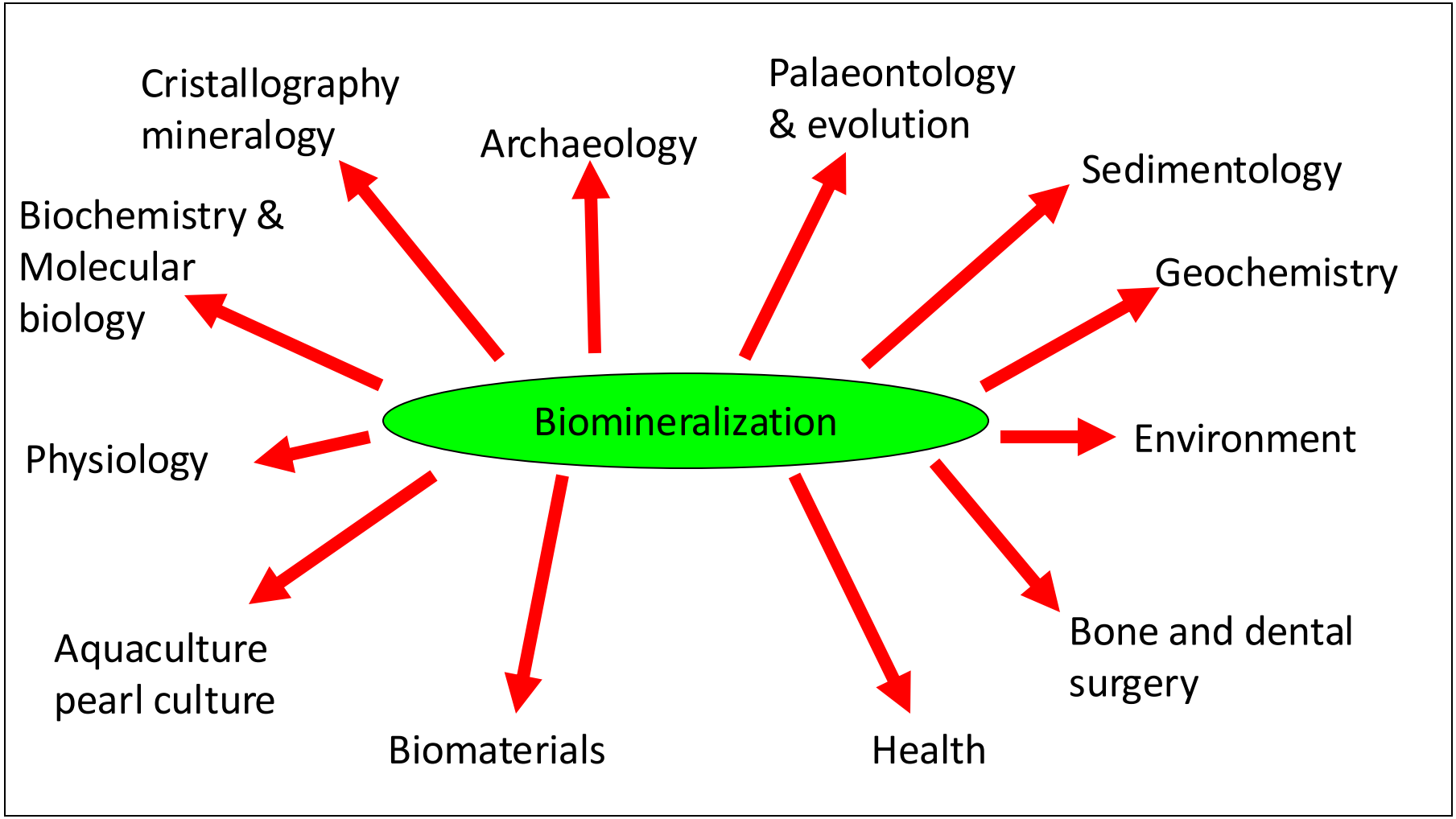
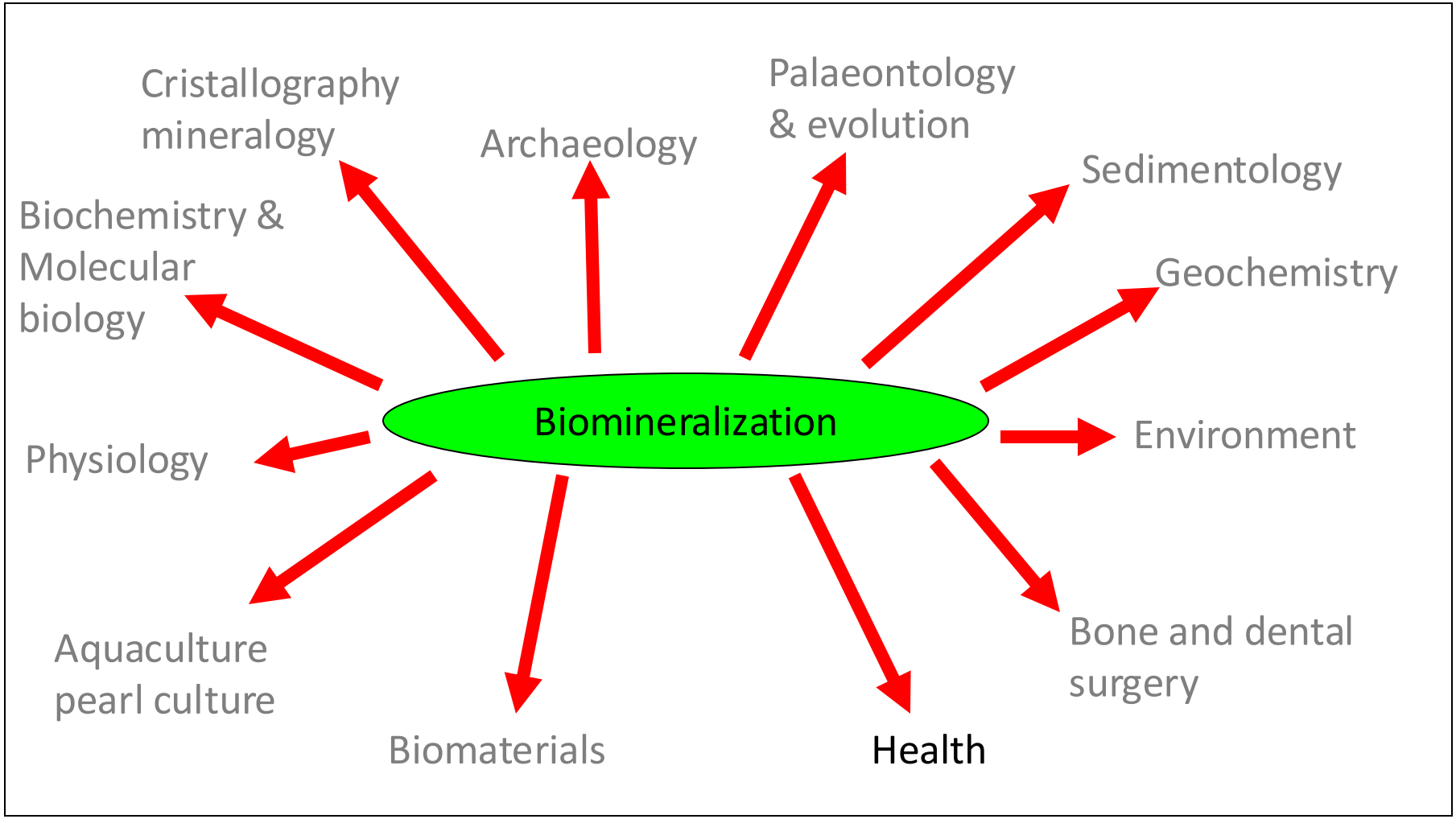
Biomineralizations

