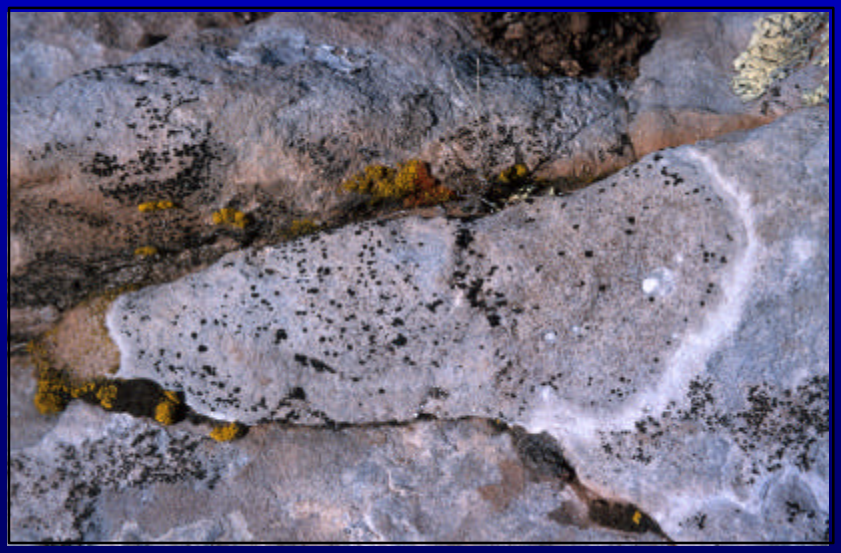
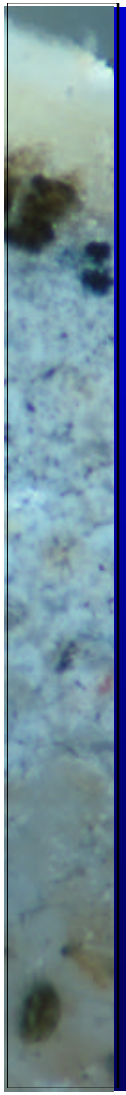
The Role of Lichens in Weathering and Soil Formation



by Frank Bungartz



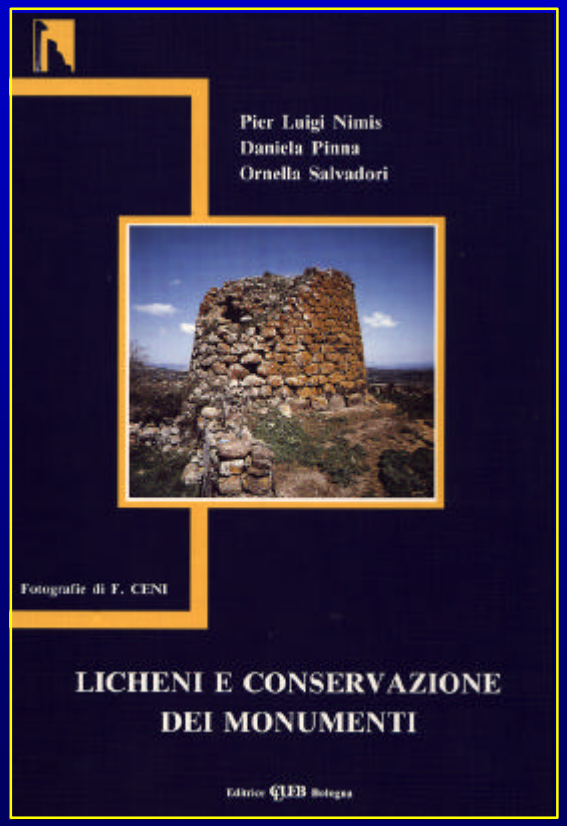
Definitions (terminology)

- 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)

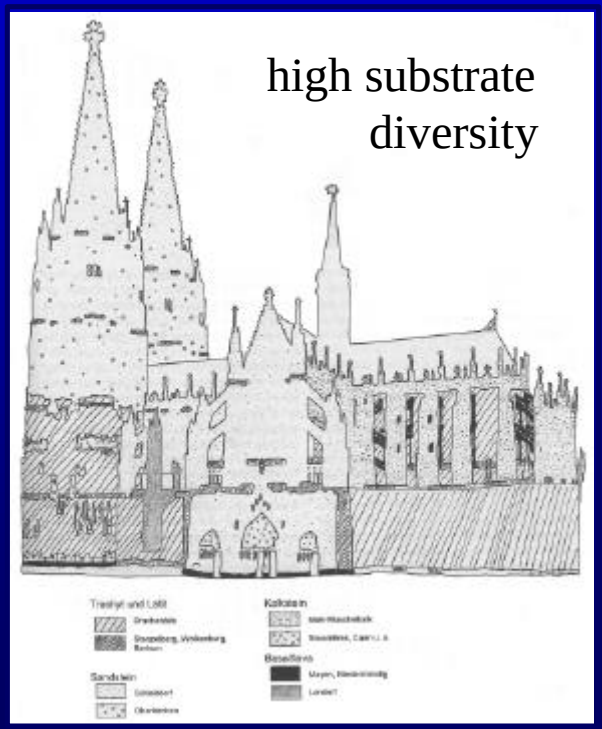
Biodegradation and Conservation of Monuments



