Calcareous Algae and Microbial Carbonates

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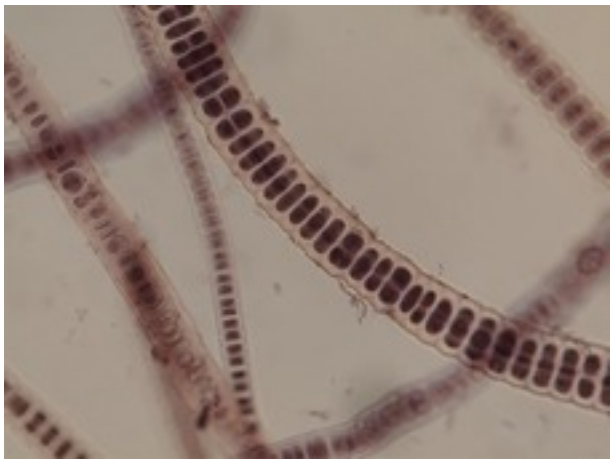
What are algae?

Algae are the photosynthetic organisms excepting land plants

They are "simple" (their tissues are not organized into many distinct organs)

From single-celled forms to large, complex multicellular forms (seaweeds, kelps)



They occur in most habitats, ranging from marine and freshwater to desert sands and from hot boiling springs to snow and ice

Major groups

prokaryotes — Cyanobacteria (blue-green algae)

eukaryotes, "true" algae

- Chlorophyta (green algae)
  - Charophytes
- Rhodophyta (red algae)
- Heterokonts
  - Bacillariophyceae (diatoms)
  - Phaeophyceae (brown algae)
- Haptophyta (coccolithophores)
- Dinoflagellates

and several other…

type of chlorophyll and other pigments

Polyphyletic: many independent endosymbiotic events

Heterokonts

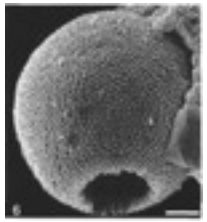
Bacillariophyceae (diatoms) test (cell wall) of silica

Phaeophyceae (brown algae) very few species calcify

Haptophyta (coccolithophores) calcite scales

plankton

Dinoflagellates calcite cysts



Chlorophyta (green algae)

Charophytes

Rhodophyta (red algae)

Cyanobacteria (blue-green algae)

A few subgroups calcify

CALCAREOUS ALGAE

Charophytes (stoneworts)

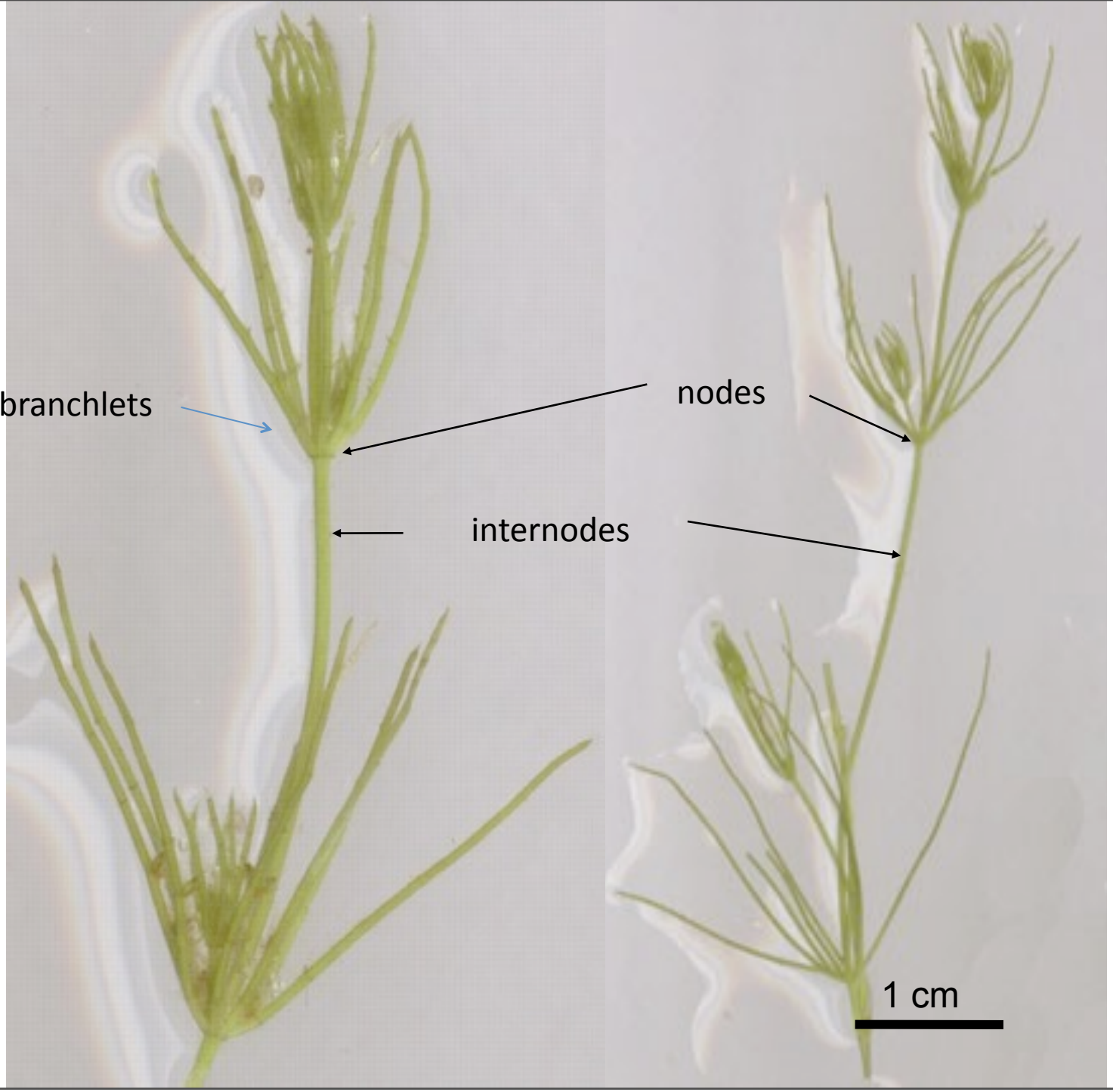
Sister group (closest relatives) of land plants

Common pondweeds

Fresh and brackish water

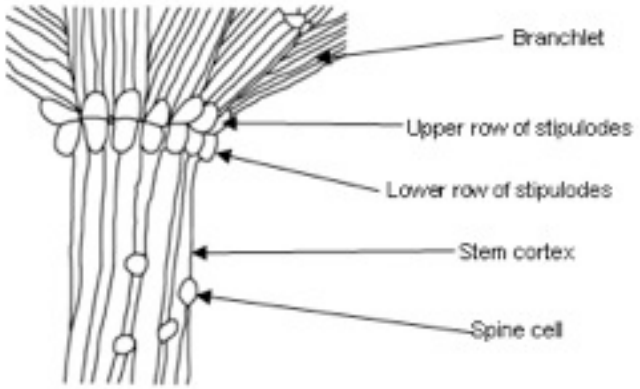
Cosmopolitan, highest abundance in warm temperate climates