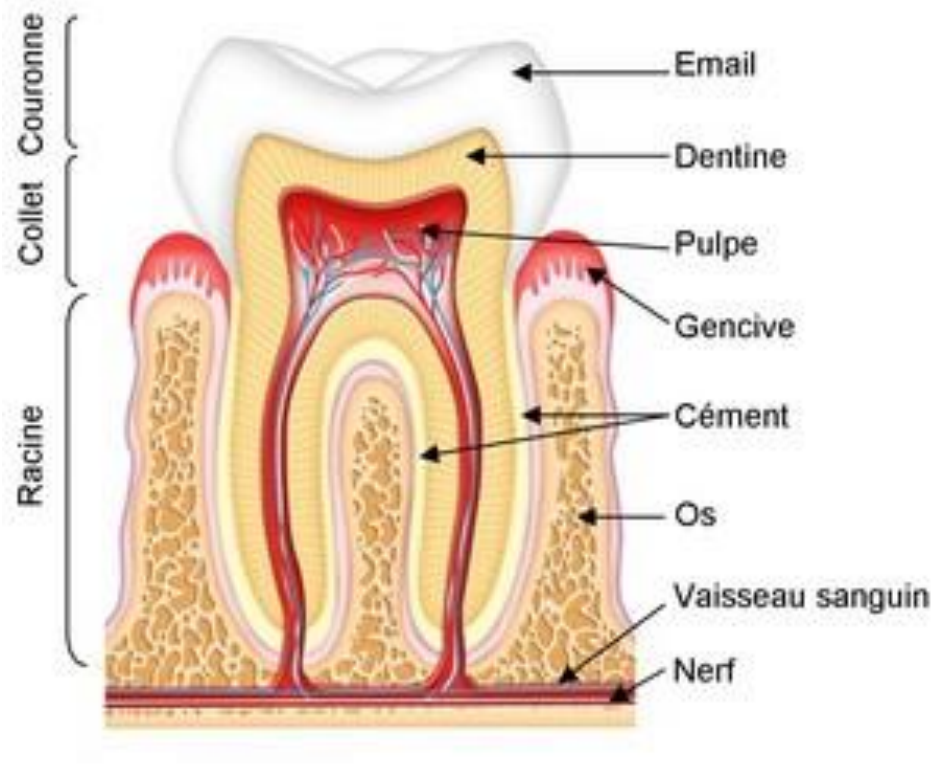
Applications


Cristallography
mineralogy
Archaeology
Palaeontology
& evolution
Sedimentology
Biochemistry &
Molecular
biology
Geochemistry
Biomineralization
Physiology
Environment
Aquaculture
pearl culture
Biomaterials
Health
Bone and dental
surgery


Cristallography
mineralogy
Archaeology
Palaeontology
& evolution
Sedimentology
Biochemistry &
Molecular
biology
Geochemistry
Biomineralization
Physiology
Environment
Aquaculture
pearl culture
Biomaterials
Health
Bone and dental
surgery

Dental surgery & implantology

- **Implants, a huge market: 3.5 billion Euros en 2014.**
- **High added value.**



Bone surgery

- **Population ageing**
- **Osteoporosis**
- **Hip / knee implants / prosthesis**
  - *** In France, per year:**
    - **Knee: 30 000 prostheses**
    - **Hip: 100000 prostheses**
  - *** In the USA: 285000 hip prostheses**

Bone surgery

Coral implants:
Porites sp.

- Decontaminated
- Thermic conversion in Ca-P

- Good porosity facilitating the migration of osteoblasts

- Relatively good mechanical properties but brittle
- Resorption capacity

Nephrology, urology

Kidney stones

Circa 5% of European population (1 à 10%), 5 to 15% in the USA. In France, 1 man on 10 and 1 woman on 20 had, has or will have kidney stone problems

Calcium-based: 80% of the cases.

- Calcium oxalate (whewellite, weddellite)

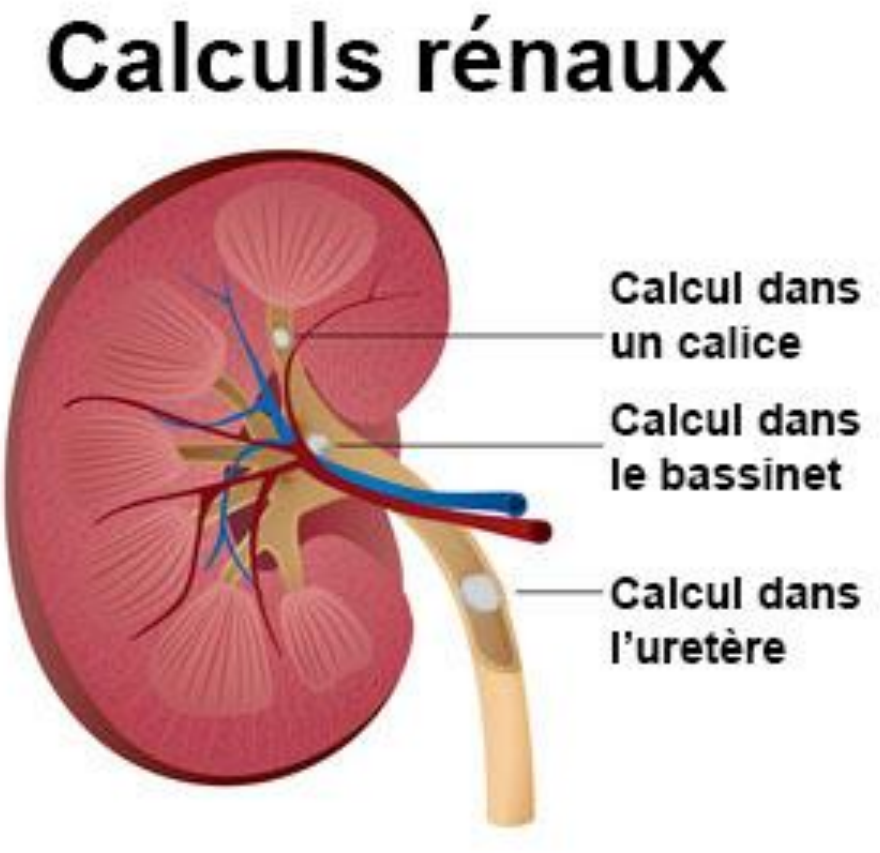
- Calcium phosphate (carbonate-apatite, brushite)

Non calcium-based: 20% of the cases

- Uric acid : 10% → gout

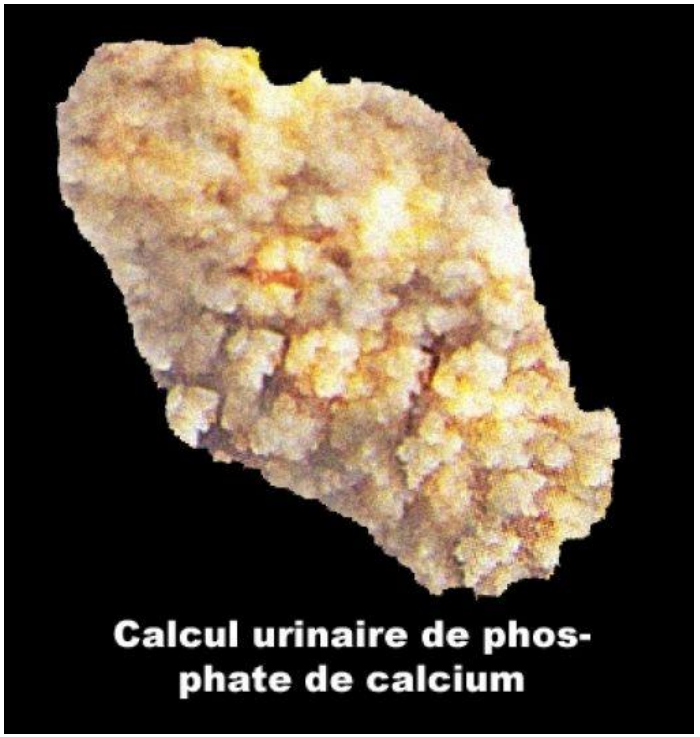
- struvite (Mg-phosphate): 10%

- cystine/xanthine: 1%.