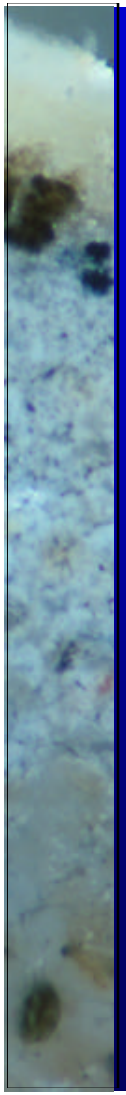
NIMIS et al. (1992): Licheni e conservazione dei monumenti. - Universitaria Bologna, 165 p.

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) $CO_2 + H_20 \longrightarrow H_2CO_3$ (carbonic acid)

  (2) $CaCO_3 + H_2CO_3 \longrightarrow Ca(HCO_3)_2$

  or $MgCO_3 + H_2CO_3 \longrightarrow Mg(HCO_3)_2$

- acidic polysacharides extracting metal ions
- oxalic acid: formation of the minerals weddellite & whewellite

  $Ca(C_2O_4) \cdot H_2O$ (whewellite = monohydrate of oxalic acid)

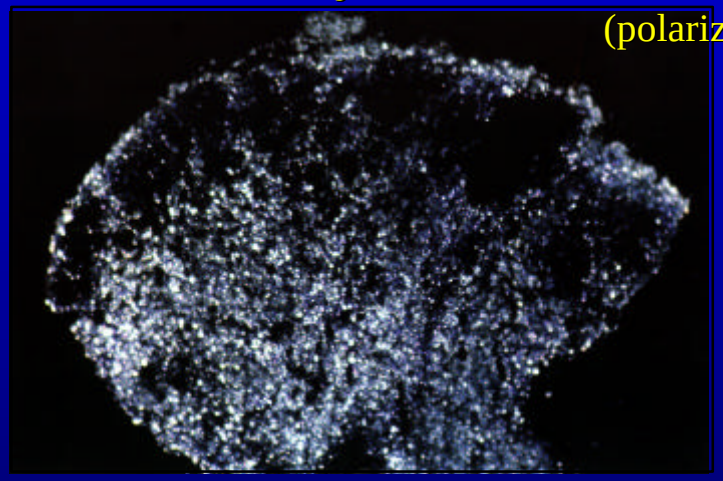
  $Ca(C_2O_4) \cdot 2(H_2O)$ (weddellite = dihydrate of oxalic acid)

- organic acids (lichen acids): chelating agents forming mineral complexes

Dirina massiliensis f. *sorediata*

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

CaOxalate crystals in a cross section
(polarized light)



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

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

from
PURVIS (2000): Lichens. - Smithsonian Institution Press, Washington, 112p.

Lecidea lactea

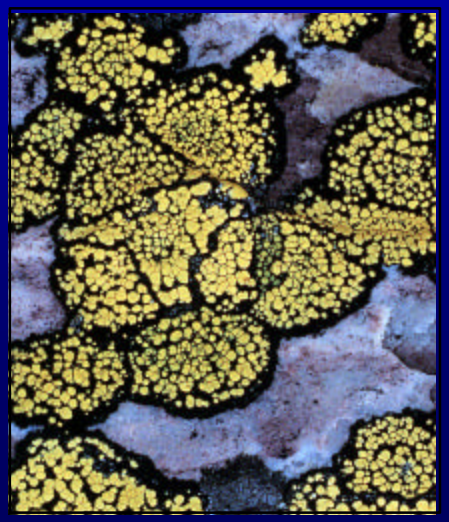
SEM of amorphous silica coated in ironoxide

from
PURVIS (2000): Lichens. - Smithsonian Institution Press, Washington, 112p.

