result of microbial activity. 3. Pits formed by cyanobacteria living in circular patches. The mechanism described in No. 2, leads there to the creation of depressions where the lithobionts are situated. Trajan's column was erected in Rome 112 C.E. Mean annual rainfall there is ca. 700 mm. The column is almost devoid of microbial life at present, but until 1942 had many patches of microbial black crusts. From 1942 to 1948 it was covered by brick walls and sand as a way of protection against war hazards. The light-demanding microorganisms that populated the monument for hundreds of years disappeared after being covered for 6 years and have not returned yet. Pits resembling those in Didim damaged much of the artistic relief on parts of Trajan's column. The most affected parts are those facing south and southeast. These are the directions of the most common incident rainfall in Rome which bring water at high energy to the marble monument.

KEYWORDS: Cyanobacteria, exfoliation, incident rainfall, marble, pits.

INTRODUCTION

When rocks are used to build a house or an open-air monument anywhere on earth, a habitat free for microbial colonization is created. The architects, conservationists, and archaeologists should be aware of the function of biological colonizers of the stone surface and crevices because of their important role in the weathering or deterioration of the monument. Basing our study on the biogenic weathering of calcareous rocks (Danin et al., 1982, 1983; Danin 1983, 1986, 1989; Danin and Caneva 1990; Caneva et al. 1992) weathering patterns associated with microorganisms were observed on two famous monuments in Italy and in Turkey. Similarities in environmental conditions between the two sites enable us to compare and to find complementary processes that may contribute to better understanding of these ecosystems and their biodeterioration processes.

The aim of the present paper is to analyse the weathering patterns found on marble monuments in Didim, Turkey and in Rome, Italy, and thus to contribute to the conservation of these and similar endangered monuments.

METHODS AND LOCATION

The Temple of Apollo was built in Didim (Didyma, Didymaion) 27°15'E/37°22'N, ca. 200 km south of Izmir, Turkey in 560-550 B.C. Marble was used to construct the columns, walls, and statues found there. Mean annual rainfall in Didim is 656 mm.

Trajan's column was erected in Rome 112 C.E. Mean annual rainfall in Rome is ca. 700 mm. The column is made of Carrara Marble and is almost devoid of microbial life at present. Old photographs (Caneva et al. 1992) show that until 1942 there were black crusts of microorganisms in many places. From 1942 to 1948 it was totally covered by brick walls as a protective measure against war hazards(Caneva et al. 1992). All the photoautotrophic microorganisms that populated the monument for hundreds of years before 1942 disappeared after being covered for 6 years. The nature of cyanobacterial colonization was studied on small marble blocks, unearthed at the end of the last century in the Trajan's Forum, near the column. Pit morphology and distribution over various sections of Trajan's column were studied between 1988 and 1991 in the site. Replicas and photos of the column from previous decades and centuries were studied as well.

Due to the preliminary nature of this report, concerning the site in Didim, only general names of the microorganisms involved with the weathering are used. For detailed lists of organisms discovered on marble monuments in Rome see Caneva et al. (1992).

RESULTS

Five patterns of weathering associated mainly with cyanobacteria were observed in Didim, June 1991:

1. Exfoliation due to the development of chasmoendolithic pleurocapsalean cyanobacteria in fissures. It is easy to remove the stone covering these organisms. The green masses of cyanobacteria imbibe noticeably when wetted. There are white or colored carbonate sediments next to these organisms. The results of this biodeterioration process is the disappearance of marble pieces from walls and columns all over the site and creation of flat depressions in certain places. It is very prominent on the north-facing walls that receive the incident rainfall. These walls are dark colored due to the microbial crust covering them and are devoid of such organisms in the microsites where flat marble pieces were removed in this weathering process.
2. Gradual removal of marble crystals by splashing rain drops. The coherence of rock particles is reduced as a result of microbial activity. Cyanobacteria which live on marble release CO_2 when wetted and respire, thus increasing the dissolving ability of the water around them. When living at rock surface they become dark-colored as a way of protection from solar

radiation. Walls facing the incident rainfall and sites where water percolates after showers support dense populations of cyanobacteria and look black. In these places marble particles, nearly free and easy to remove, project above the dark cyanobacterial crust.