Calcium-based kidney stones

‘Coralliform’ kidney stone in calcium oxalate

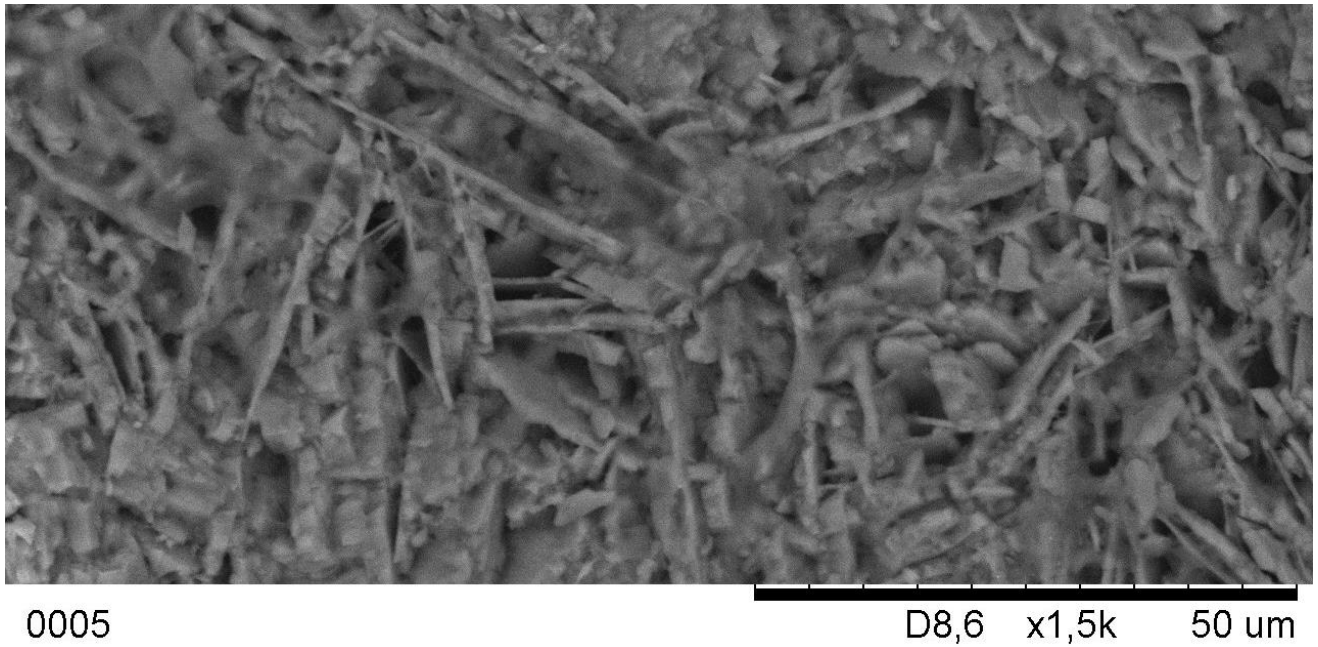


Crystallization inhibiteurs:

Non specific:
- Citric acid.
- Magnesium.
- Oligo-elements

Specific:
- GAGs
  - Nephrocalcin
  - Uropontin
  - Pyrophosphates

Uric acid kidney stones



Gastroenterology

PANCREATIC STONES

Up to 10% of the European population

More or less mineralized

Inhibitor of pancreatic stones: lithostatin

Pharmacology

Discovery of natural biactive substances, beneficial for health, extracted from biominerals

<u>The nacre example</u>:

- Bone surgery:

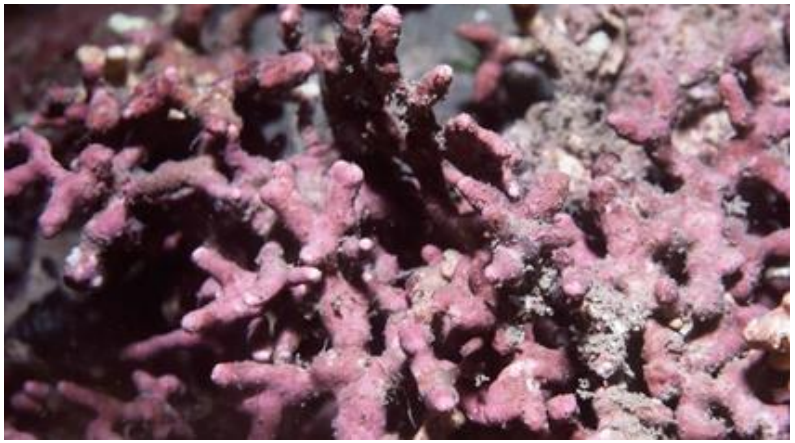
*** Osteoinductive and osteogenic properties of nacre matrix.**

- Cosmetology / dermatology:

