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Remnants of biogenic weathering as a tool for studying palaeoclimates

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Abstract

Various organisms growing on limestone leave typical patterns of weathering. Bacteria, cyanobacteria, fungi, lichens, roots of trees and shrubs, and land snails were used in studies of biogenic weathering in Israel. The distribution of weathering patterns caused by these organisms was correlated with present day macro- and micro-climatic conditions. Rocks and detached stones that were uneaerthed in archaeologic and prehistoric sites were used to evaluate the climatic conditions of the time when the site was built. If the excavated weathering pattern is similar to that of rocks or stones today in the vicinity of the archaeological site, it is assumed that the climatic conditions of the past were similar to those of the present. If a more drought resistant lithobiont community or more mesophytic lithobiont community prevailed on the excavated rocks, we assume that the climate was accordingly drier or wetter than that of the present.

Stones and boulders found in Neolithic sites in the Jordan Valley showed that the climate 9-10,000 years ago was wetter than that of the present. This moist climate followed a period with drier climate that prevailed some 15-18,000 years B.P. The climatic regime of the present started some 6,000 years ago when in many sites rocks and stones displayed weathering patterns that are similar to those of the present.

Introduction

The use of fossils of plant and animal in palaeoecology through palaeobotany is an every day procedure. The aquatic environments, where best preservation of the organisms can be detected, are used so widely that it is not necessary to quote any specific paper or textbook. We had not found many references for *in-situ* fossils of micro- and macro-organisms of continental lithoflora of the last dozens of millennia (DANIN et al. 1982). We studied some typical weathering patterns that are caused on calcareous rocks by: bacteria, cyanobacteria, fungi, lichens, land snails and roots of trees and shrubs (DANIN et al. 1982; DANIN et al. 1983; DANIN, GARTY 1983; DANIN 1983, 1985, 1986a, 1986b; HUNGATE et al. 1987). Rocks and detached stones that were unearthed in archaeologic and prehistoric sites were used to evaluate the climatic conditions of the time when the site was built. In the present paper our palaeoclimatic research in Israel is reviewed.

Environment

Moisture regime seems to be the most important factor influencing the distribution of lithobionts on hard limestones and dolomites. We studied mainly rocks and detached stones with 0.5-2.0% water-holding capacity. *In-situ* rocks and detached stones differ remarkably in their moisture regime (DANIN, GARTY 1983). Detached stones are cooled during the night at a faster rate than *in-situ* rock and may therefore be supplied with considerable amounts of dew. In areas where dew is a common event there are marked differences in the lithobiont communities of *in-situ* rocks and detached stones (Danin 1985, 1986a). The distribution of the principal lithobiont communities as related to climatic conditions in Israel were presented by DANIN (1986a).

Paterns of weathering caused by lithobiont communities

The weathering types and the organisms that caused them were described in detail and illustrated in our previous papers. A short reference to these types is listed here.

Rock varnish on calcareous rocks is associated with the activity of manganese and iron oxidizing bacteria (Staley et al. 1983; Hungate et al. 1988). This life form prevails on calcareous rocks

in areas with less than 100 mm mean annual rainfall and low amounts of dew.

Microscopic pits on elevated rock and stone faces with ascocarps were attributed to unidentified fungi (DANIN 1986a). These fungi from a few locations in Israel were recently determined as *Lichenothelia intermixta* Henssen (HENSSEN 1987, and personal communication). These fungi, or related taxa that induce a similar type of weathering, occur all over Israel from extreme deserts with 25 mm mean annual rainfall up to areas with more than 1,000 mm mean annual rainfall. They occupy specific micro-habitats in each climatic zone and can be used as leading fossils mainly in deserts.