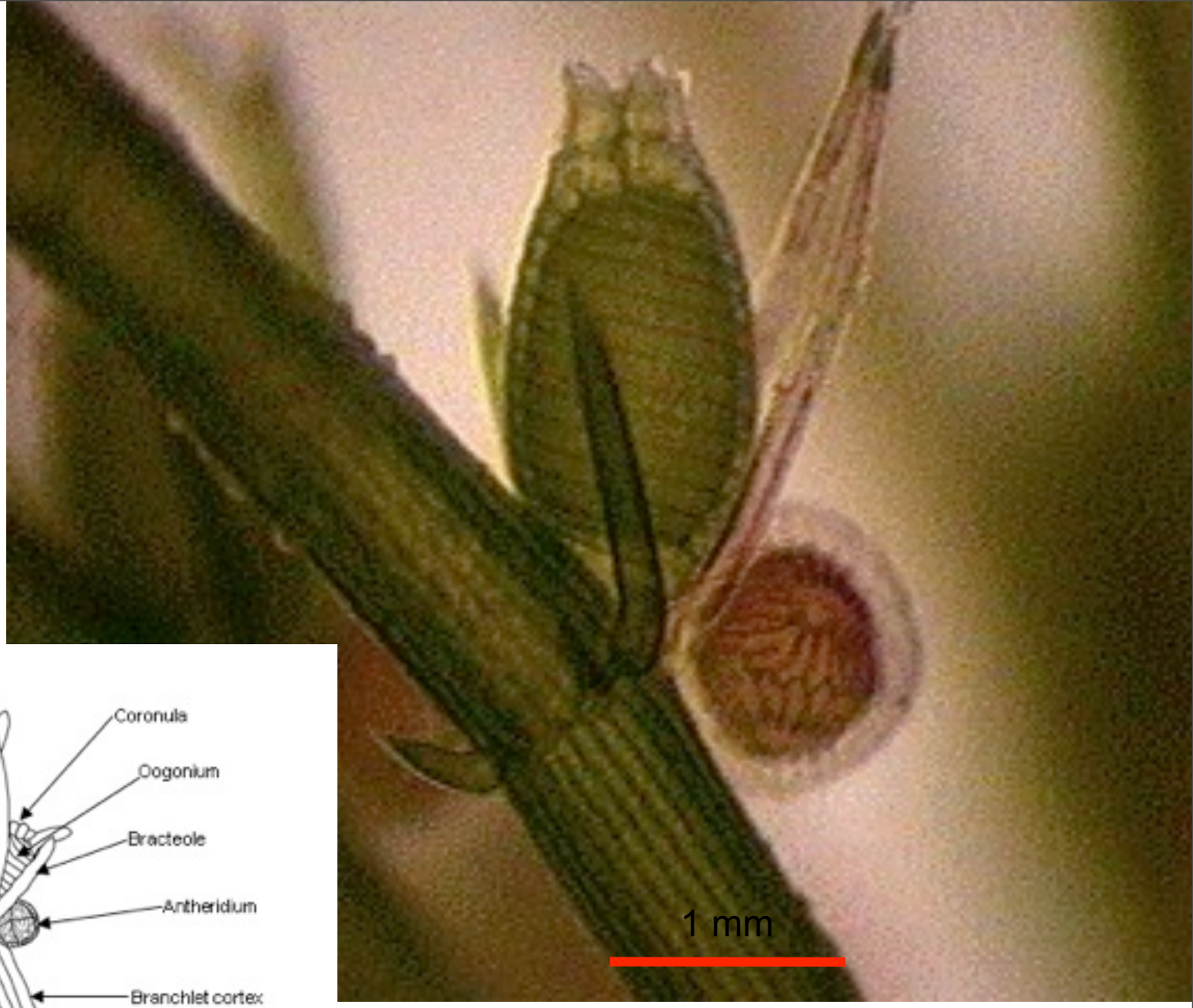

Muskgrass
Chara spp.
Photo by Vic Ramey
Copyright 2000 Univ. Florida


whorls of branchlets
nodes
internodes
1 cm

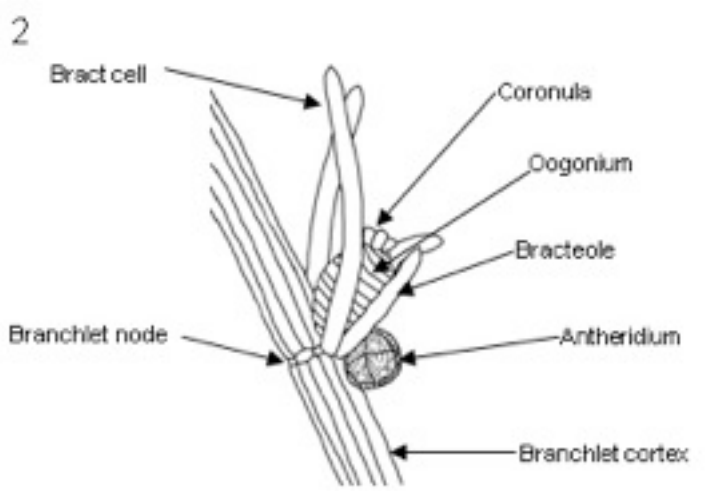

1 mm

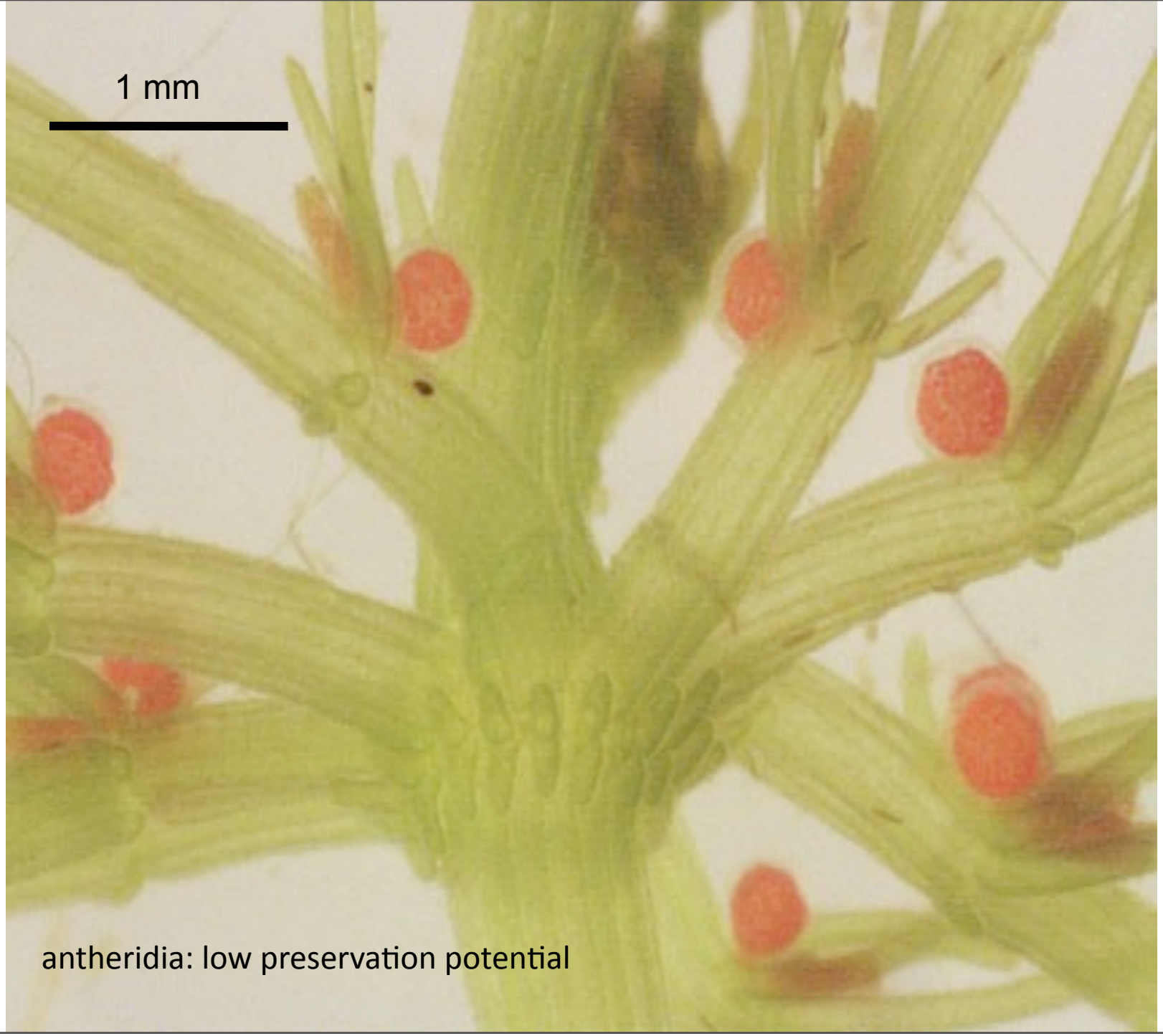
3


Branchlet
Upper row of stipulodes
Lower row of stipulodes
Stem cortex
Spine cell


1 mm

2