*** Nacre extracts in dermal applications.**

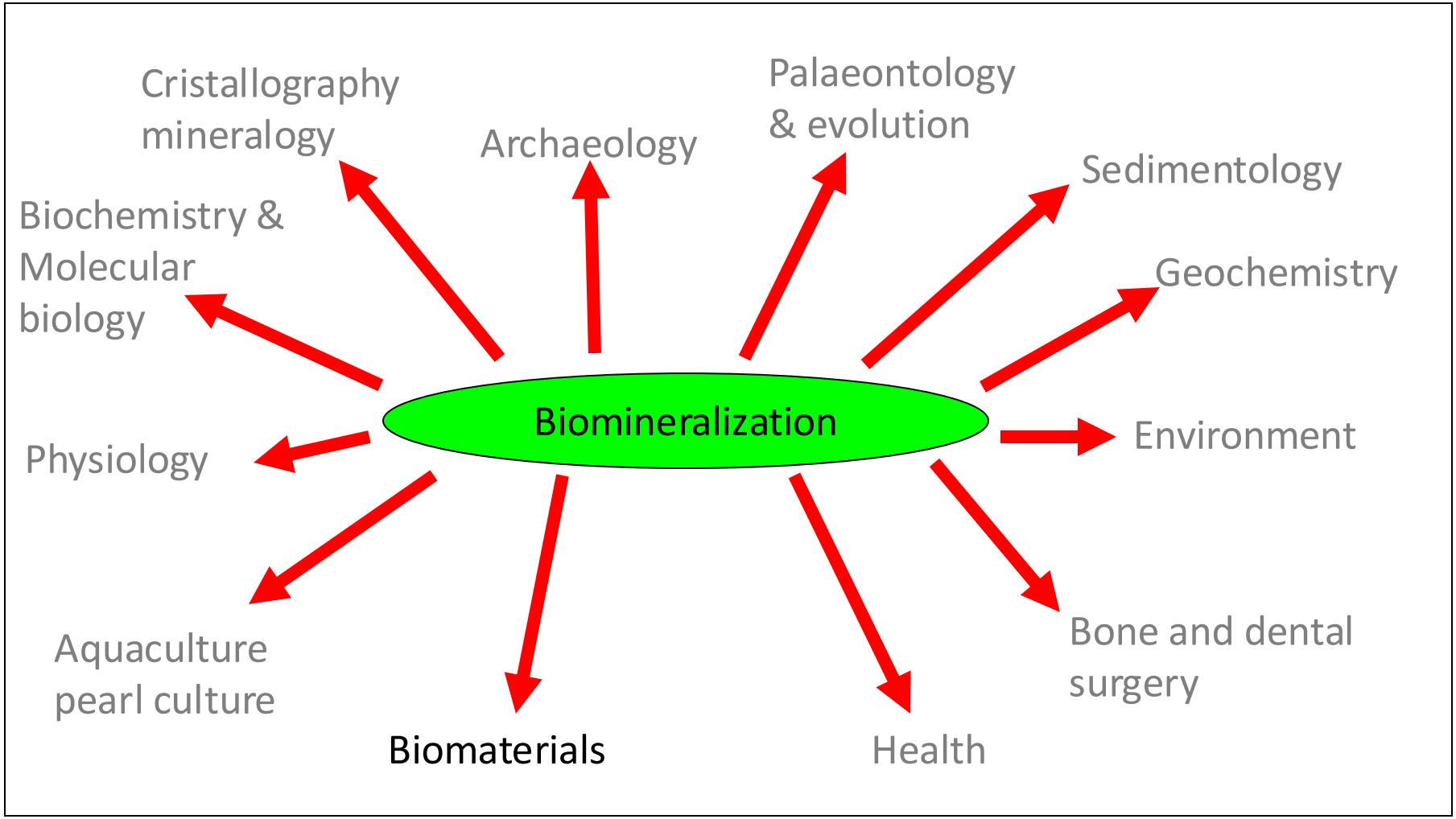
Pharmacology

Food supplement:



- Maerl (red algae)
- Nacre powder
- Coccoliths extracts

- ‘Organic silica’ (in reality, diatoms)


Cristallography
mineralogy
Archaeology
Palaeontology
& evolution
Sedimentology
Biochemistry &
Molecular
biology
Geochemistry
Biomineralization
Physiology
Environment
Aquaculture
pearl culture
Biomaterials
Health
Bone and dental
surgery

Construction materials

Limestone

Chalk

Lime

Other materials

Diatomites

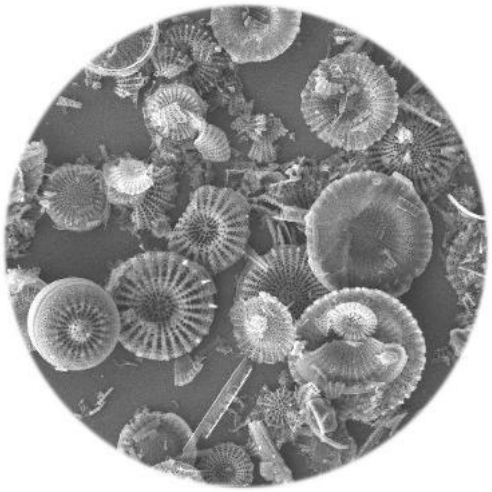
- Filters (wines)
- Abrasives
- Depolluting
- Mineral filler for

Painting

- Some natural deposits:

California (Lompoc,the biggest in the world), Turkey, China, Island.

World prod.: 1.8 millions tons/yr, 50% from USA.



- Coastal marine deposits
- Lacustrine deposits in relation to volcanism

Biomimetic materials
Bioinspired materials

*Most of the processes used in industry for making materials are **costly**:*
sintering of ceramics made at high temperature
*And / or **polluting** (polymers chemistry).*

➔ Development of a **Green Chemistry**, basedon synthesis processes made at room temperature, with a minimum of energy.

⇒ Nature fabricates biominerals under these conditions.

⇒ Observe Nature & try to mimic what it does: « bottom-up » approach

Biomimetic materials
Bioinspired materials

- **Nanocages (& nanotubes) made of silica or other**
- **Inspired from diatoms:**
  - **Applications: delivery of active substances in the body**

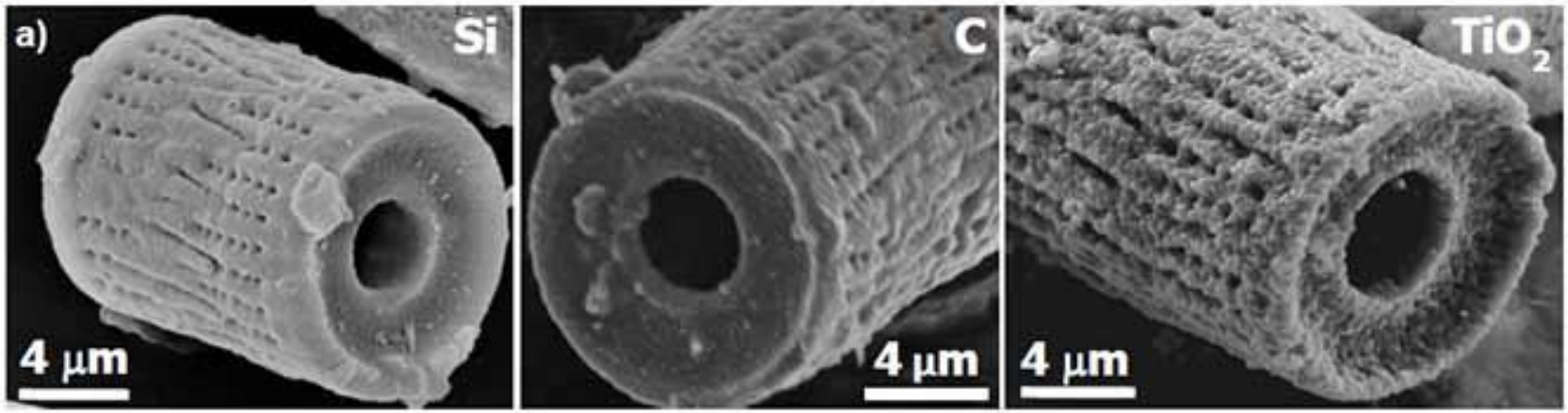


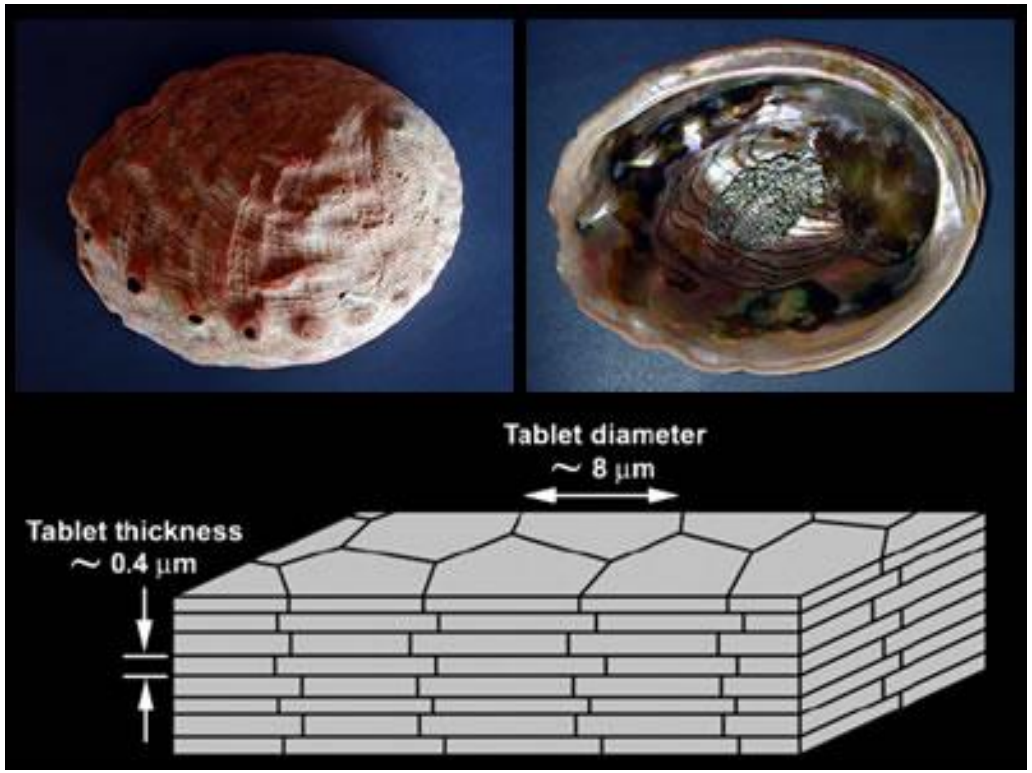
Figure 10. Secondary electron images of: a) porous Si, b) porous C, and c) TiO_2 replicas of *Aulacoseira* diatom frustules generated via shape-preserving gas/solid reactions.