Pits, 0.5-3 cm deep, with spongy floor (Fig. 1) are caused by the activity of coccoid cyanobacteria and microscopic cyanophilous lichens in dry habitats (DANIN et al. 1982; DANIN 1983, 1986a). In most cases these organisms develop in slightly wetter microhabitats than those of the fungi and succeed micro-pits that were induced on the substratum by *Lichenothelia*-like fungi. These cyanobacteria and cyanophilous lichens induce faster weathering rate than the preceding fungi. Under desert conditions or on cliffs in wetter areas they lead to development of pits in occasional depressions.

Spongy layer of about 0.1 mm prevails on rock faces in sub-Mediterranean conditions (150-350 mm mean annual rainfall). This layer is formed by dissolution of clobular microscopic holes surrounding coccoid cyanobacteria and cyanophilous lichens which are similar to those involved with the pits mentioned above. However, under conditions that are less extreme than in desert or on dry cliffs, they develop all over the rock surface. The rate of weathering over the rocks is at least similar throughout the rock surface and no pits are formed here.

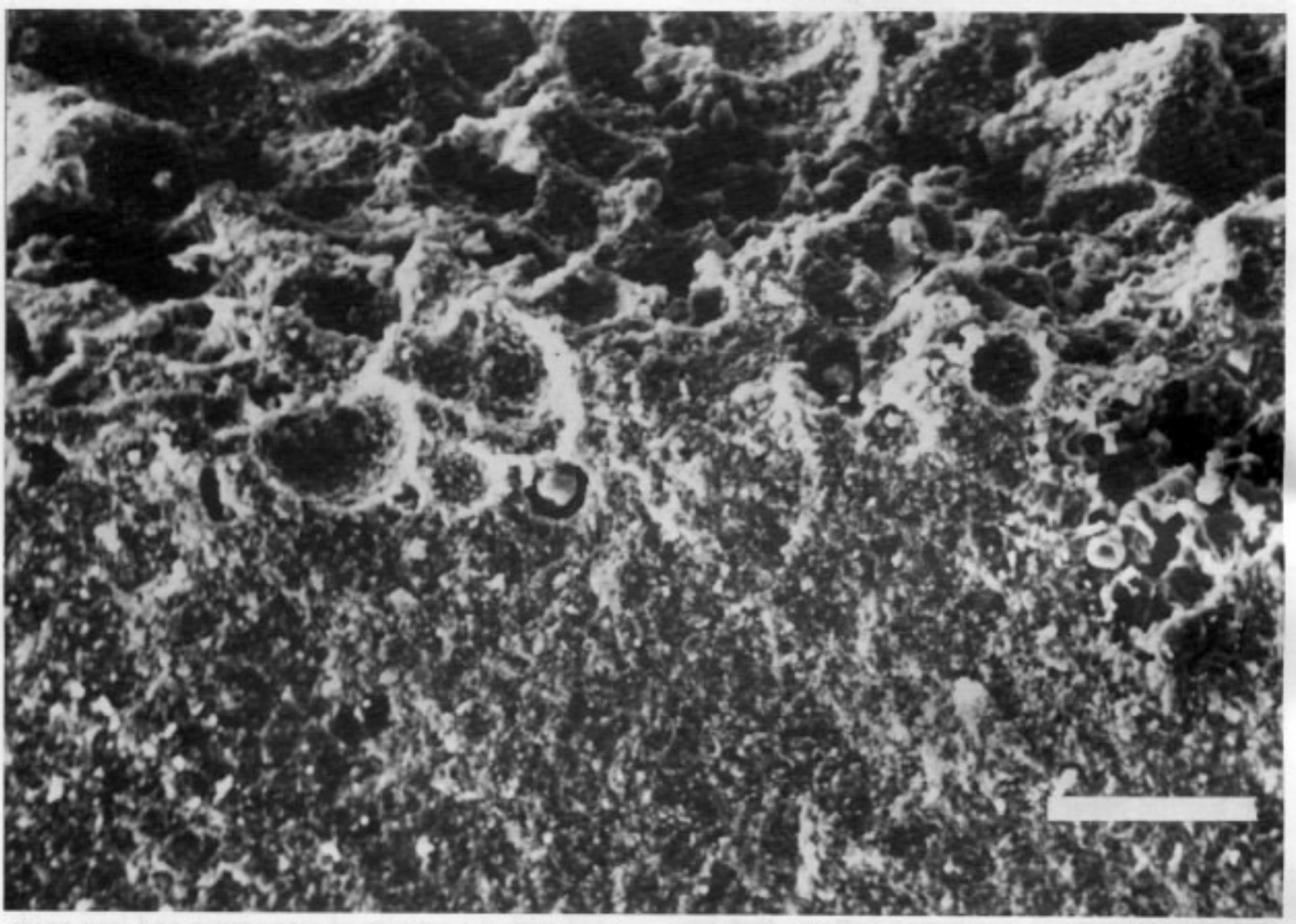

Fig. 1 - Scanning electron micrograph of the spongy surface of a rock as in pits' floor or on rock surface under sub-Mediterranean conditions. The lower half of the photo is perpendicular to the upper spong face, thus displaying a few globular organisms *in-situ*. (Bar = 200 μm).

Fig. 2 - Jigsaw-puzzle like pattern on a detached stone from the Negev Highlands near Sede Boqer. The pinhead holes are in place of the ascocarps of the endolithic lichens; the micro-grooves are in the meeting zone of two thalli with more efficient dissolution of the rock by the fungal component of the lichen.

Jigsaw-puzzle like pattern (Fig. 2) is induced by the activity of a few species of endolithic lichens. This pattern is found on south-facing slopes of rocks in the Mediterranean zone of Israel (400-1,000 mm mean annual rainfall) and on detached stones in areas with 80-1,000 mm mean annual rainfall and high amounts of dew. Land snails grazing on these lichens make their appearance more prominent (SHACHAK, GRANOT 1982; DANIN, GARTY 1983; DANIN 1986a, 1986b; SHACHAK, JONES, GRANOT 1987).