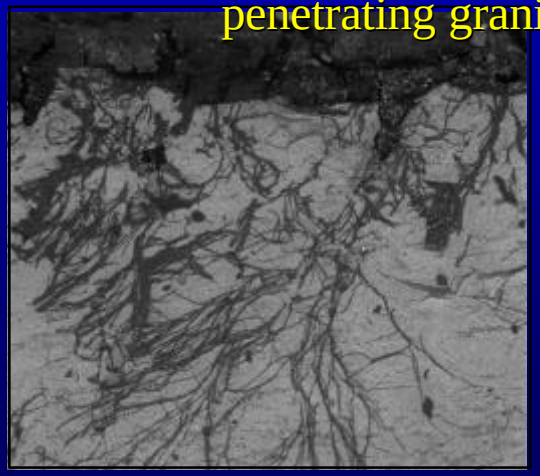
rust colored runoff of ironoxide

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



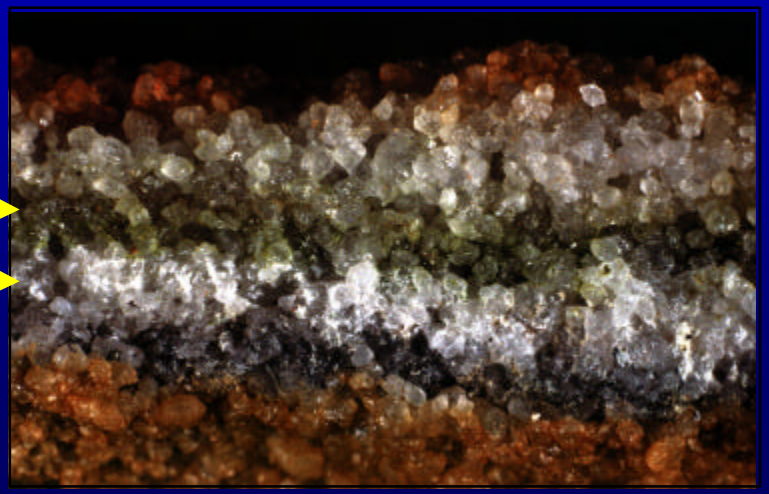
from PURVIS (2000):
Lichens. - Smithsonian Institution Press, Washington, 112p.

Anatomy of Endosubstratic 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 →

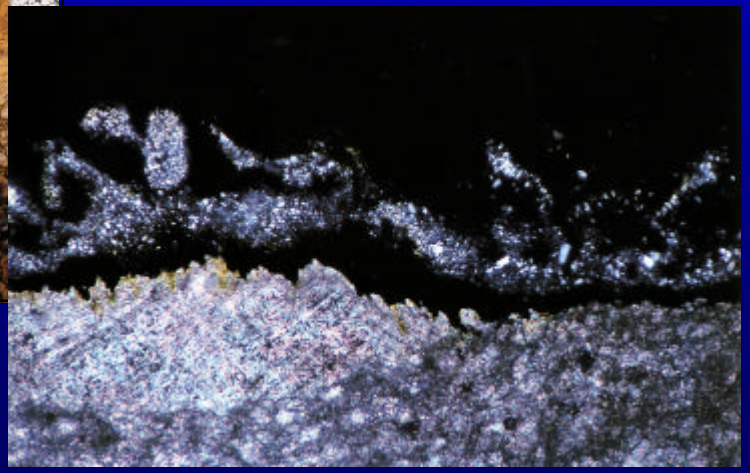


from
PURVIS (2000): Lichens. - Smithsonian Institution Press, Washington, 112p.

Epilithic Lichens

e.g. *Caloplaca aurantia*

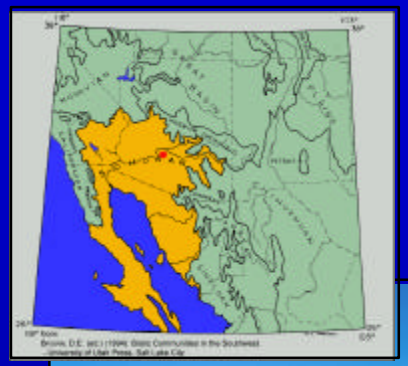
from WIRTH (1992):
Die Flechten Baden-Württembergs. Vol.1- Ulmer Verlag, Stuttgart, 527p.

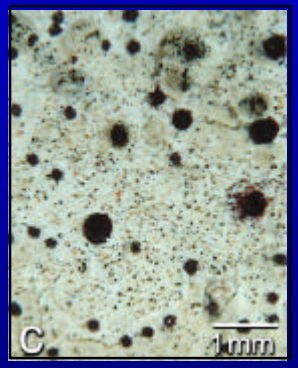


from NIMIS et al. (1992):
Licheni e conservazione dei monumenti. - Universitaria Bologna, 165 p.