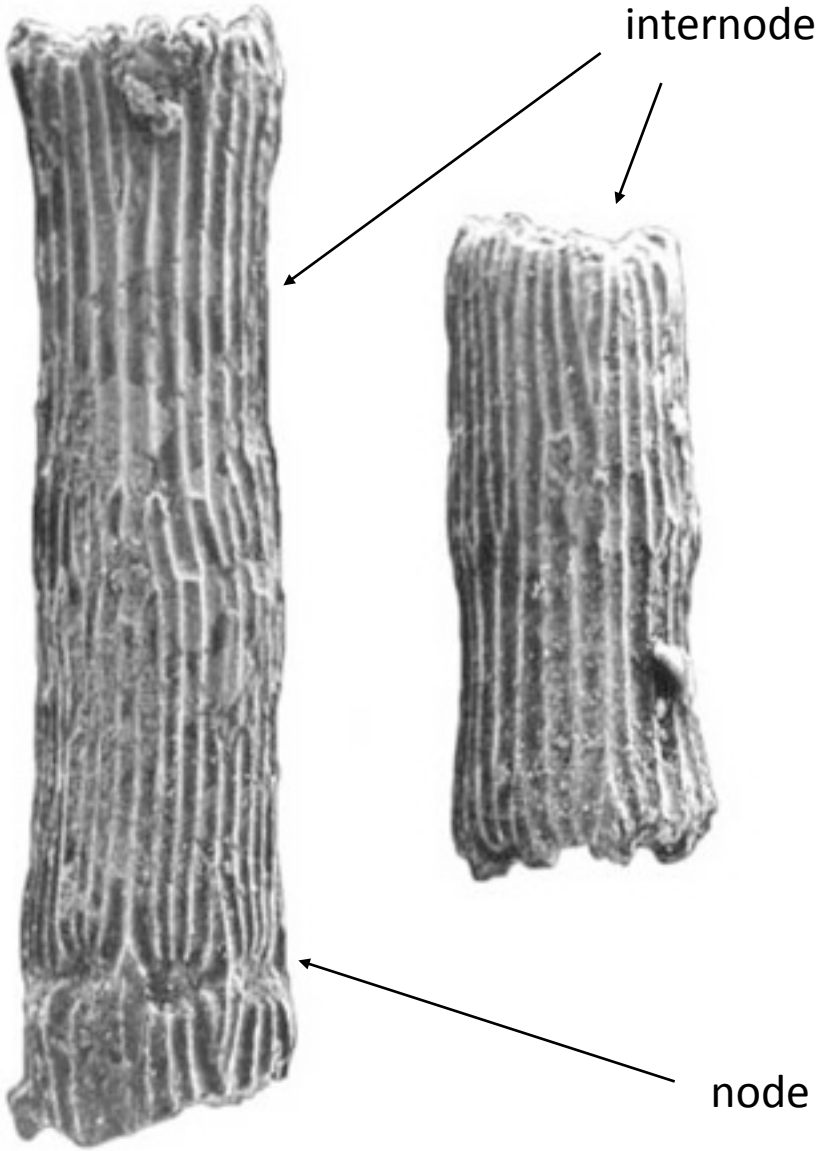

Bract cell
Coronula
Oogonium
Bracteole
Branchlet node
Antheridium
Branchlet cortex

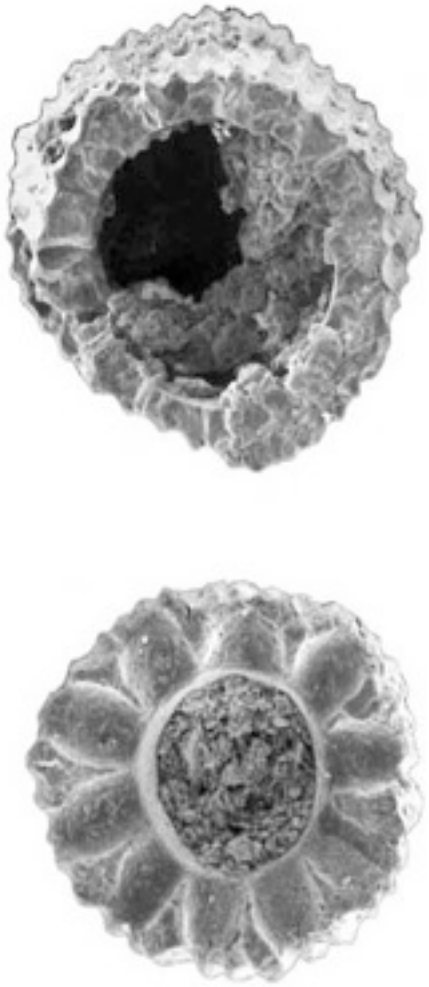

1 mm
antheridia: low preservation potential

calcite (plus aragonite) precipitation around stem cells and branchlets

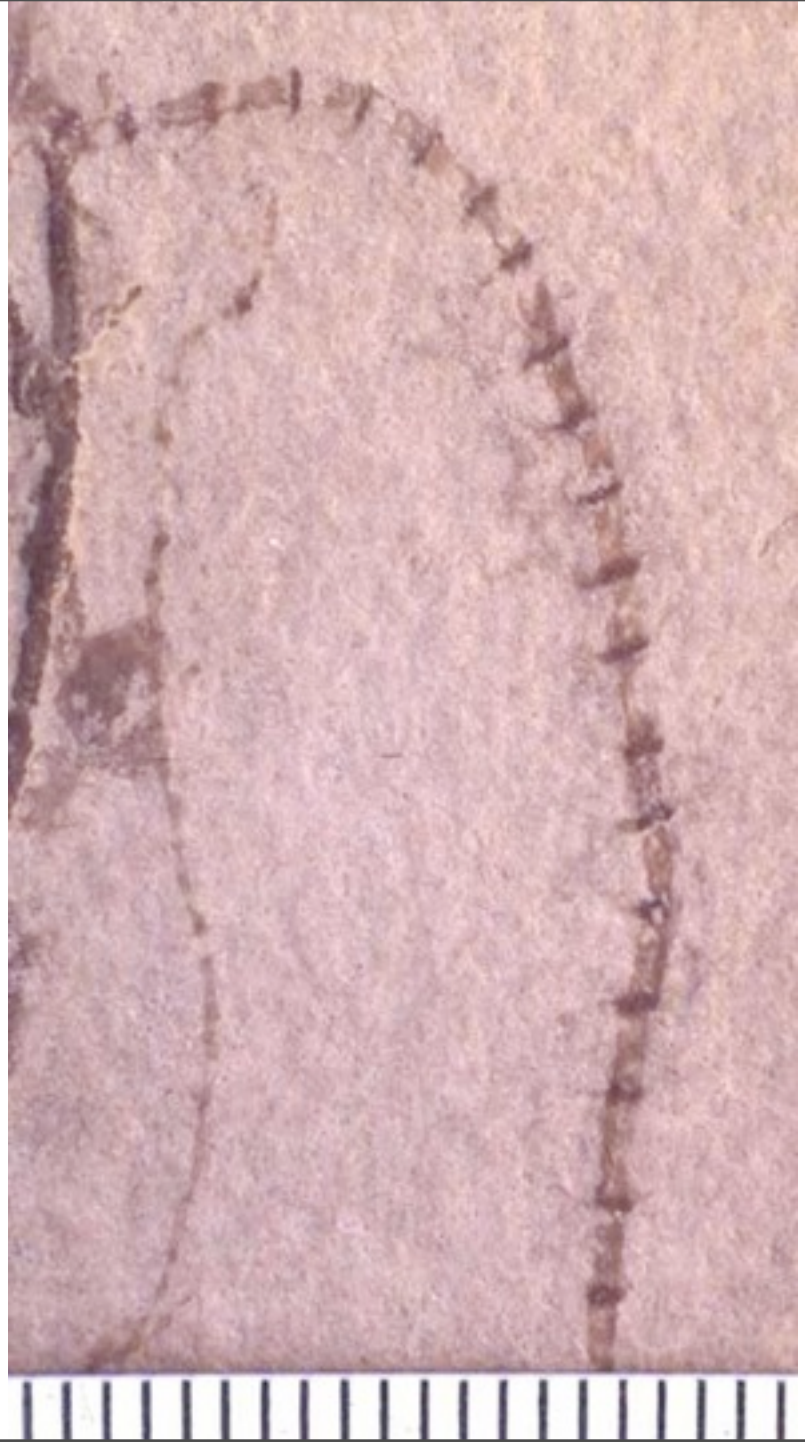
calcite formation in cells surrounding the egg cell