Foveolate pattern is formed by a few species of endolithic lichens in place of their ascocarps (Smith 1921; Danin 1985, Fig. 2).

Smooth-faced rock surfaces are formed below the crust of epilithic lichens. These lichens protect therock's surface from the destructing effect of rain drops. Water that passed the lichen crust reach the rock gradually and the relatively homogeneous complete cover of rock surfaces by these lichens leads to the formation of smooth faces.

Root grooves (Fig. 3) are formed in joints and between hard layers of limestones under Mediterranean conditions by trees or shrubs (DANIN, WIEDER, MAGARITZ 1987). Carbonate fillings of the root grooves can be analyzed and carbon- dated.

Honeycomb pattern with holes 2-3 cm in diameter are formed by land snails (DANIN 1986, 1986b). This pattern is formed mainly under Mediterranean conditions with 300-1,000 m mean annual rainfall.

Indications of palaeoclimates

Rock outcrops are populated in most places by one type of lithobiont community and cause simple pattern of weathering. Rocks that are expo-

Fig. 3 - Root grooves on a joint surface at the Judean Desert of Israel. These are remnants of the activity of trees or shrubs some 30,00 years ago.

sed for many thousands of years and «witnessed» climatic changes may display these changes on its surface as complex weathering pattern. A few case histories are listed below.

Simple weathering pattern

Massive limestone near Horvat Medin, northeastern Dead Sea area, display at present fungal micro-pits on elevated faces and pits of cyanobacteria and cyanophilous lichens in depressions. Detached stones display there mainly fungal micropits. The unearthed fort of the Hellenistic period at Horvat Medin is built up of large boulders, a few of which display the same pattern as the rocks on the slopes. Detached stones that were put among the boulders also display micro-pits (Danin 1985).