Endolithic Lichens

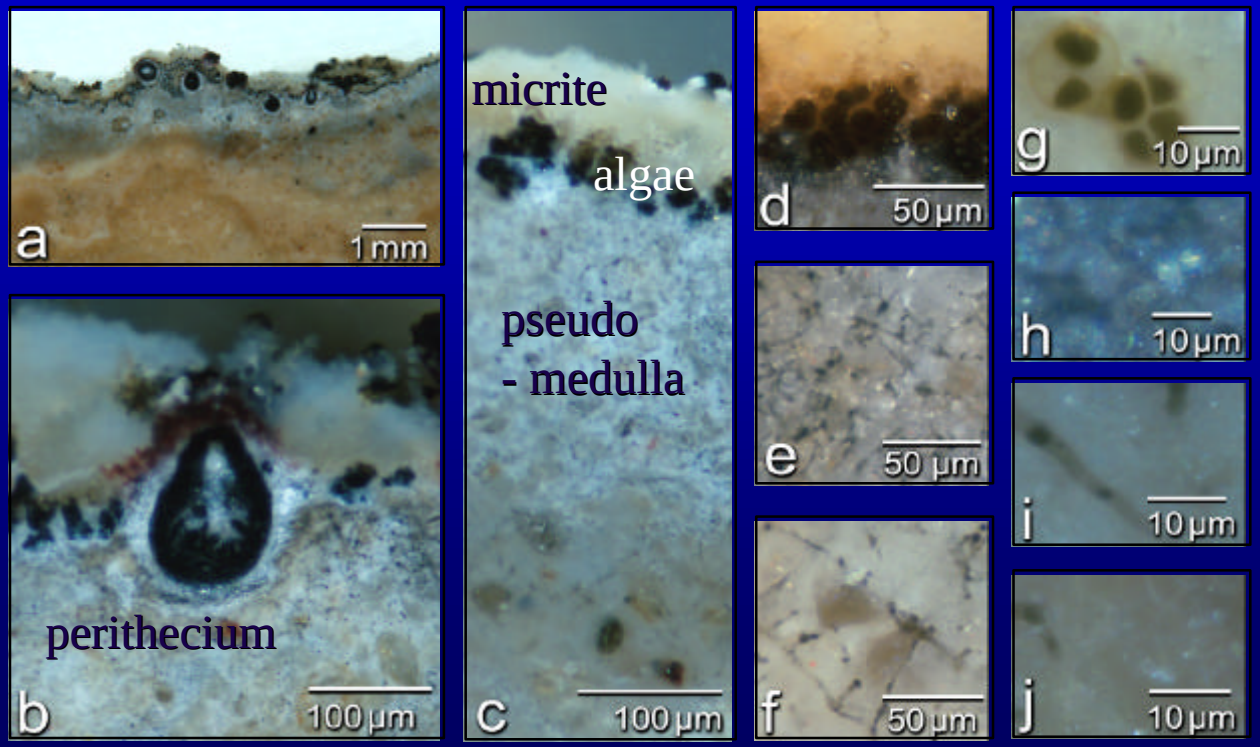
e.g. *Verrucaria rubrocincta*





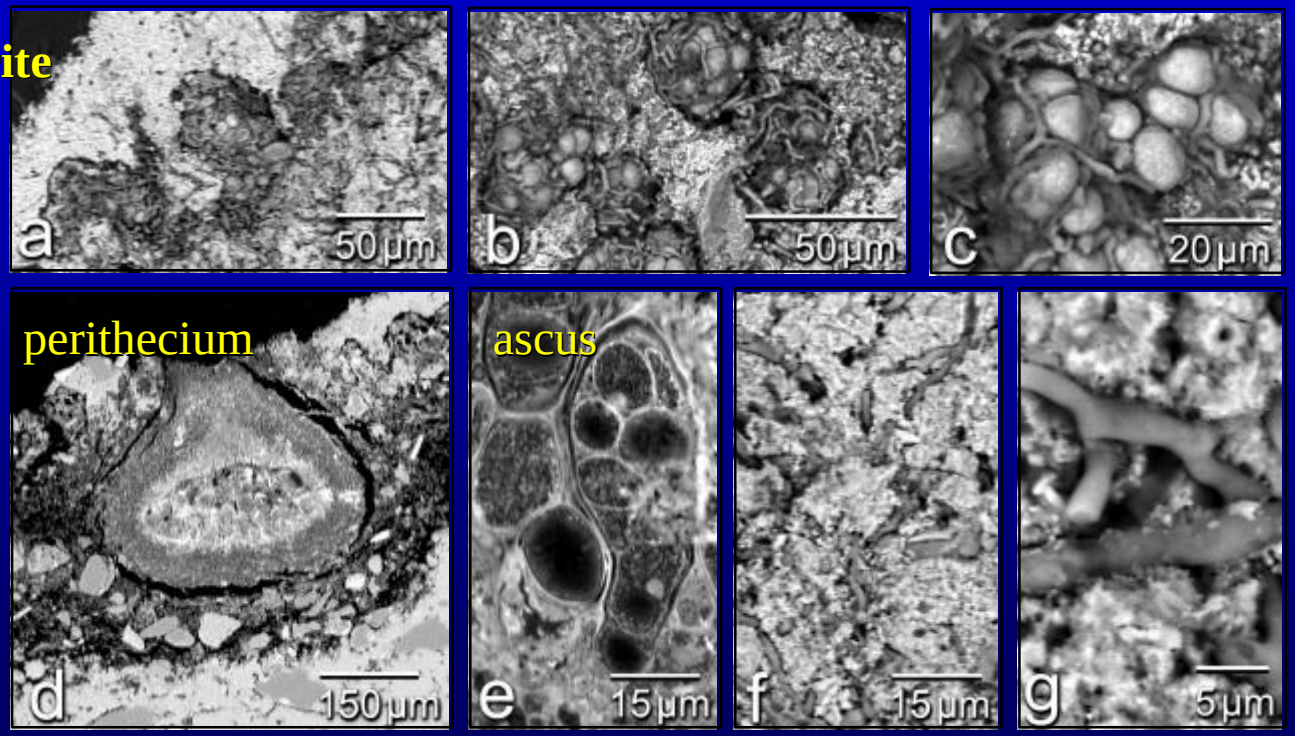
Verrucaria rubrocincta

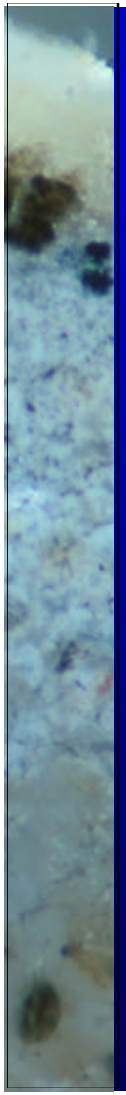
Reflected Light Microscopy



Verrucaria rubrocincta

Backscattered Scanning Electron Microscopy





Stable Isotope Analysis

- stable isotopes of Carbon & Oxygen: ^{13}C & ^{18}O
- δ (delta) is the value of stable isotopes in $^{0}/_{00}$
- δ is a ratio value,

  e.g.