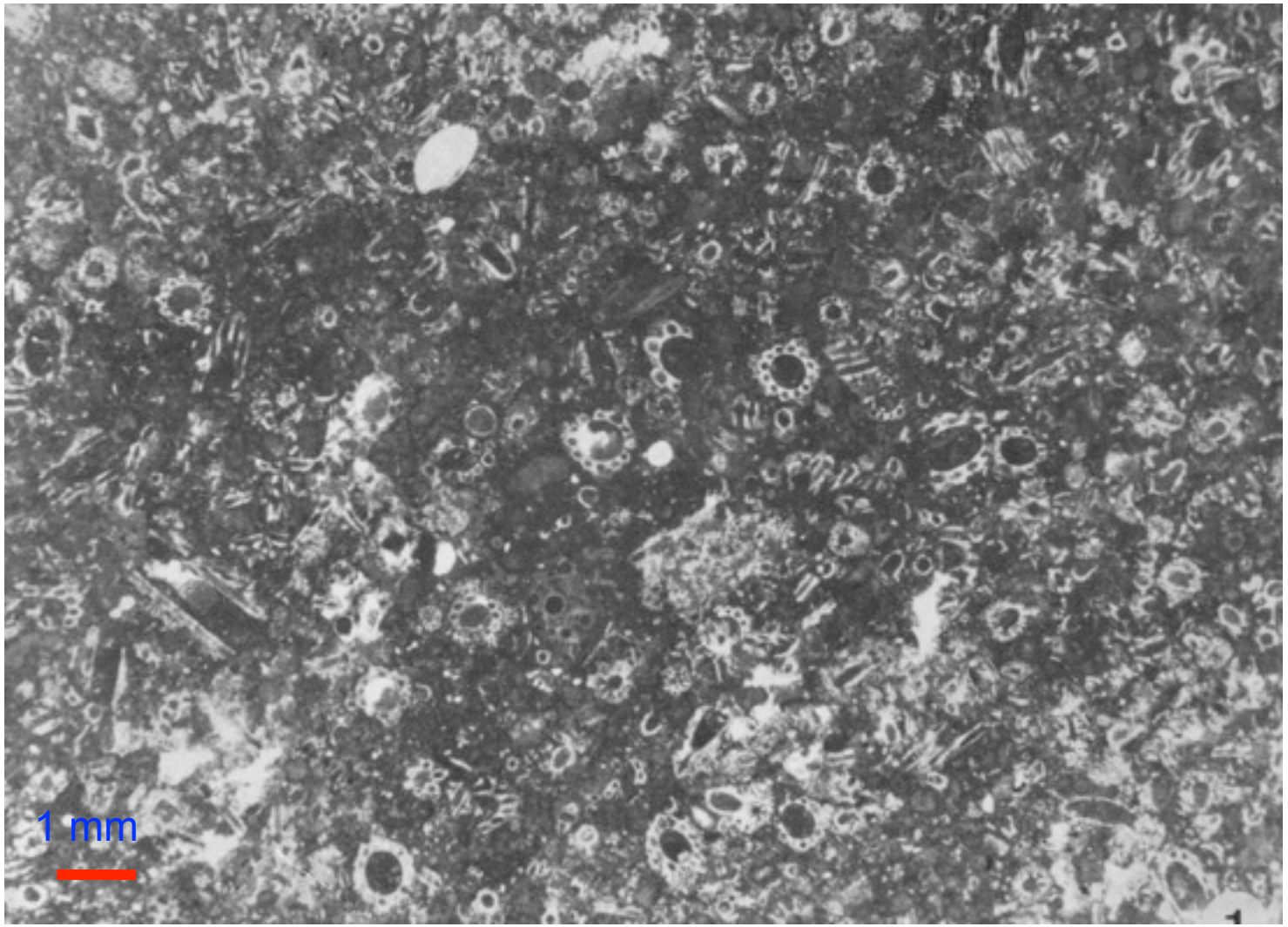
gyrogonite





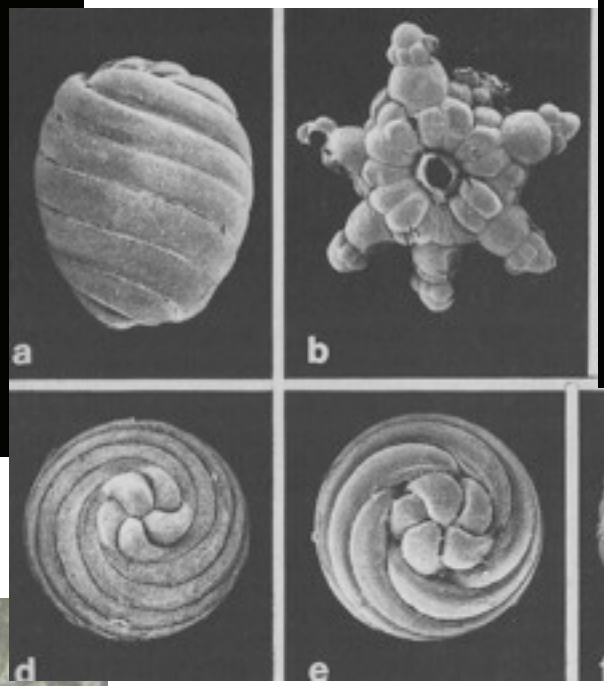
calcified stems

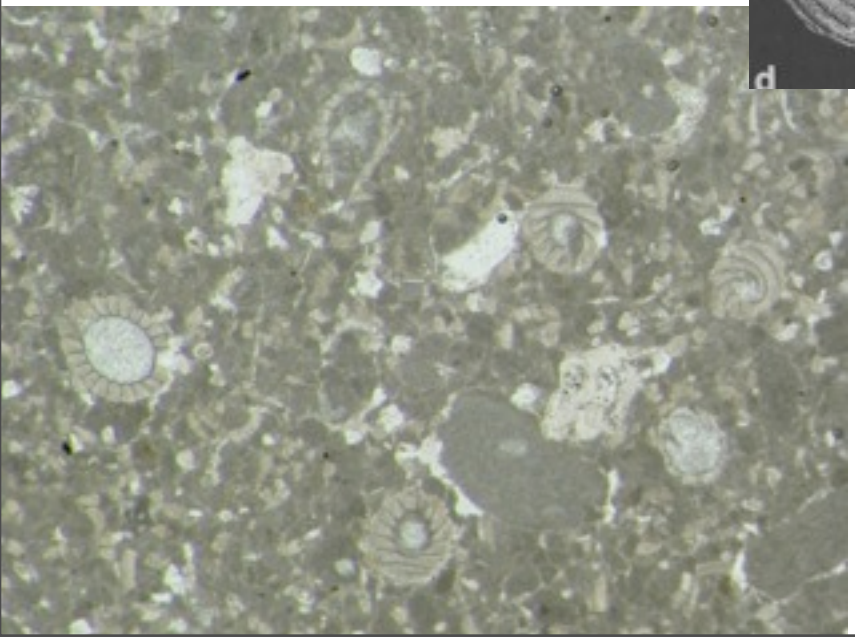




stems of charophytes

Early Cretaceous. Southern Spain





gyrogonites

Early Cretaceous. Southern Spain

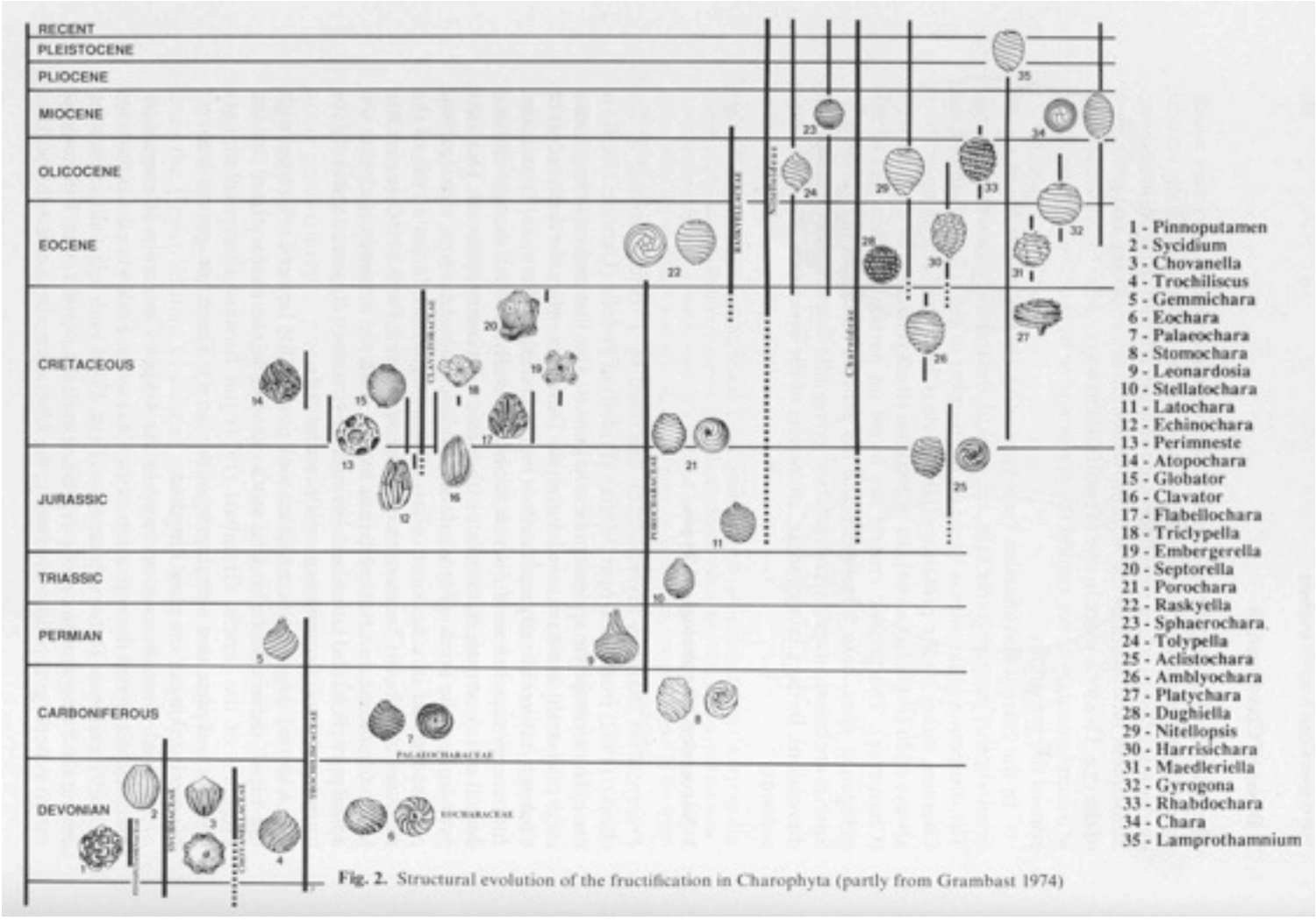
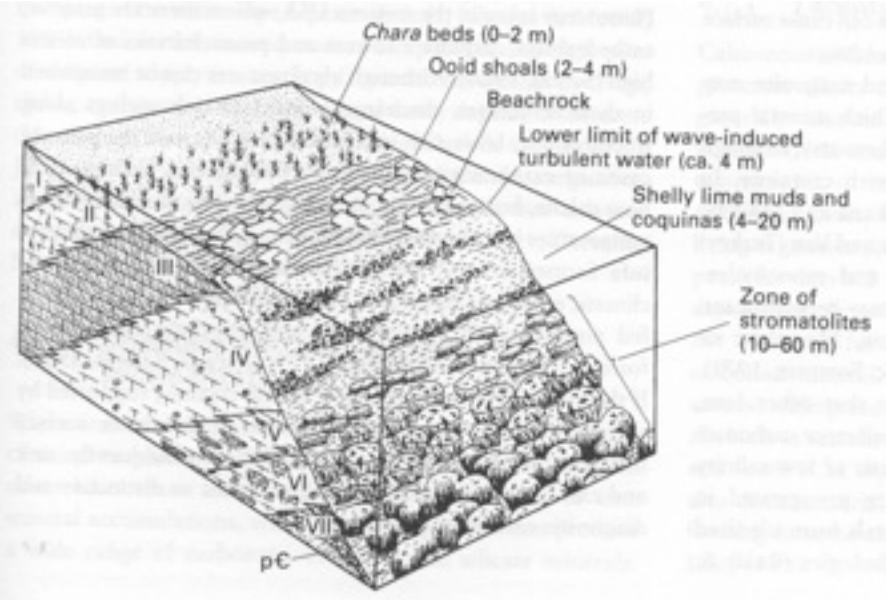