Biomimetic materials
Bioinspired materials

- Siliceous sponge spicules behaving like optical fibers

Biomimetic materials
Bioinspired materials

- Materials in ‘tablets’ that mimic nacre in its microstructure

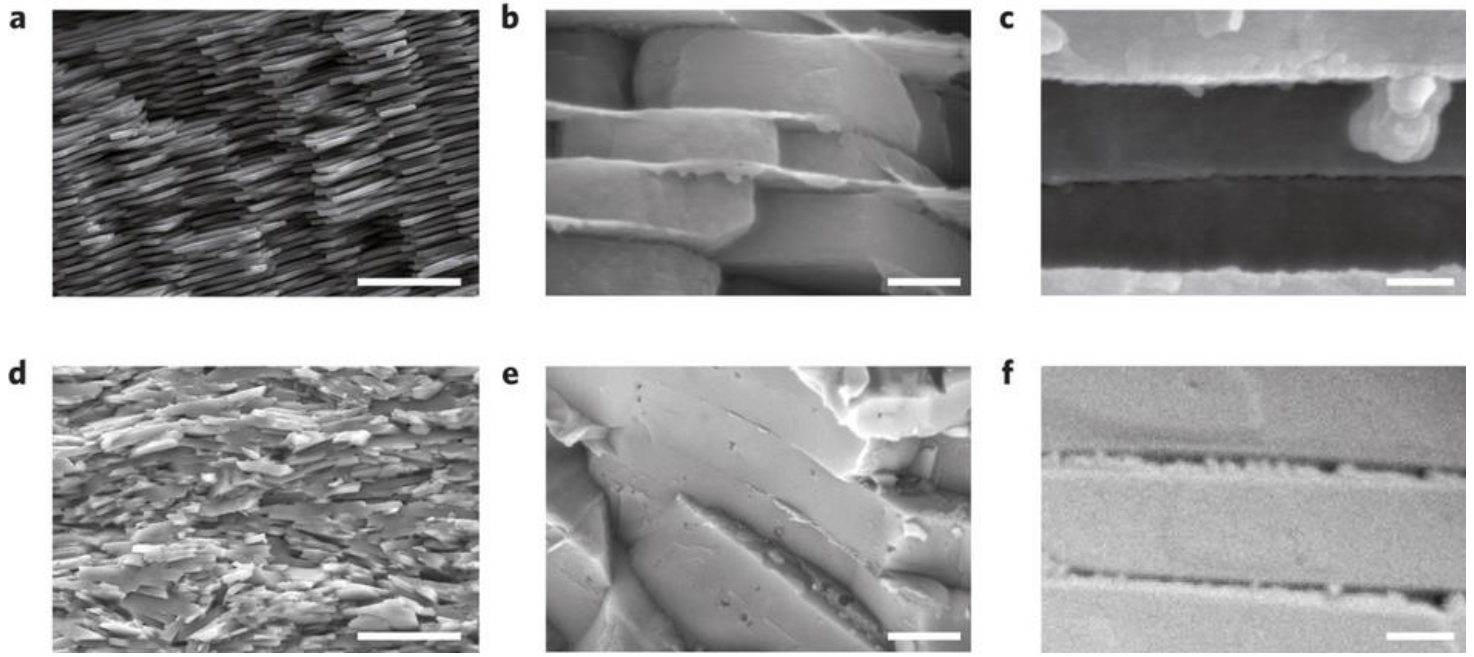


Resistance to fracture 1000 higher than that of chemical aragonite

CaCO3: cheap !

