The Role of Lichens in Weathering and Soil Formation

by Frank Bungartz
Definitions (terminology)

- **weathering:**
  - physical = mechanical (insolation, salt, frost)
  - chemical (water, heat and acids)
  - biological (both physical and chemical; biodegradation)

- **erosion** (wind and water)

- **bioprotection** (shelter provided by the vegetation)

- **soil formation** (pedogenesis)
Biodegradation and Conservation of Monuments

The Lichen Flora of the Cathedral of Cologne

- floristic surveys in 1965, 1984 and 1999: very few, pollutant resistant species
- air pollution major cause for deterioration and low species diversity

KLEMENT (1965): 6 species
PRINZ & FOLLMANN (1984): 6 species
(3 species are the same as in KLEMENT 1965)
BUNGARTZ (1999): 32 species
Chemical Mechanisms of Lichen Weathering

- deterioration of CaCO$_3$ and MgCO$_3$ through carbonic acid from respiration:
  1. $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$ (carbonic acid)
  2. $\text{CaCO}_3 + \text{H}_2\text{CO}_3 \rightarrow \text{Ca(HCO}_3\text{)}_2$
     or $\text{MgCO}_3 + \text{H}_2\text{CO}_3 \rightarrow \text{Mg(HCO}_3\text{)}_2$
- acidic polysacharides extracting metal ions
- oxalic acid: formation of the minerals weddellite & whewellite
  $\text{Ca(C}_2\text{O}_4) \cdot \text{H}_2\text{O}$ (whewellite = monohydrate of oxalic acid)
  $\text{Ca(C}_2\text{O}_4) \cdot 2(\text{H}_2\text{O})$ (weddellite = dihydrate of oxalic acid)
- organic acids (lichen acids): chelating agents forming mineral complexes
Dirina massiliensis f. sorediata

CaOxalate crystals in a cross section
(polarized light)

up to 1cm thick, chalk-like crusts
with huge amounts of CaOxalates

from
**Acarospora rugulosa**  substrate specificity

- tolerant to Cu-rich substrates
- up to 16% dry weight of CuOxalate

SEM of moolooite crystals (CuOxalate) on the surface of lichen hyphae

**Lecidea lactea**

SEM of amorphous silica coated in iron oxide

*rust colored runoff of iron oxide*

from
Mechanical Mechanisms of Lichen Weathering

- physical penetration of rock crevices between mineral grains
- swelling of hyphae (turgor pressure, drying and rehydration)

*Rhizocarpon geographicum* penetrating granite

Anatomy of Endosubstrastic Growth

- epilithic: main thallus growing on top of the rock substrate
- endolithic: main thallus growing inside the rock substrate
  - chasmolithic
  - cryptoendolithic:
    - algal layer
    - lower medulla

Epilithic Lichens

e.g. *Caloplaca aurantia*

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*from Wirth (1992):*

*from Nimis et al. (1992):*
Licheni e conservazione dei monumenti. - Universitaria Bologna, 165 p.
Endolithic Lichens

e.g. *Verrucaria rubrocincta*
**Verrucaria rubrocincta**

Reflected Light Microscopy

- (a) 1 mm
- (b) 100 μm
- (c) 100 μm
- (d) 50 μm
- (e) 50 μm
- (f) 50 μm
- (g) 10 μm
- (h) 10 μm
- (i) 10 μm
- (j) 10 μm

- micrite
- algae
- pseudo
- medulla

- peritheciu
Verrucaria rubrocincta
Backscattered Scanning Electron Microscopy

micrite

perithecium

ascus

algal cells

gumentum

pseudo - medulla
Stable Isotope Analysis

- stable isotopes of Carbon & Oxygen: $^{13}$C & $^{18}$O
- $\delta$ (delta) is the value of stable isotopes in $\%_0$
- $\delta$ is a ratio value,
  
  e.g.
  
  $\delta = 5 \%_0$ means that the $^{13}$C/$^{12}$C ratio of a sample is 5 parts per thousand greater than the $^{13}$C/$^{14}$C ratio of the standard
Isotope Analysis

Oxygen Analysis:
- Micrite in contact with rain water should have a $\delta^{18}O \approx +24\%$.
- A $\delta^{18}O = +29\%$ therefore indicates evaporative enrichment.

Carbon Analysis:
- Calcite precipitated in contact with atmospheric CO$_2$ should have a $\delta^{13}C$ of $\approx +3\%$.
- The micrite layer is therefore $\approx +5\%$ enriched in $^{13}C$. 

Calcite ppt in contact with atm CO$_2$ should have $^{13}C$ of ca. +3.

$\delta^{18}O$ of water $\approx -6$

$\delta^{13}C$ of CO$_2$ $\approx -7$

$\delta^{18}O$ of water $\approx +29$

$\delta^{13}C$ of living material $\approx +8$

$\delta^{18}O$ of water $\approx +29$

Calcite dissolution by fungal hyphae
Isotope Analysis

Conclusions:

- Preferential fixation of $^{12}\text{C}$ into algae leaves local $^{13}\text{C}$ enrichment.
- The localized alkaline microenvironment at the cell surface allows precipitation of $^{13}\text{C}$- and $^{18}\text{O}$-enriched CaCO$_3$.
**X-ray Diffractometry (XRD)**

**Bragg’s equation:**

\[ n \cdot \lambda = 2d \sin \theta \]
X-ray Diffractometry (XRD)

**Typical XRD pattern of weddellite (CaOxalate) in Verrucaria rubrocincta**
Other endolithic species (light microscopy)

- Acrocordia conoidea
- Petractis clausa
- Rinodina immersa
- Verrucaria marmorea
- Verruaria baldensis

Scanning Electron Microscopy


void formed by *Petractis clausa*

perforated calcite crystal

oil cells

lithocortex

algal layer

medullary hyphae
most endolithic lichens characterized by:

- lithocortex
- photobiont layer
- inner layer or pseudo-medulla with oil cells
- no CaOxalates

other observations:

- *Petractis clausa*: substrate voids
- *Verrucaria rubrocincta*:
  - protective micrite layer on surface
  - CaOxalate in pseudo-medulla
Biodegradation vs. Bioprotection

- do lichens provide a protective layer?
- does removal of lichens increase deterioration?

from NIMIS et al. (1992):
Licheni e conservazione dei monumenti. - Universitaria Bologna, 165 p.
Soil Formation (= Pedogenesis)

Three main factors:

- humus formation from organic material
- weathering
- relocation and re-formation of minerals
Soil Formation and Succession

- classical hypothesis:
  cyanobacteria ➔ algae ➔ lichens ➔ bryophytes ➔ vascular plants
  rock substrates ➔ microsoils ➔ soils

- probably much more complex:
  - biolithic communities
    can persist centuries
  - soil crust do not necessarily increase humification
Desert Soil Crusts

- probably widespread in the Sonoran desert before the introduction of cattle
- hold soil together & prevent erosion
- provide organic material
- Cyanobacteria: N-fixation / Denitrification
- but:
  - lichen substances may prevent seed germination