Fig. 2. Structural evolution of the fructification in Charophyta (partly from Grambast 1974)

usually in still, clear, non-flowing, water

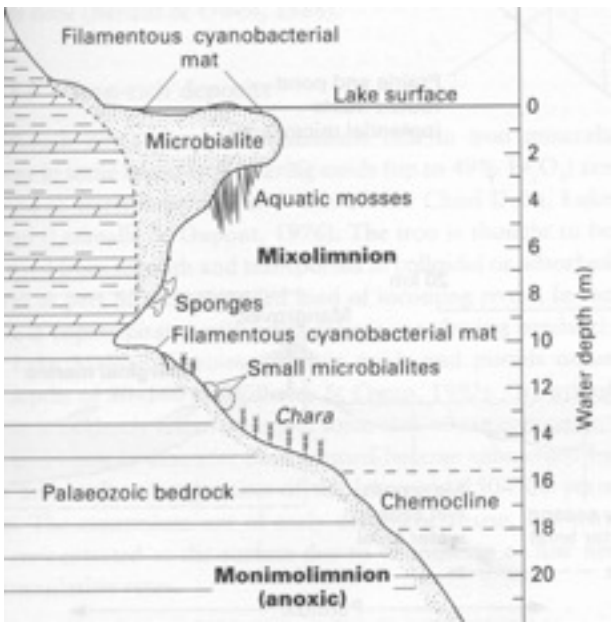
low to medium nutrient-rich water

tend to disappear with eutrophication



Lake Tanganyika

Taken from Talbot and Allen (1996)