Biomimetic materials
Bioinspired materials

- Materials in ‘tablets’ that mimic nacre in its microstructure



True nacre

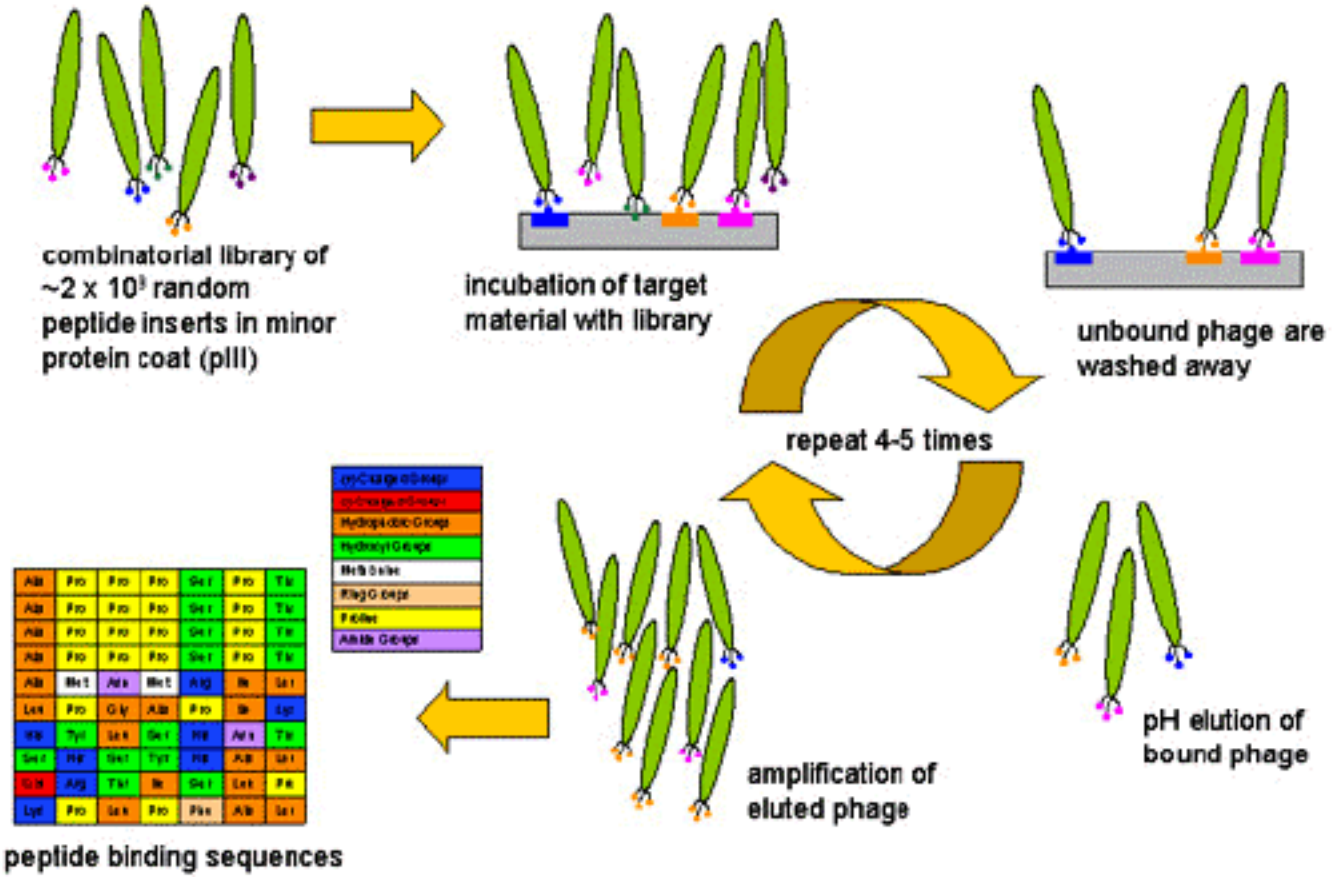
« Nacre » in aluminium oxide

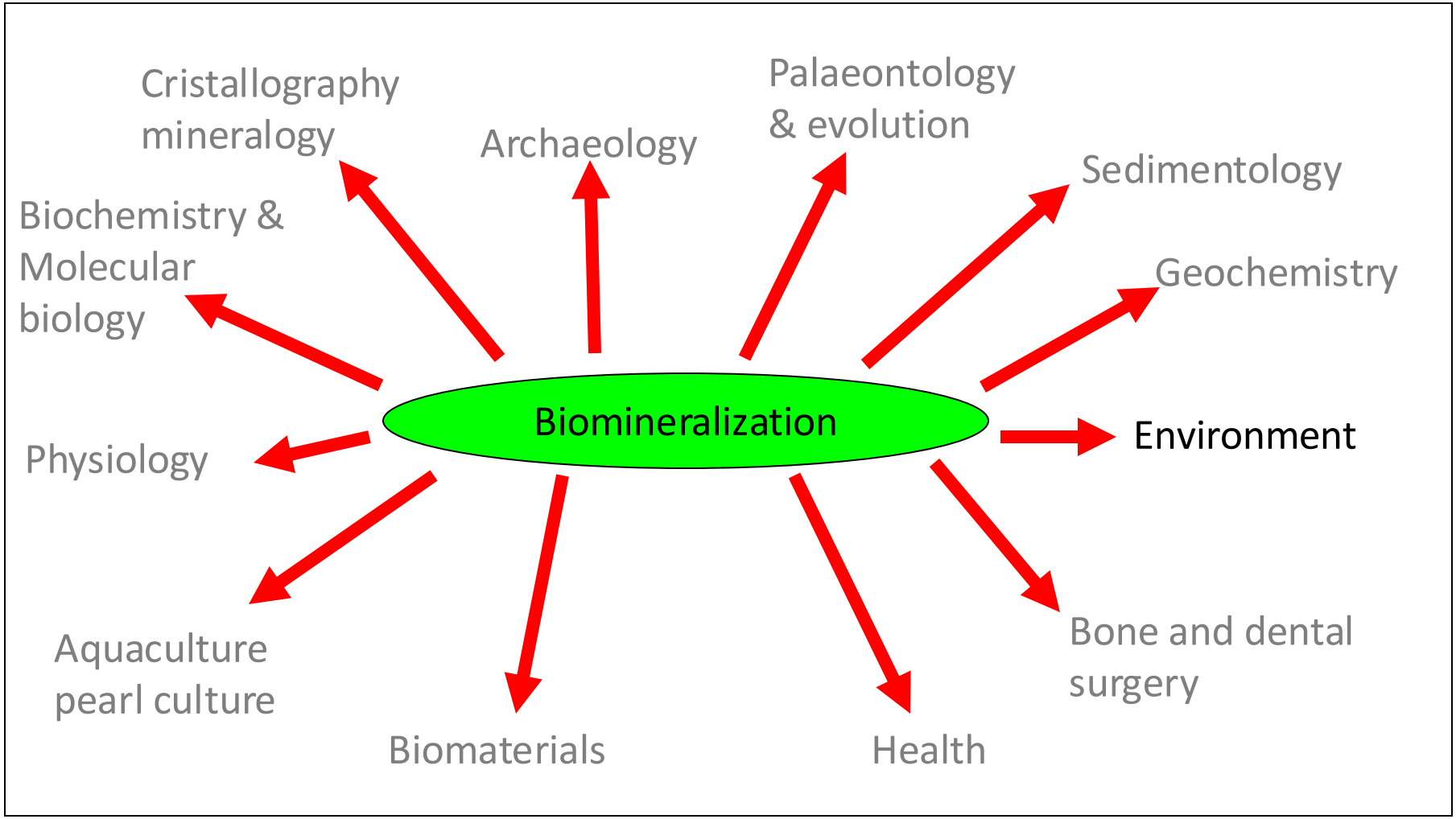
Bouville et al., 2014

Materials of the Future

Organo-mineral hybrid materials: nano-electronics, semi-conductors...

Phage display peptide library




Cristallography
mineralogy
Archaeology
Palaeontology
& evolution
Sedimentology
Biochemistry &
Molecular
biology
Geochemistry
Biomineralization
Environment
Physiology
Aquaculture
pearl culture
Biomaterials
Health
Bone and dental
surgery

Environment: biofouling

Biofouling
(colonization of surfaces by living organisms that make ‘crusts’)

- Threat: endolithic microorganisms
- Use of calcifying bacteria to remineralize construction materials degraded by pollution

Environment: anti-fouling

Anti-fouling substances on boat hulls

- Super-tankers, gas (LNG) carrier without antifouling = up to 40% increase of fuel consumption

- > 25000 marine species able to colonize a submerged surface
- 1 to 2 mm of encrusting algae = 15% loss of speed.
- 1 m^2 of boat hull: can welcome up to 150 kg of organisms.

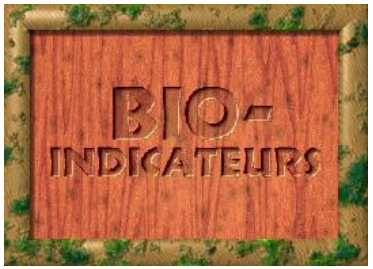
Bacterial biofilm→ Foraminifera, algae
→ barnacles, mollusks, calcifying worms

Environment

Ecological monitoring:
Biomineralizations = ‘ecological sentinel’ of the environment

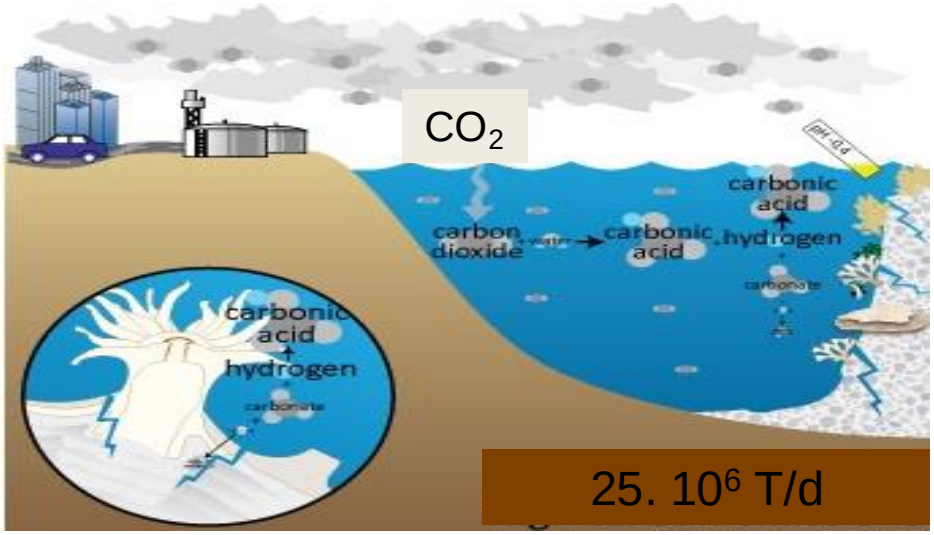
Biomineralizations = archives of environmental parameters:

- **Temperature, salinity,**
- **Pollutions: heavy metals, organic pollutants, pesticides...**



Environment: CO_2 storage

CO_2 storage



Oceanic acidification

Moment	pH
Pre-industrial period	8.2
Today	8.1
2100	7.8

- Perennial storage (in comparison to vegetal storage)
- Trap CO_2 with calcifying organisms:
  - Calcifying bacteria