3. Pits formed on horizontal, vertical, or inclined faces by cyanobacteria which live in circular patches. The increasing rate of dissolution and removal of particles by rain drops lead to the creation of depressions near the lithobionts. The much faster rate of weathering near the lithobionts is expressed by the formation of pits 1-5 cm in diameter. This pattern is less common than the two previous ones. Further investigations are needed to explain why cyanobacteria induce pit formation in one microsite and general removal of marble crystals in other microsites.
4. Pits formed in outlets of temporary dripping water below fissures in walls. Although not observed in the site after rain, it is obvious, from observations in similar sites elsewhere, that water accumulated behind the wall percolates from fissures among the wall stones. There is obviously a dense population of dark colored microorganisms associated with these pits.
5. Combined weathering by slugs or snails grazing on faces that are covered by lithobionts. A north facing wall covered by a continuous crust of epilithic lichens and cyanobacteria have white trails where lithobionts were grazed by snails or slugs. When scratching the wet crust the snails remove loose marble particles as well.

In Trajan's column there are pits that resemble those populated by cyanobacteria in Didim and in other marble monuments in Rome (Fig. 1, top right and top left). The pits near figures or other reliefs on the monuments may be regarded as second kind of pits that join together to form long and irregular depressions. Similarities to this kind of weathering should be searched in marble monuments in Rome, where microorganisms are active at present. These pits and depressions have damaged much of the artistic relief on parts of Trajan's column. The most affected parts are those facing south and southeast. These are the directions of the most common incident rainfall in Rome which bring water at high energy to the vertical faces of the marble monument.

A scatter diagram displaying the relationships between diameter and depth (Fig. 2) of more than 100 pits, the diameter of which is more than 3 mm, shows a highly significant coefficient of linear regression ($R = 0.5183$, $p \lll 0.01\%$)

The edges of the pits on Trajan's column that were sharp and with a black microbial crust (Fig. 3) for a few hundred years until 1942 are blunt at present.

In houses 60-70 years old, far from the centre of Rome the walls facing south and southeast are densly covered by lithobionts. The principle source of moisture for these lithobionts is the incident rainfall (Caneva et al. 1991).

Fig. 1. Details of relief on Trajan's Column (in 1989) where the isolated pits are prominent on vertical parts and long depressions caused by joined pits or induced in a different way are common throughout.