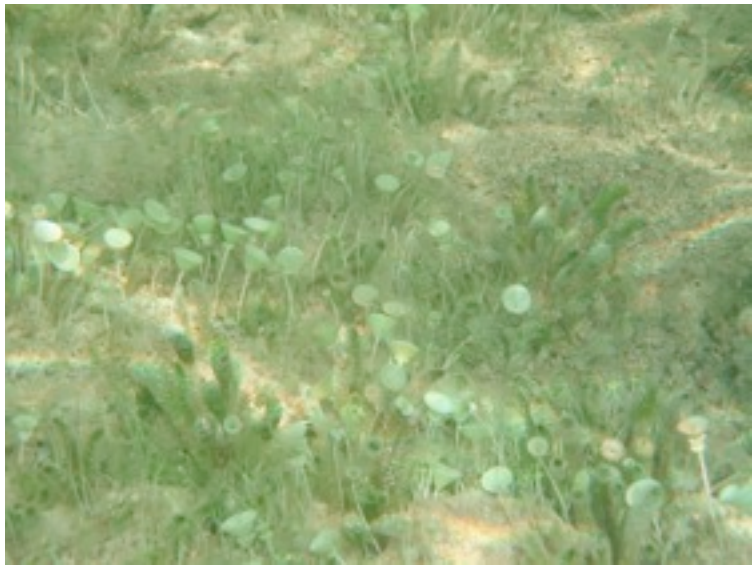


Green Lake, NY


rock-forming fossils
major components in many lacustrine limestones
Pleistocene, Baza Basin, S Spain

Chlorophyta (True green algae)

Two main groups calcify:



most DASYCLADALES

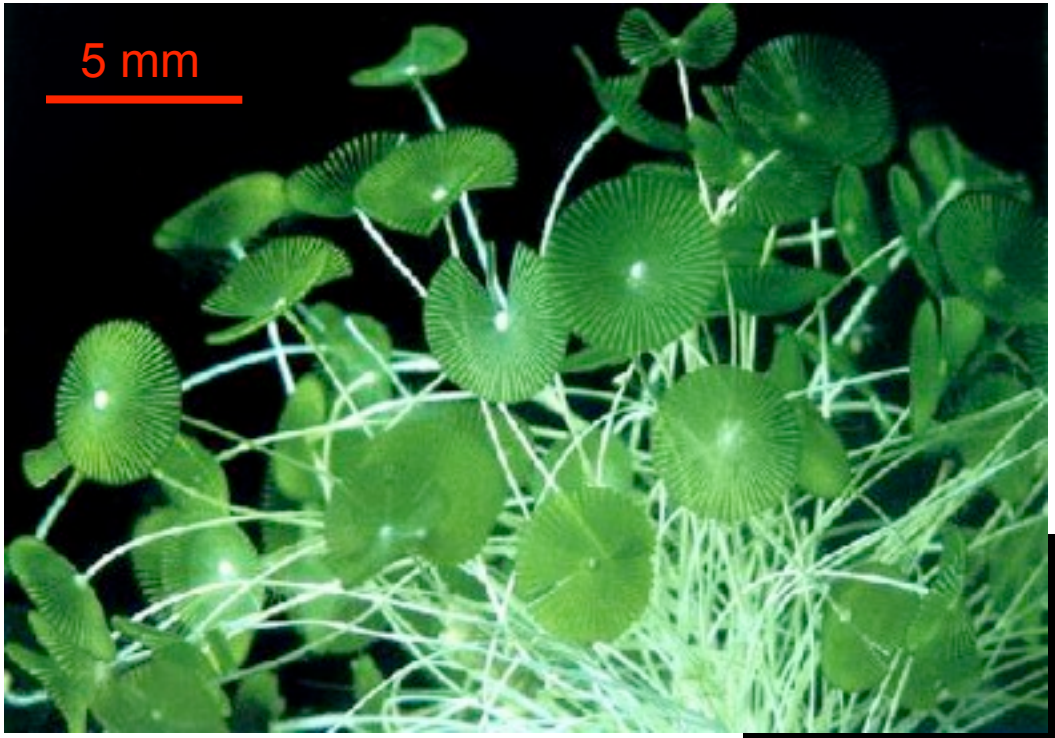
some BRYOPSIDALES
(or HALIMEDALES)

DASYCLADALES

The order includes two families:

Polyphysaceae
(Acetabulariaceae)