Environment: water dépollution

Biominerals, when reduced in powder have interesting surface charge properties, due to the presence of organic polyanionic macromolecules

- Flocculation of clay minerals that are in suspension in meteoric waters, during flood
- Trapping of metallic cations
- Example of maerl: alkalinisation of acidic waters (drinking water treatment)

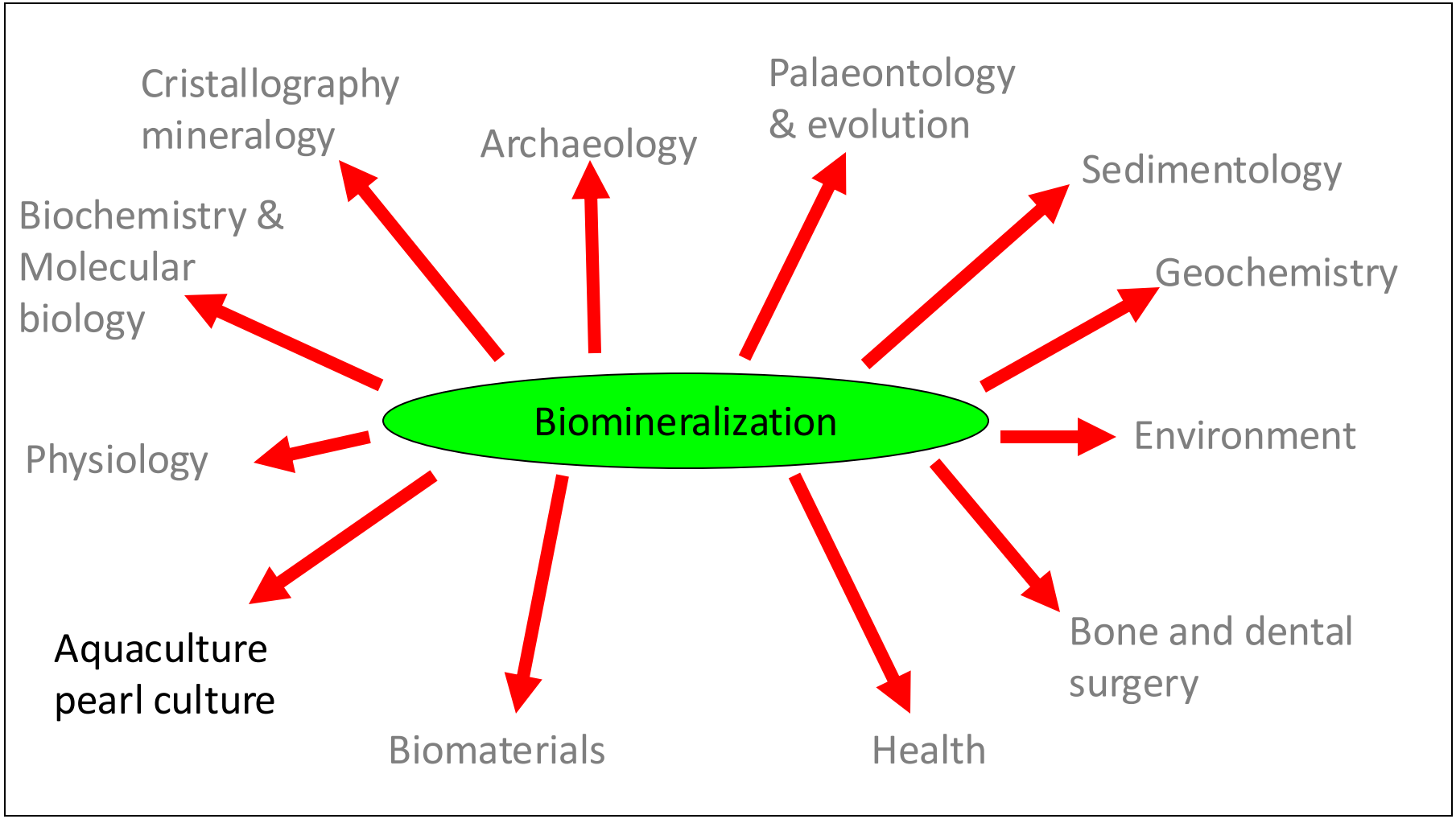
Environment: soils amendment

Soils poor in Ca

Soils poor in Mg

Acidic soils

- Crushed mollusk shells
- Chalk
- Maerl (rich in Mg)


Cristallography
mineralogy
Archaeology
Palaeontology
& evolution
Sedimentology
Biochemistry &
Molecular
biology
Geochemistry
Biomineralization
Physiology
Environment
Aquaculture
pearl culture
Biomaterials
Health
Bone and dental
surgery

Zootechnics: aquaculture

Shellfish farming
(pathology affecting the shell of edible species)

Examples:

- Chambers in oyster shells in the 80 – TBT
- Scallop shells
- Manila clam (*Venerupis philippinarum*) brown ring disease