  $\delta = 5\ ^{0}/_{00}$ 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

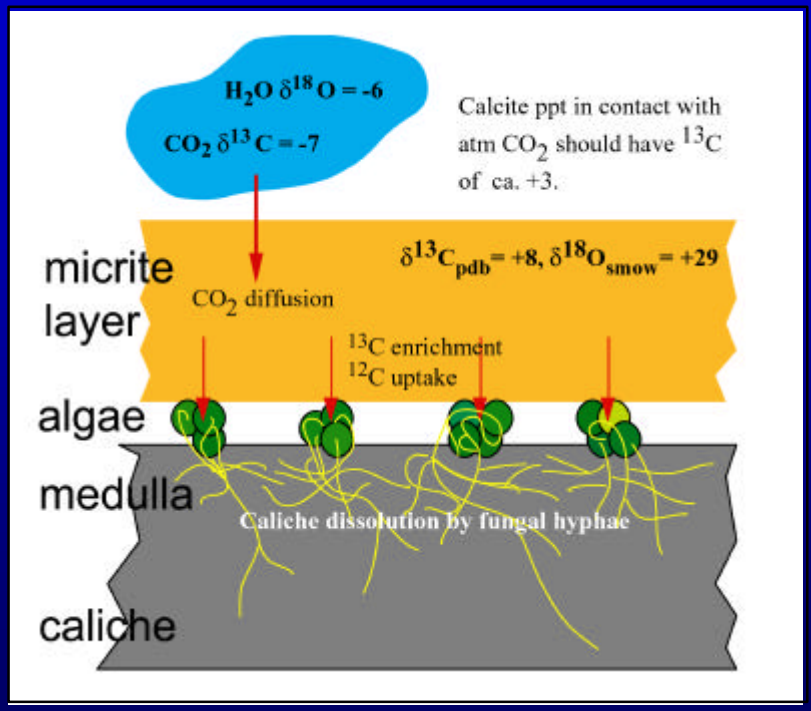
Isotope Analysis

Oxygen Analysis:

- Micrite in contact with rain water should have a $\delta^{18}O \approx +24\ ^{0}/_{00}$.
- A $\delta^{18}O \approx +29\ ^{0}/_{00}$ therefore indicates evaporative enrichment.

Carbon Analysis:

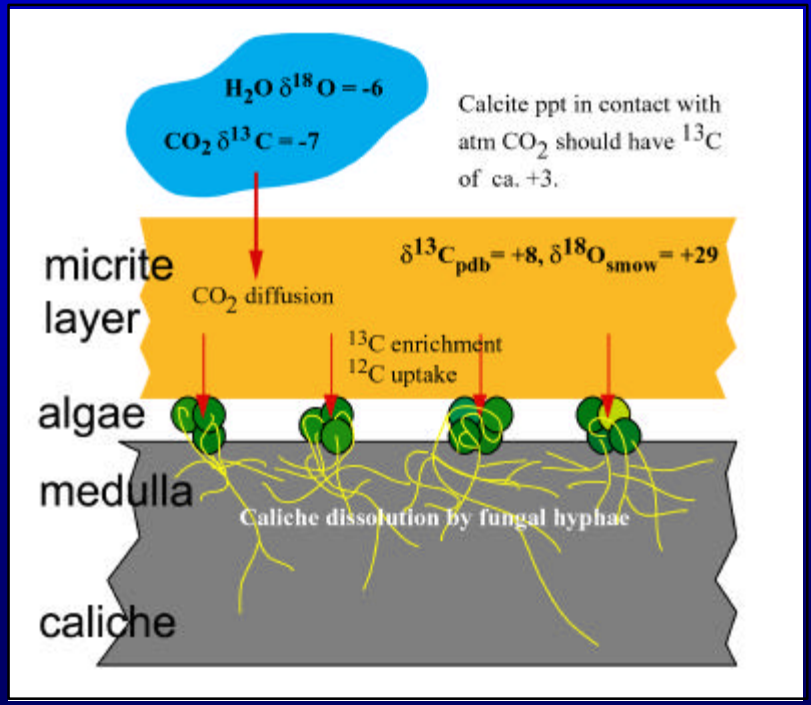
- Calcite precipitated in contact with atmospheric CO_2 should have a $\delta^{13}C$ of $\approx +3\ ^{0}/_{00}$.
- The micrite layer is therefore $\approx +5\ ^{0}/_{00}$ enriched in ^{13}C.



