Inorganic Structures of Life

**Biomineralization:** the study of the formation, structure and properties of inorganic solids deposited in biological systems

Biomineralization is a new type of chemistry

New type of chemistry

Synthesis
(construction)
(hard and soft matter)

Design of functionalized inorganic-organic materials
(small and large)
Biomineralization: the “big” picture

Selective extraction and uptake of elements from local environment
Strict biological control

This process leaves “traces” (signatures) in contrast to other biological transformations
(Examples: bones, shells, fossils)

Biomineralization became abundant ~ 570 millions of years ago

Evidence (stromatolites) for inorganic biomineralization
3500 millions of years ago
(the Earth is ~ 4200 millions of years old)

Random processes
Biomineralization: the “big” picture

ENVIRONMENT

Abundance and Availability

enzymes

Uptake

Transport

BIOMINERALIZATION

Structural role

Waste centres

Gravity-device

Rejection

Direction-finding device

lipids
proteins
carbohydrates
etc.
Biomineralization: implications at the global scale

EARTH SCIENCES

Global cycling of elements
Sedimentology
Fossilization (paleontology and taxonomy)
Marine chemistry
Geochemistry
Biomineralization and the silicon cycle
Biomineralization is involved at some stage in element cycling

Elements such as calcium, iron, phosphorus and silicon are cycled over millions of years through complex pathways that at some stage involve biomineralization

Huge chalk deposits (Dover, S. Britain) are a result of calcification in small single-celled organisms that lived ~ 200 millions of years ago in warm shallow sea
Biomineral structures: coccoliths
(calcium sulfate dihydrate)
Biomineralization gives a lot of information

Fossils contain a record of
- The distant biology
- Local climate
- Chemical conditions
- Marine environment

18O/16O isotopic ratio $\rightarrow$ paleotemperatures
Amounts of trace metals (Sr) $\rightarrow$ salinity of ancient water
Biomineralization provides organisms with a tough building material. There are tough skeletons constructed by an organic polymer (α-chitin in insect cuticle). But the energy demand is high.

Organic “armor” resists bashing or hammering…. But…

It does not work well in the arms of a predator.

There is much to be gained when hard and stiff (but brittle) organic materials are combined with inorganic strength.
Nature has found the solution

Building on a light-weight organic frame (to save on metabolic energy)
Fill it with “cheap” inorganic material (eg. calcium carbonate)

Inorganic-organic hybrid (biocomposite)
With well-defined mechanical properties
Biomineralization provides more than just support and mechanical strength.

 Variety of important biological functions

 Protection
 Motion
 Cutting and grinding
 Buoyancy
 Optical, magnetic and gravity sensing
 storage
Tissues

The higher-order structures arise from the evolution of Specialized tissues

These structures must be integrated into the body as a whole And they have to function properly and efficiently
Fundamental importance of hard tissues

Pathological biomineralization

Serious medical consequences when something “goes wrong”

Kidney stones, urinary stones, dental calculus, arthritis, osteoporosis

TIME Magazine
June 9, 2003
ΠΑΘΟΛΟΓΙΚΗ ΚΡΥΣΤΑΛΛΩΣΗ Ca(ox) ΣΕ ΒΙΟΪΑΤΡΙΚΑ ΟΡΓΑΝΑ

«ΦΥΣΙΚΟΙ» ΚΡΥΣΤΑΛΛΟΙ

«ΤΕΧΝΗΤΟΙ» ΚΡΥΣΤΑΛΛΟΙ

Biomineralization: a new chemistry

Biomineralization has shifted towards a chemical perspective

- Bioinorganic Chemistry
- Biomimetic Materials Chemistry

Structural and compositional characterization of biominerals
- Understanding the functional properties of biominerals
- Control by biomacromolecules
- Organization and construction of biominerals

- Supramolecular chemistry
- Organized matter chemistry
Biomineralization: inspiration

The inorganic-based structures of life – biominerals – represent a new area of study for bioinorganic chemistry and a source of inspiration in materials chemistry. Biomineralization is an example of organized-matter chemistry, which is concerned with the chemical construction, synthesis and emergence of organized architectures and complex forms.