Zootechnics: pearl culture

PEARL CULTURE / AQUACULTURE

The French Polynesia example

Black pearl of French Polynesia

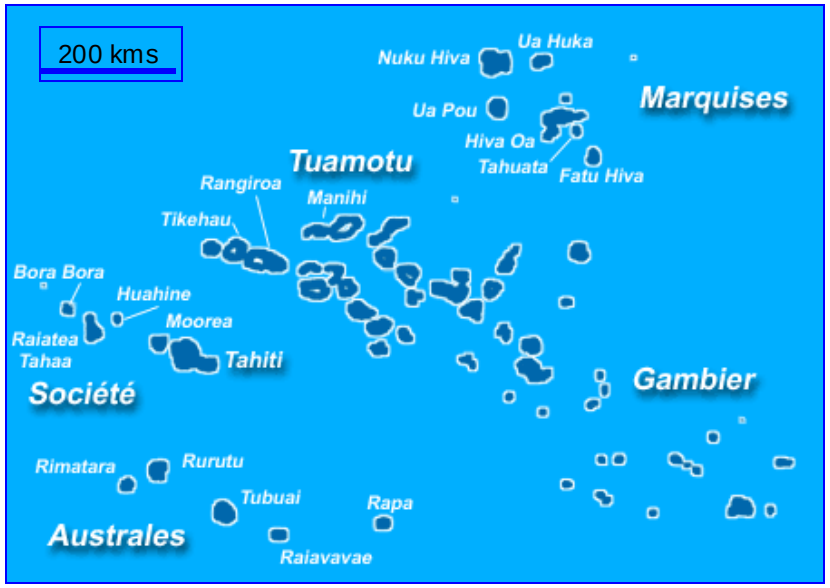


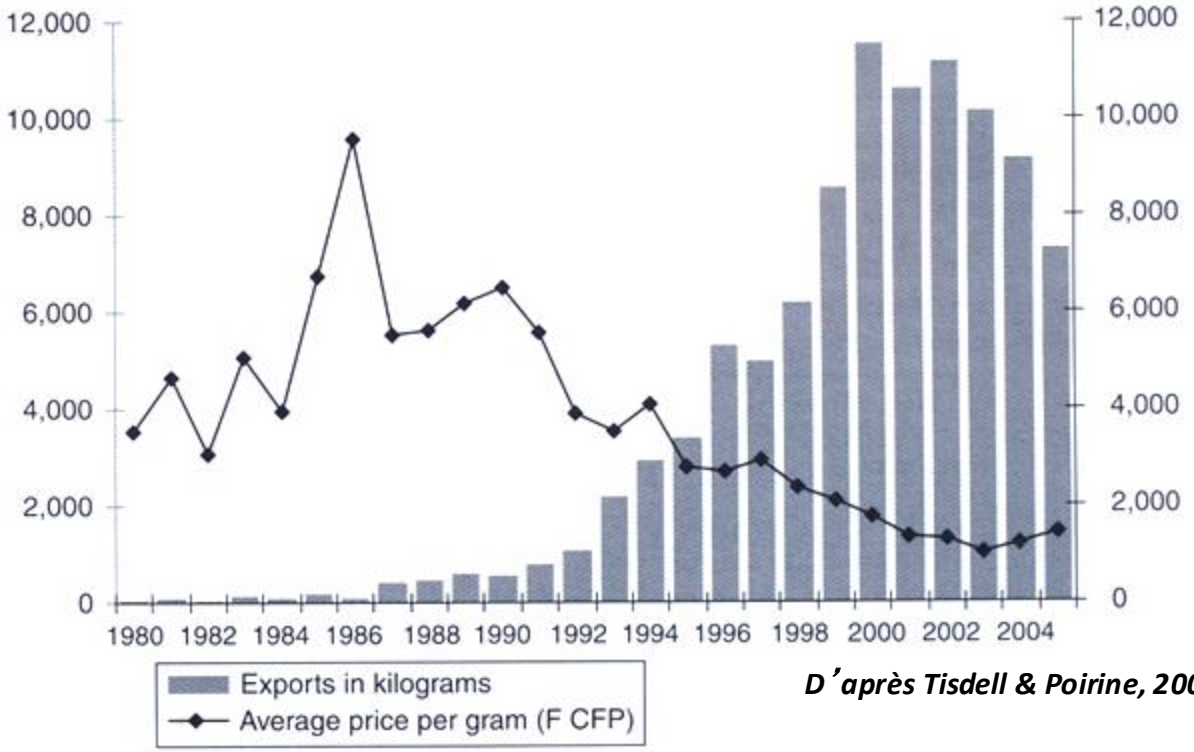

Photo F. MARIN

Population: circa 280 000
Pearl activity: 4000/5000
800 pearl farms
Polynesia : 90% of black pearl of southern seas

58% of exportation

120 millions US $ per year

Economic situation in French Polynesia



D'après Tisdell & Poirine, 2008

A domain in crisis between late 90 until 2015

Decrease of pearl quality

Decrease of demand

New competitors

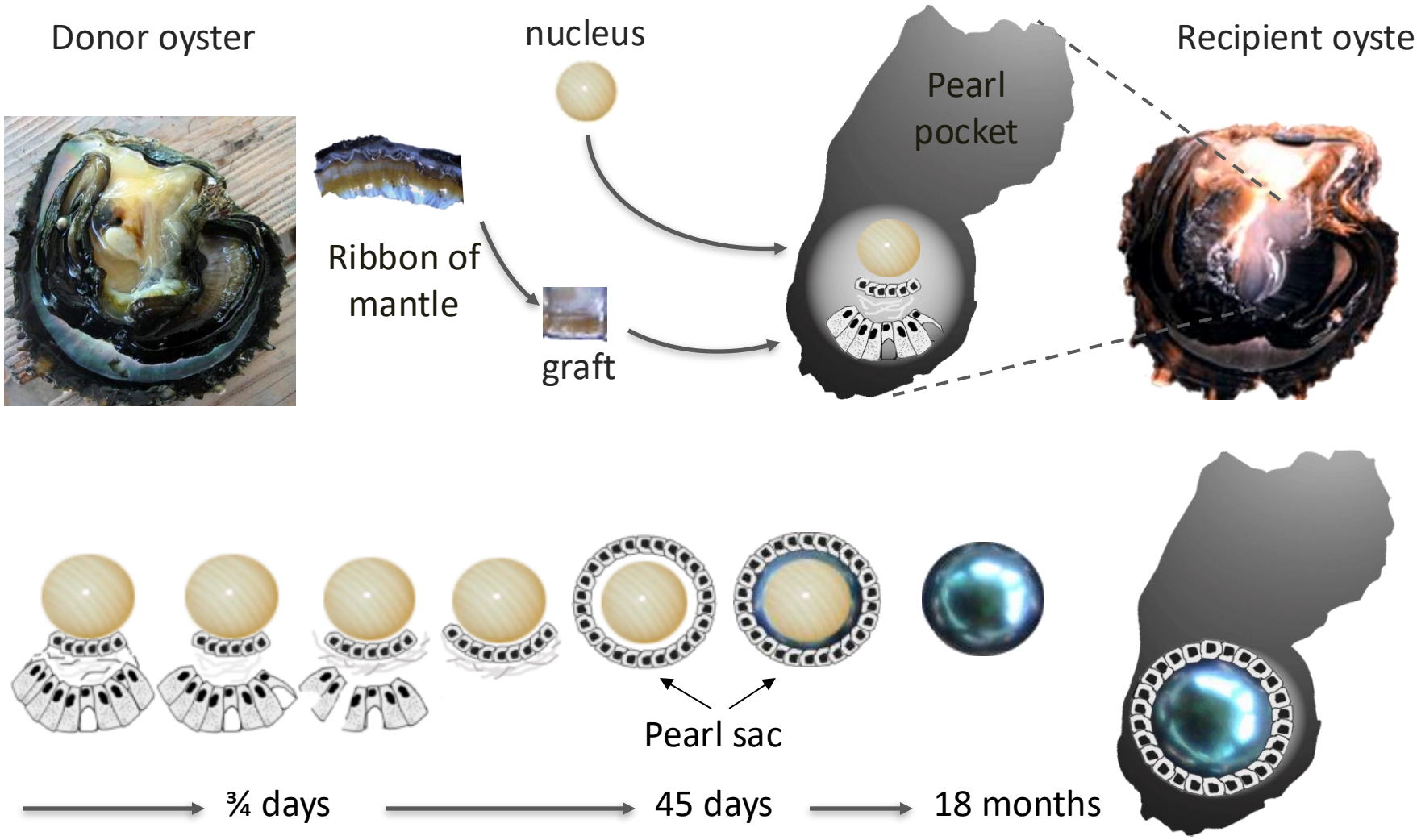
Solution => Produce again pearls of quality

=> GDR ADEQUA (Ifremer 2008-2012), 10 partners

Film MNHN Paris (BOME, C. Milet)

Pearl culture in Polynesia

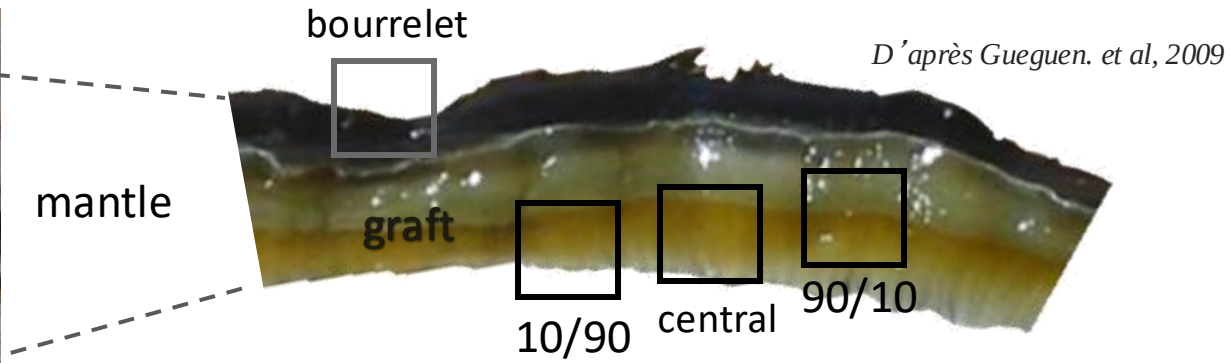
How to fabricate a pearl



Drawing C. Montagnani

Role of the graft in the quality of the pearl

Huître donor



D'après Gueguen. et al, 2009

Where the graft is taken is important for the quality and color of the future pearl

Need to understand the mechanisms of mineral deposition regulation in the mantle