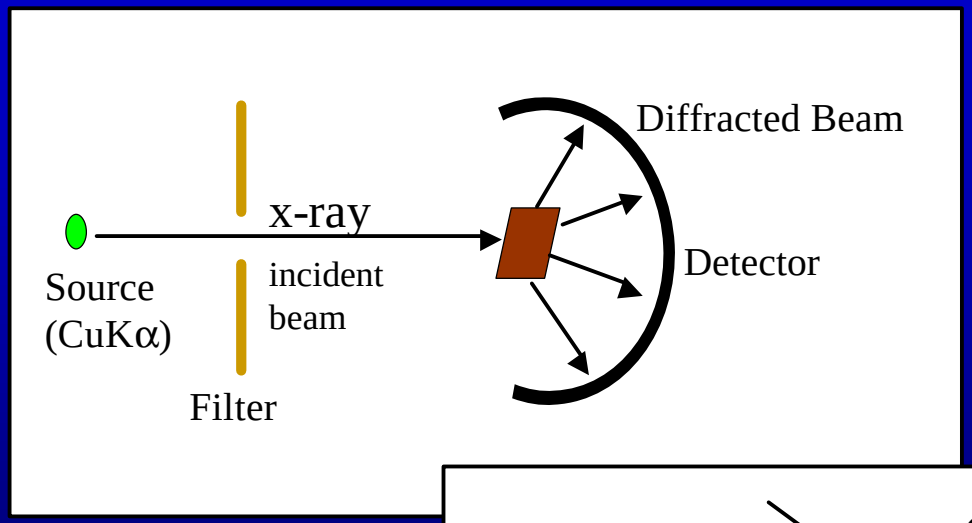
Isotope Analysis

Conclusions:

- Preferential fixation of ^{12}C into algae leaves local ^{13}C enrichment.
- The localized alkaline microenvironment at the cell surface allows precipitation of ^{13}C- and ^{18}O-enriched $CaCO_3$.

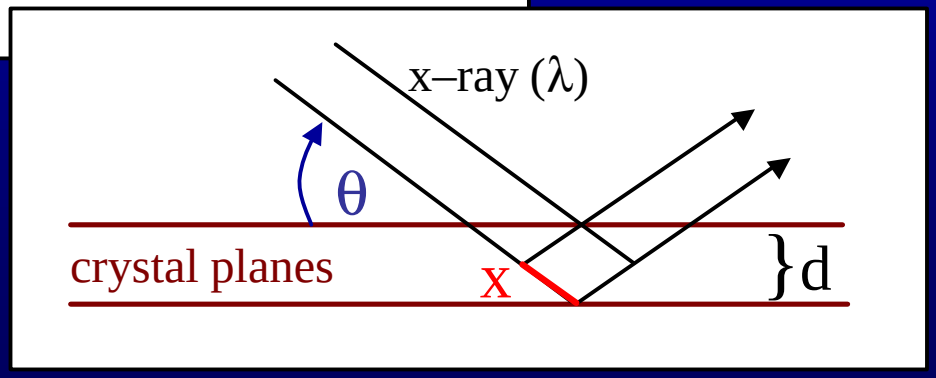


X-ray Diffractometry (XRD)