Rocks in the Negev Highlands support fungi in micro-pits and cyanobacteria and cyanophilous lichens on their south-facing slope as mentioned above for the Dead Sea area. Detached stones are covered by endolithic lichens that induce the jigsaw-pattern on their surface. Rocks and detached stones buried in the Byzantine period were found in a few sites in Nahal Haroa (Danin 1985). The weathering patterns on the excavated rocks had the same type of weathering as that of these habitats at present. This example and its preceding indicate that in both cases climate in the past was similar to that of the present.

Complex weathering pattern

Rocks and boulders in the vicinity of the Neolithic site of Netiv Hagdud, Jordan Valley (DANIN 1985), are covered at present by cyanobacteria and cyanophilous lichens that are associated with a spongy layer at the rock surface. Remnants of jigsaw pattern can be observed on many boulders. No living endolithic lichens that are associated with the latter pattern occur on these rocks. This patern of lines and pinhead holes typical for endolithic lichens indicates a period when

the area was moister. The jigsaw pattern is situated in a few boulders in pits 1-3 cm deep. These were formed presumably when the climate was drier than that of the present. Boulders that were unearthed in the neighbouring prehistoric site did not have spongy pattern on the jigsaw pattern. However, the latter was found in a few places on pitted micro-relief. This means that the climate there in the Neolithic period was wetter than that of the present but was preceded by much drier period. Rock pieces found in a site15-18,000 years old, not far from Netiv Hagdud, displayed pits and micro-pits such as those described above for the dry area of the Dead Sea. Consequently the rocks near Netiv Hagdud indicate a period wetter than that of the present that prevailed in the area just before being covered by soil and buried in the site. These boulders also displayed a very dry period that preceded the Neolithic period.

Rate of weathering

Each lithobiont community has its own rate of establishment, growth and creation of its typical pattern. The rate of pitting by a community of cyanobacteria and cyanophilous lichens on limestone walls of Jerusalem was found to be 1 mm/200 yr (DANIN 1983). This rate represents the mean rate of pitting over a period of some 2,600 years. It is the rate of a composite process where lithobionts locally dissolve the rock and rain drops detach minute rock particles from its surface.

Climatic changes in Israel

The period covered partly by remnants of biogenic weathering patterns starts some 30,000 years ago. Root grooves found in the Judean Desert indicate that the wet climate of the Late Pleistocene terminated then (DANIN, WIEDER, MAGARITZ, 1987). The drought caused the death of the trees and shrubs on slopes of this area. We do not have evidence for what happened between 30,000 and 18,000 yr B.P., but during the latter period the climate was drier than that of the present (DANIN 1987). Between 10,000 and 9,000 years B.P. the climate was wetter than at present. The climate that is similar to that of the present started some 6,000 years ago. Our findings agree with conclusions from other fields of research, as discussed in our articles quoted above.

Summary

Physiological activity of various organisms living on or inside limestone rocks and stones lead to accelerated weathering of the rock near these organisms. Long term localized dissolution and splashing of minute rock particles by rain drops from the vicinity of circular patches where cyanobacteria and cyanophilous lichens live lead to the formation of pits with spongy floor. Such pits are formed under desert conditions because the organisms can not develop throughout the rock surface. Under moister conditions endolithic lichens develop and induce typical weathering pattern that looks either as an assemblage of pinhead holes, created by their ascocarps, or as jigsaw puzzle. The latter becomes more prominent after being differentially abraded by land snails. Land-snails that obtain from the rock, at least, part of the calcium carbonate needed for constructing their shell, leave dissolution holes that resemble honeycomb with deep and wide holes. Trees and shrubs, the roots of which penetrate into crevices of limestone, lead to the formation of root grooves. Each of the organisms mentioned above develop under determinable environmental conditions and thus leave typical patterns of weathering that may be associated with these conditions. The remnants of biogenic weathering may function as leading fossils indicating climates of the past. The main events of climatic changes in Israel during the last 30,000 years were correlated in the studies under review with weathering patterns found on rocks and stones that could be dated. Most dated amples were found on building stones that were buried in archaeologic or prehistoric sites. Carbonate fillings of root grooves were dated using isotopes of carbon.

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