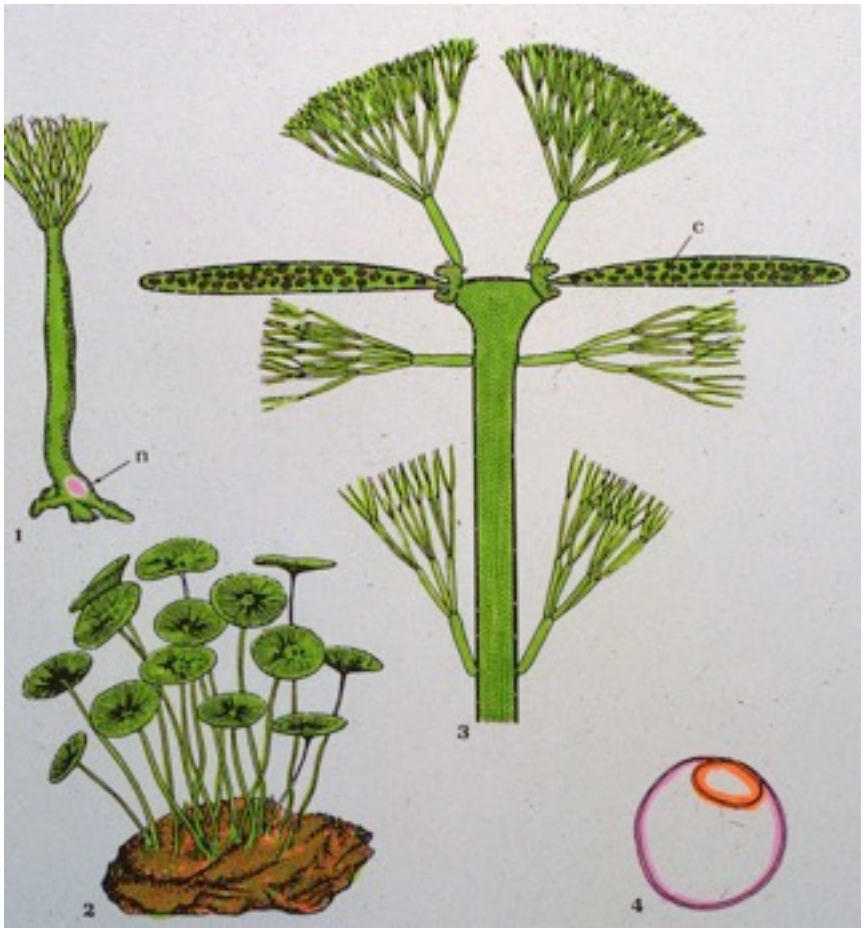
Dasycladaceae



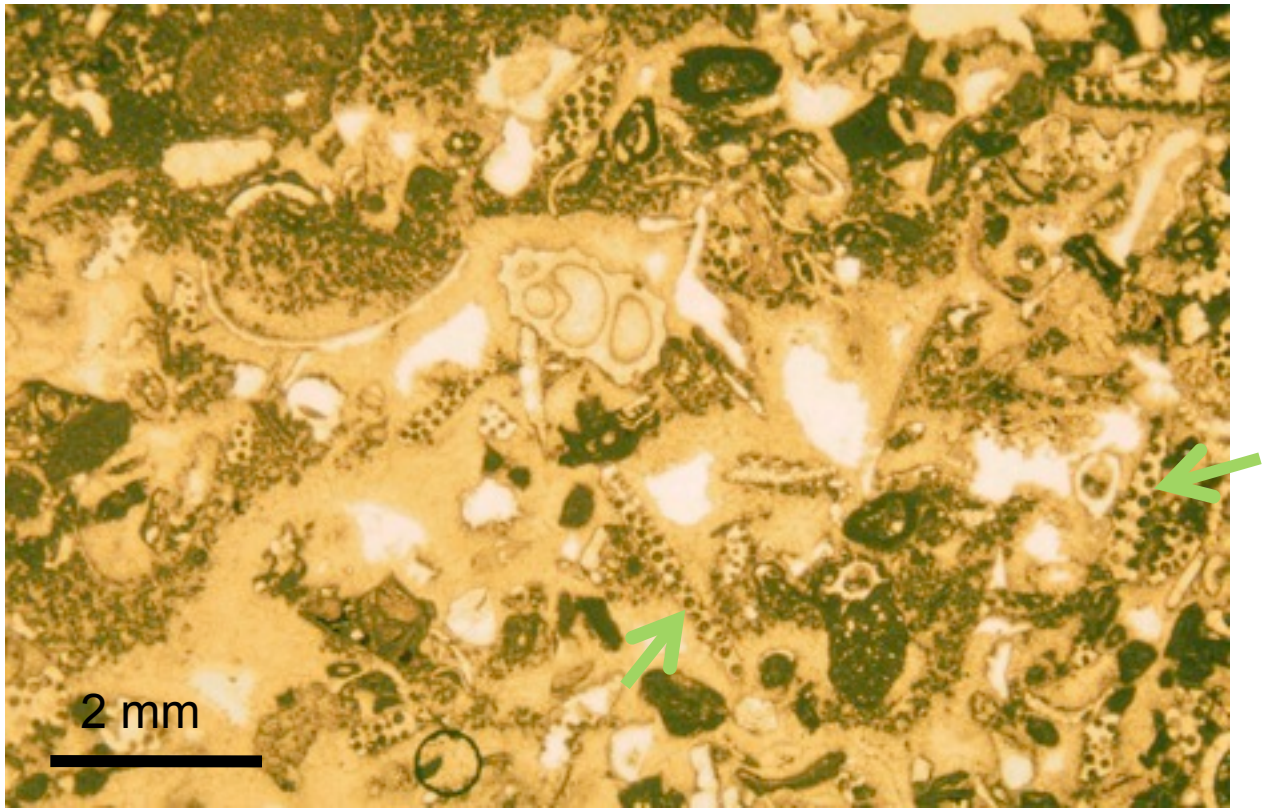
Polyphysaceae
(Acetabulariaceae)