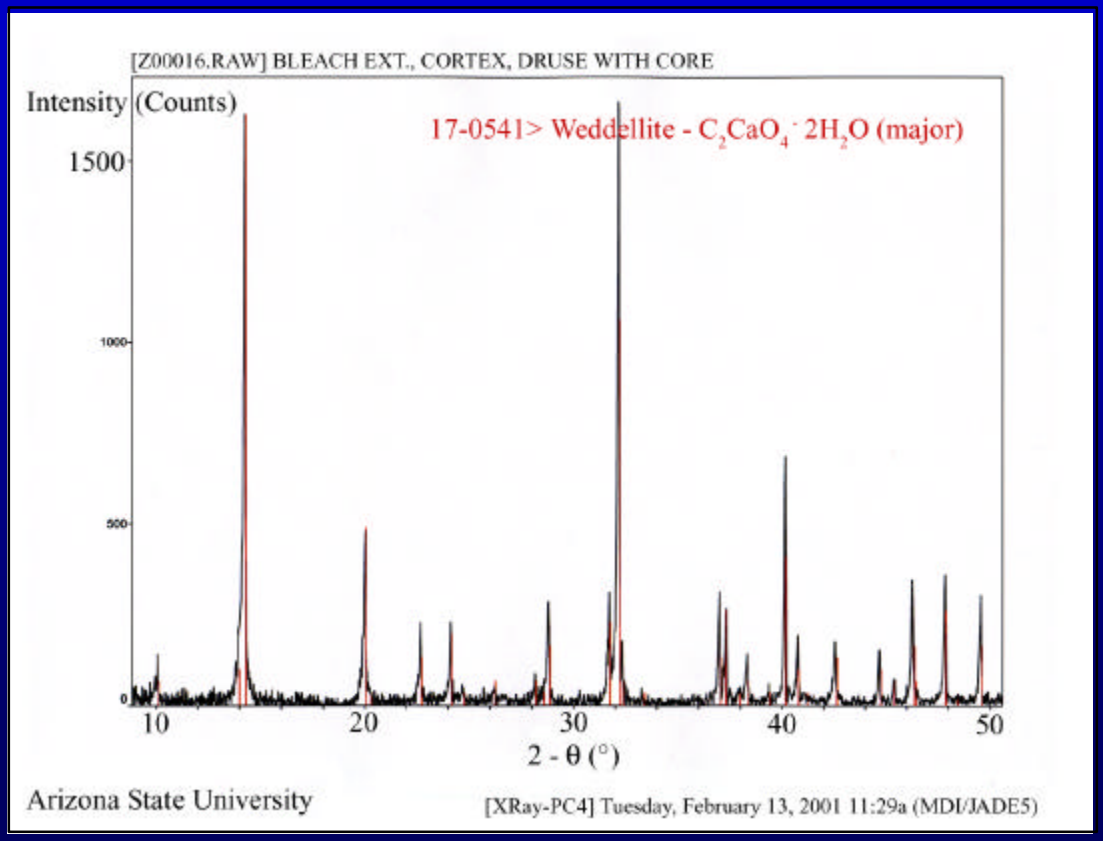


Bragg's equation:

$n \cdot \lambda = 2d \sin \theta$

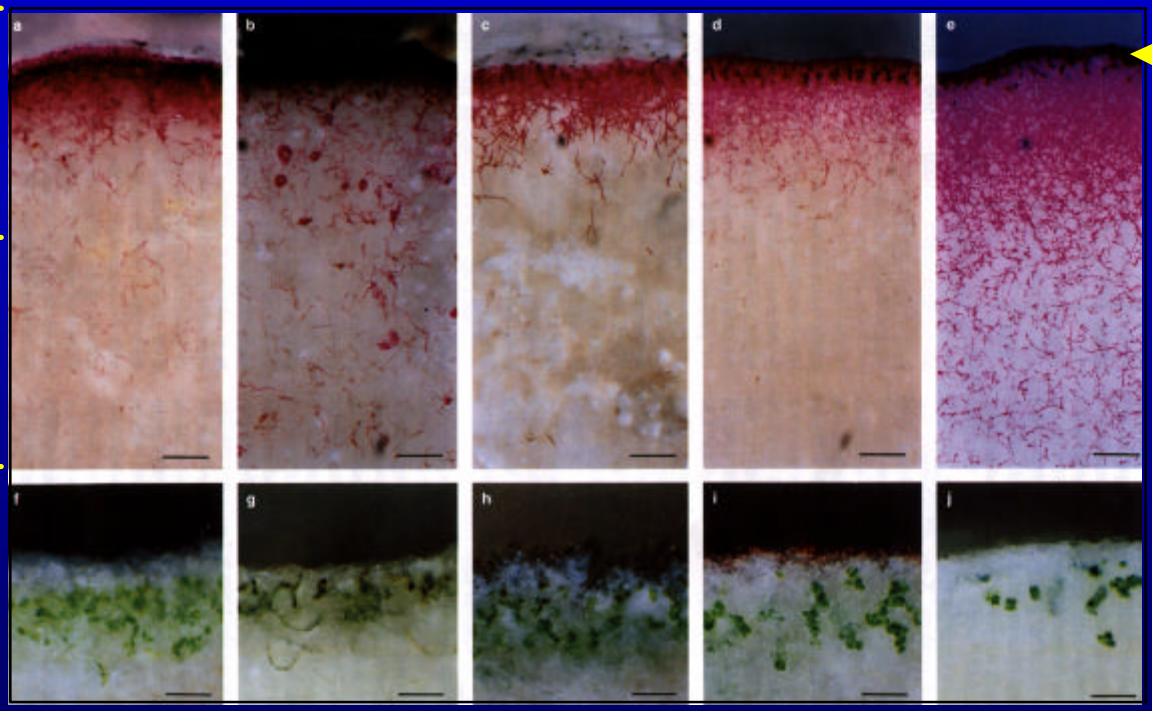


X-ray Diffractometry (XRD)



typical XRD pattern of weddellite (CaOxalate) in *Verrucaria rubrocincta*

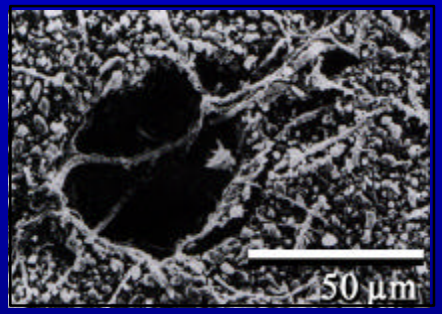
Other endolithic species (light microscopy)



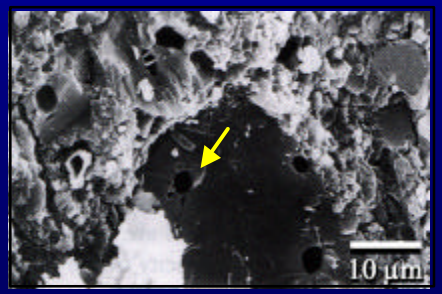
from

PINNA et al. (1998): An anatomical investigation of calcicolous endolithic lichens from the Trieste karst (NE Italy). - Plant Biosystems **132**:183-195