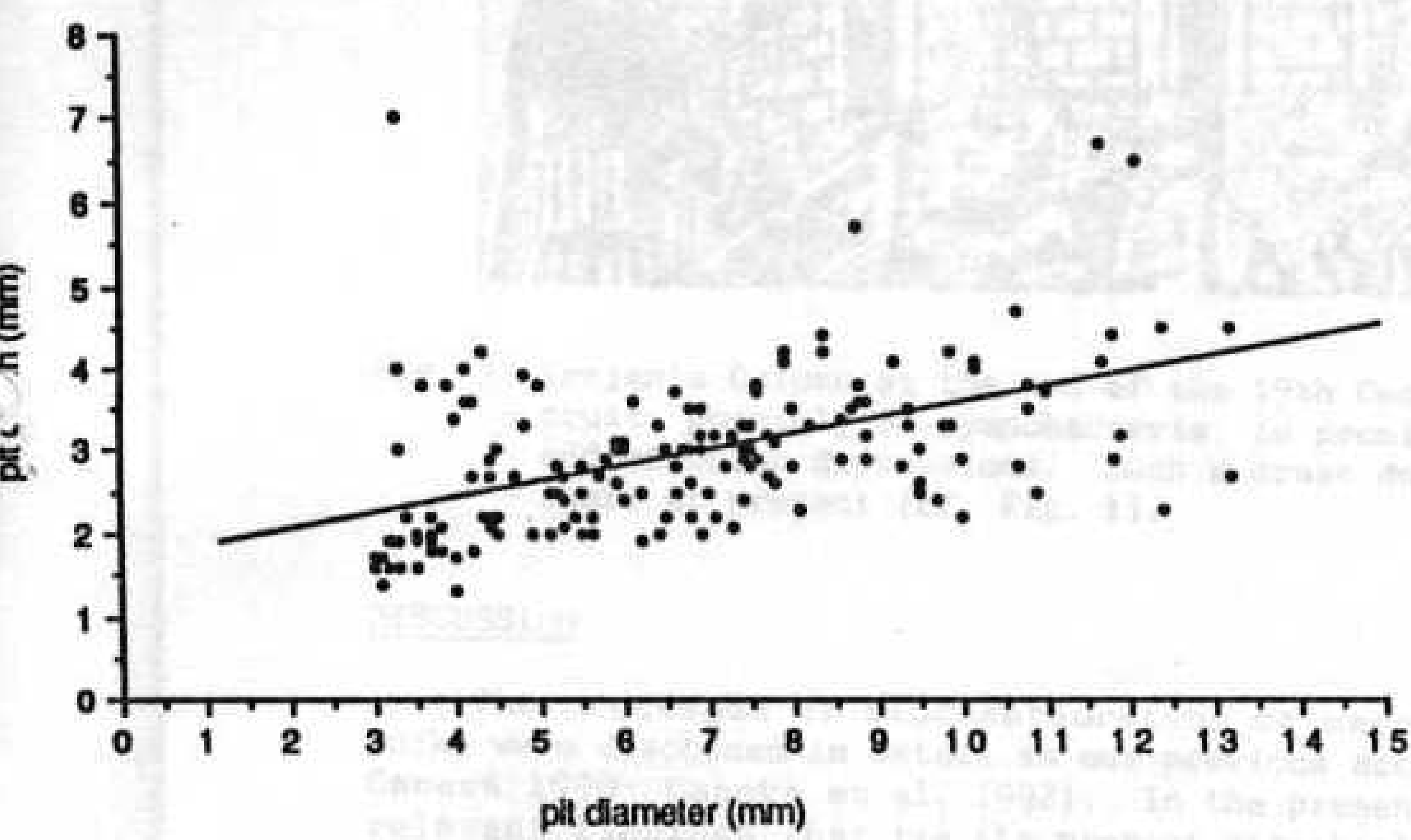

Fig. 2. Linear regression between pit diameter and depth on Trajan's Column, R = 0.5183, $p \lll 0.01\%$.

Fig. 3. Trajan's Column at the end of the 19th Century. Dark crust, possibly of cyanobacteria, is prominent in long and circular depressions. Such a crust does not exist there at present (cf. Fig. 1).

DISCUSSION

The processes of biodeterioration of marble or carbonate rocks were discussed in detail in our previous accounts (Danin and Caneva 1990; Caneva et al. 1992). In the present paper only the relevant findings that tie the present microbial colonization in Rome and Didim with biodeterioration are mentioned.

The first prominent bio-weathering process is exfoliation. The contribution of cyanobacteria colonizing crevices in marble to the removal of pieces of rock covering them was described by Danin and Caneva (1990). The process of carbonate sedimentation around the cyanobacteria cells from the nearby aqueous solution is:

$$Ca(HCO_3)_2 \rightleftharpoons CaCO_3 + H_2O + CO_2.$$

When a molecule of CO_2 is fixed by cyanobacteria in their photosynthesis processes, a molecule of $CaCO_3$ is sedimented nearby. The growth of carbonate crystals in the fissure leads to a gradual opening of the fissure. Dust particles, pollen grains, pleurocapsalean cyanobacteria, fungi, small insects, and spiders occur at the expanding space of the fissure. In time this accumulation results in peeling off the part of the stone that covered the fissure space. This kind of weathering has caused much damage in a few locations in the Didim monument and the authorities responsible for its maintenance are called to consider the damages caused already.