Scanning Electron Microscopy



void formed by
Petractis clausa



perforated calcite crystal

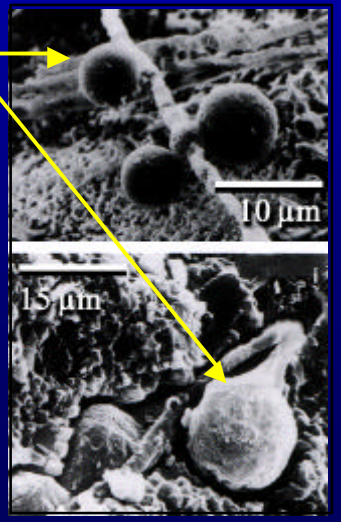
from
PINNA et al. (1998): An anatomical investigation of calcicolous endolithic lichens from the Trieste karst (NE Italy). - Plant Biosystems **132**:183-195

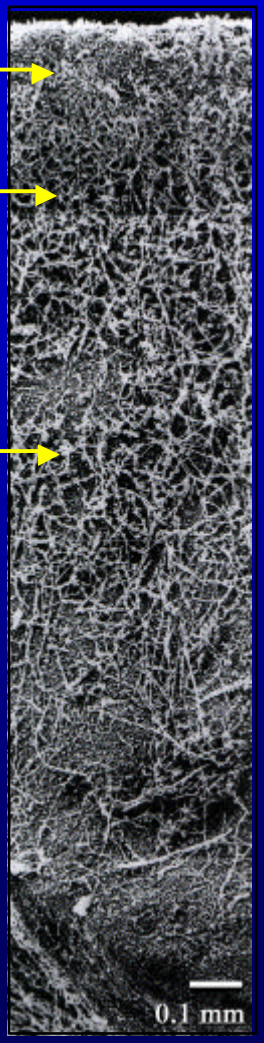
lithocortex

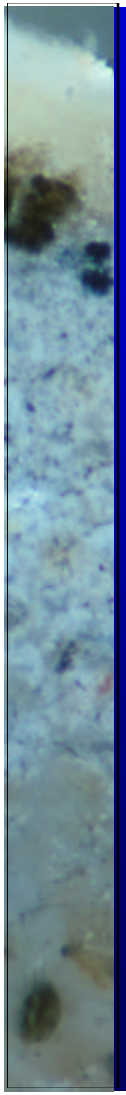
algal layer

medullary hyphae

oil cells







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 lichen 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

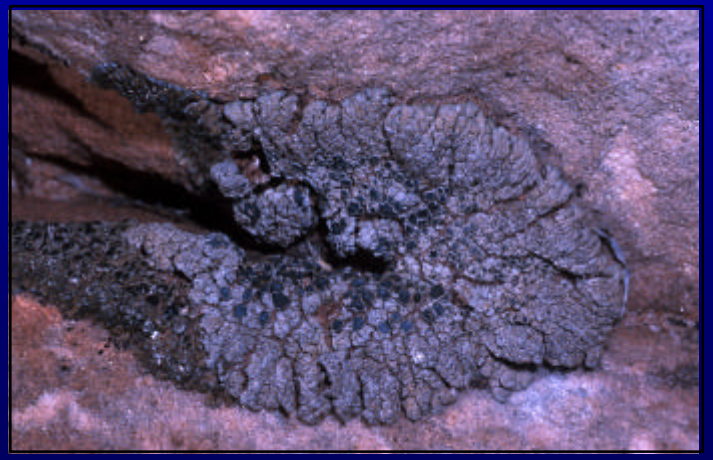
Soil Formation and Succession

- classical hypothesis:

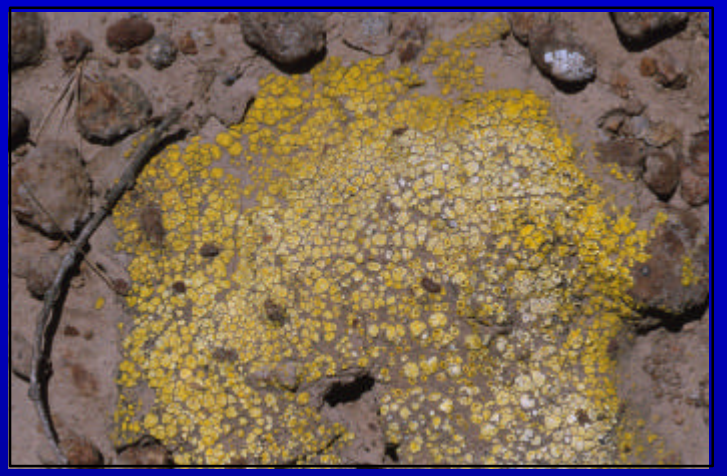
  cyanobacteria ➔ algae ➔ lichens ➔ bryophytes ➔ vascular plants

  rock substrates ➔ microsoils ➔ soils

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



Desert Soil Crusts



- probabely 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