The second prominent process of weathering in Didim is pitting. As found by Caneva et al. (1992) in marble blocks in Trajan's and Roman Fori in Rome, there are several species of cyanobacteria that populate the pits. The pits are formed as a result of faster weathering near patches of these organisms. The microbial activity leads to a reduction in the coherence of marble crystals by increasing the acidity of water surrounding the microorganisms. The rate of splashing out of marble crystals from near the cyanobacteria is faster than that from marble with no such organisms. The result is that the rate of weathering near the round patch of cyanobacteria is higher than in the area not populated by them. The longer they live the deeper becomes the round hole, and a pit is formed (Danin and Caneva 1990). As long as the microorganisms which induced the formation of pits were alive on Trajan's Column there was a faster rate of weathering in the pits. The large difference between weathering rates in and out of the pits was expressed in the sharp edges of the pits. As a result of the protection measures against the 2nd World War hazards, the pits' microorganisms disappeared. The general weathering processes that influenced the entire surface indifferently led to the weathering of the sharp edges, thus making them blunt.

The many opinions published in literature since the 16th century and concerning mainly physical and non-biological explanations for the pitting of Trajan's Column were dealt with by Caneva et al. (1992). Studying the biogenic precesses involved with pit formation in Didim may promote our undestanding of the causes for such deterioration of monuments in Rome or any other place with similar monuments and environmental conditions.

Further microbiological research is needed in Didim to achieve better understanding of the pitting process. Quantitative evaluation of the rate of marble deterioration in two types of habitats is needed as well. The first is the result of crystal removal by raindrops from sites covered by a crust of dark cyanobacteria. The action of slugs or snails on lichens should also be evaluated.

ACKNOWLEDGEMENTS

Thanks to Ms. Meryem Bekliogelu for the help in field work in Turkey and to Dr. Giulia Caneva for the cooperation in the study of marble weathering in Rome.

REFERENCES

Caneva, G., Gori, E.G. and Danin, A. 1991. Contributo della pioggia battente alla colonizzazione biologica di superfici murarie di Roma Bollettino di Geofisica, CNR-IFA, Roma (in press).

Caneva, G., Danin, A., Ricci, S. and Conti, C. 1992. The pitting of Trajan's Column, Rome: an ecological model of its origin (manuscript).

Danin, A. 1983. Weathering of limestone in Jerusalem by cyanobacteria. Z. Geomorph. 27: 413-421.

Danin, A. 1986. Patterns of biogenic weathering as indicators of palaeoclimates in Israel. Proc. Roy. Soc. Edinburgh Biol. Ser. 89B: 243-253.

Danin, A. 1989. The use of biogenic weathering of limestone in palaeoclimatic research. In: E. Spanier, Y. Steinberger and M. Luria (eds.) Environmental Quality and Ecosystem Stability: Vol. V-B: 53-64. ISEEQS Publication, Jerusalem.

Danin, A. and Caneva, G. 1990. Deterioration of limestone walls in Jerusalem and marble monuments in Rome caused by cyanobacteria and cyanophilous lichens. Biodeterioration International 26: 397-417.

Danin, A., Gerson, R. and Garty, J. 1983. Weathering patterns of hard limestone and dolomite by endolithic lichens and cyanobacteria: supporting evidence for eolian origin of Terra-Rossa soil. Soil Science 136: 213-217.

Danin, A., Gerson, R., Marton, K. and Garty, J. 1982. Patterns of limestone and dolomite weathering by lichens and blue-green algae and their palaeoclimatic significance. Palaeogeogr., Palaeoclimatol., Palaeoecol. 37: 221-233.