each plant is a single giant cell with many nuclei

relatively common in shallow-water in tropical and warm temperate regions

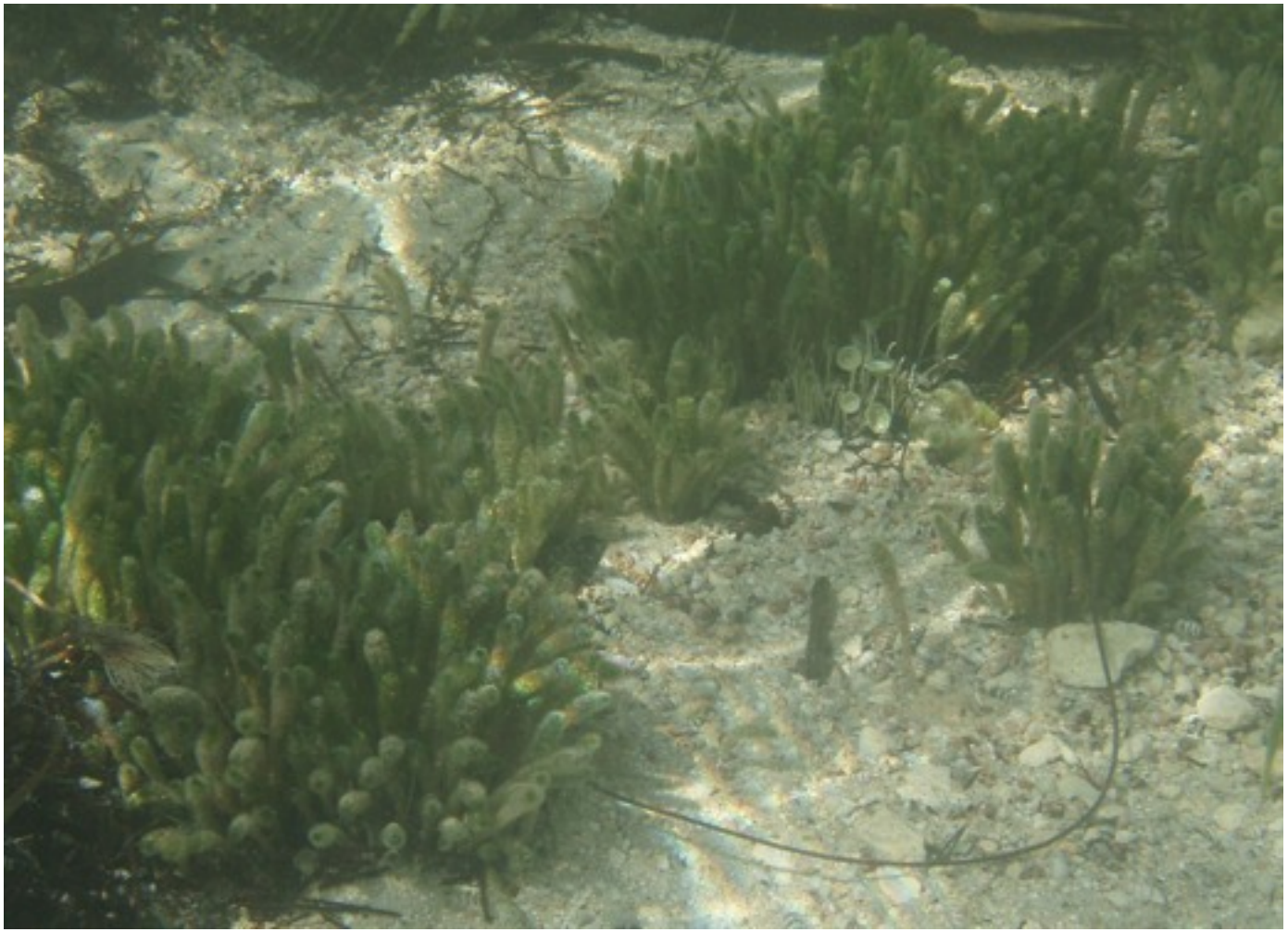


calcified “ampullae” in fertile plants



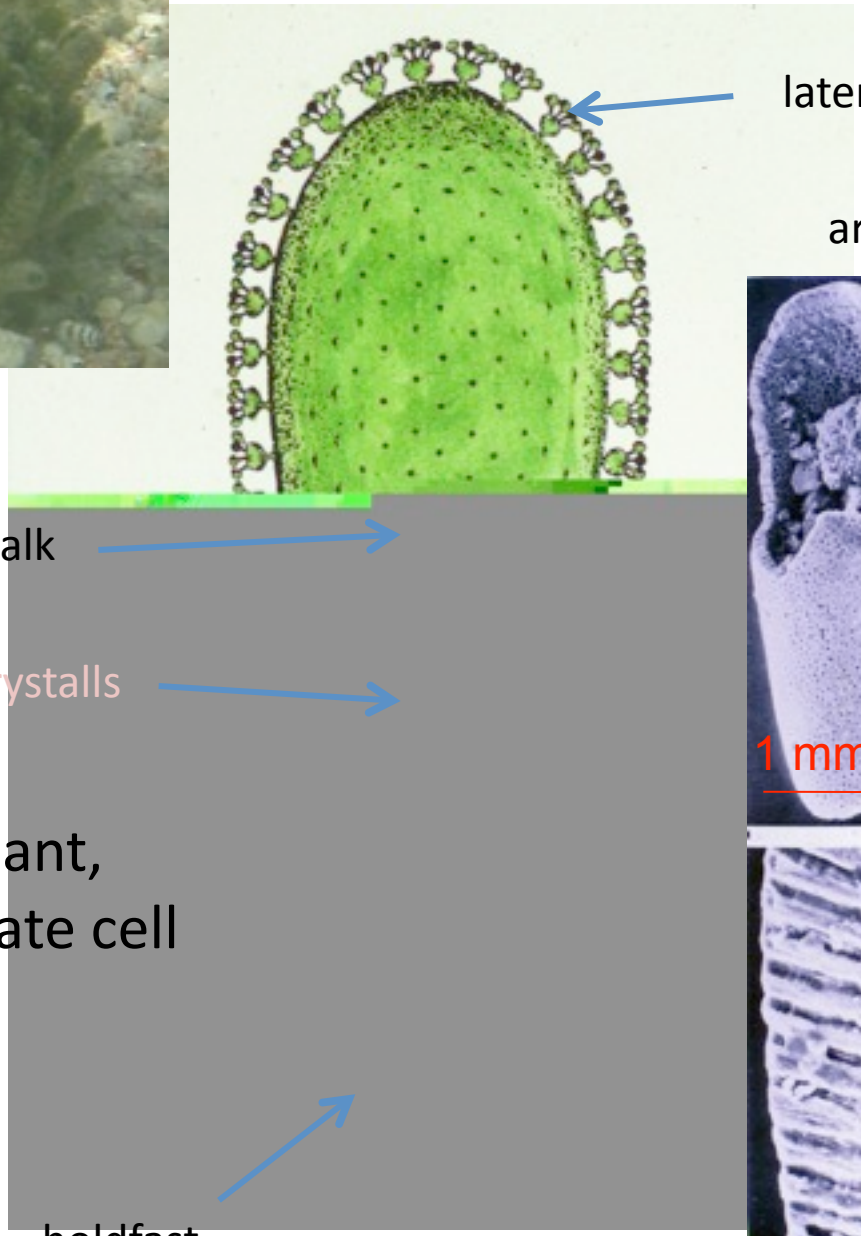
occasional components of shallow-water tropical & subtropical carbonates

Dasycladaceae

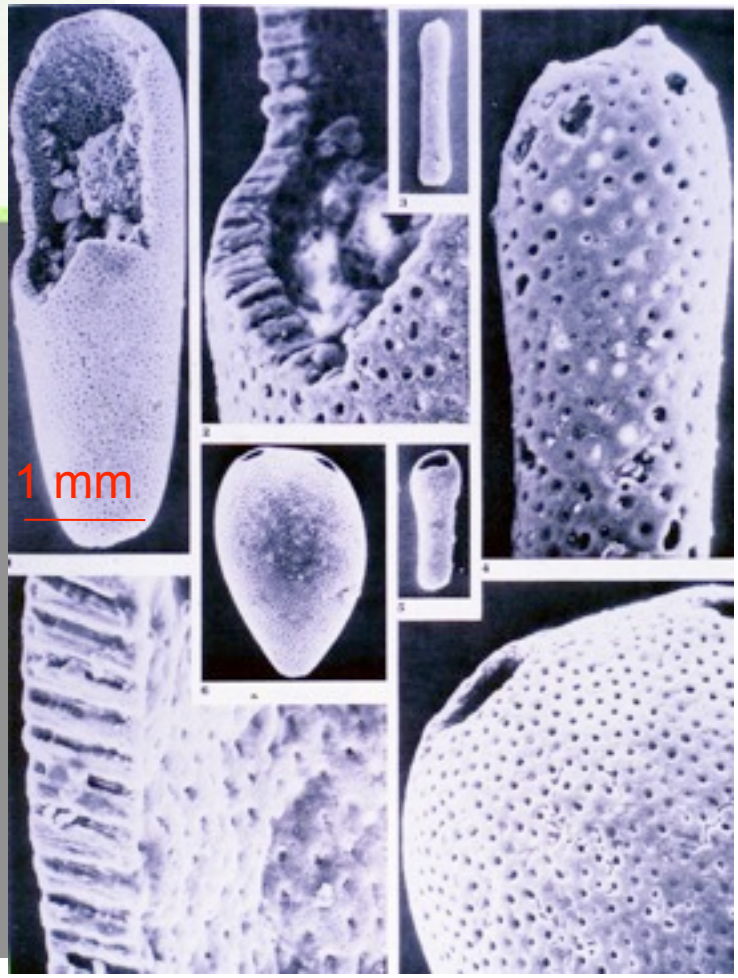



5 mm

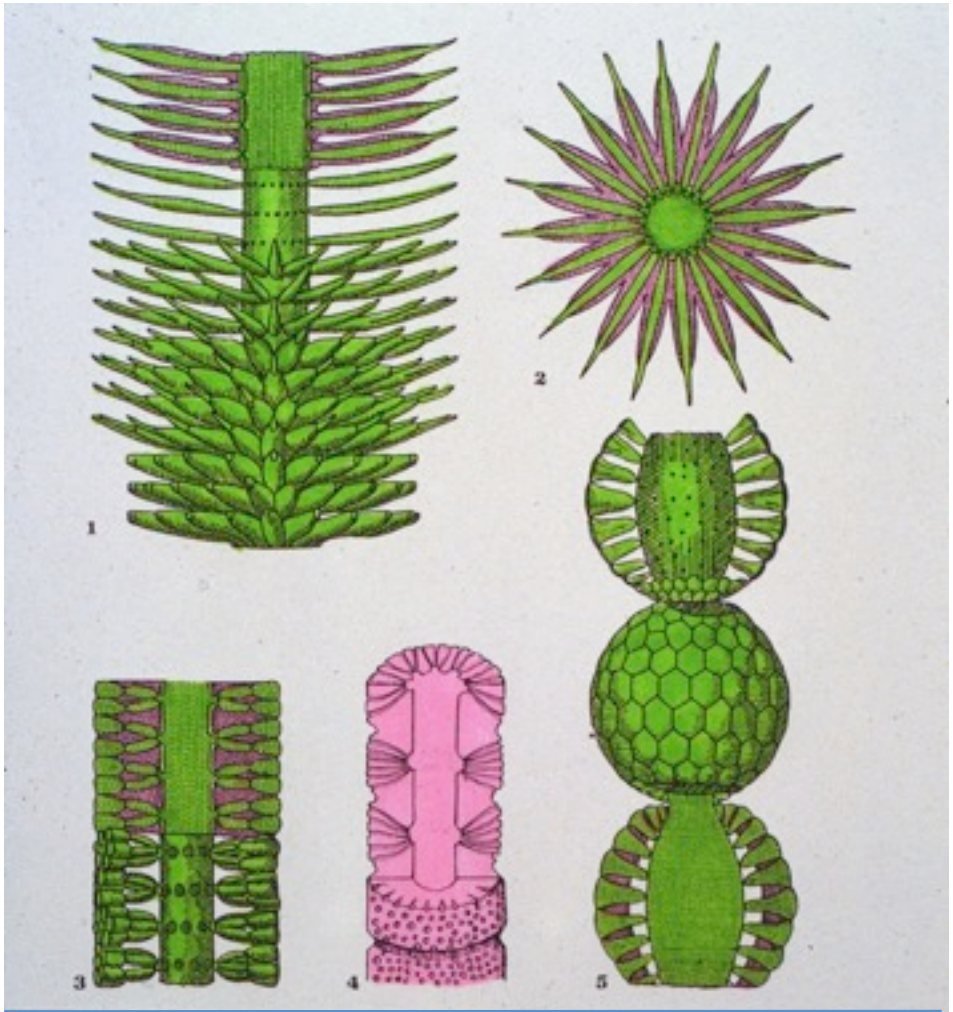

5 mm

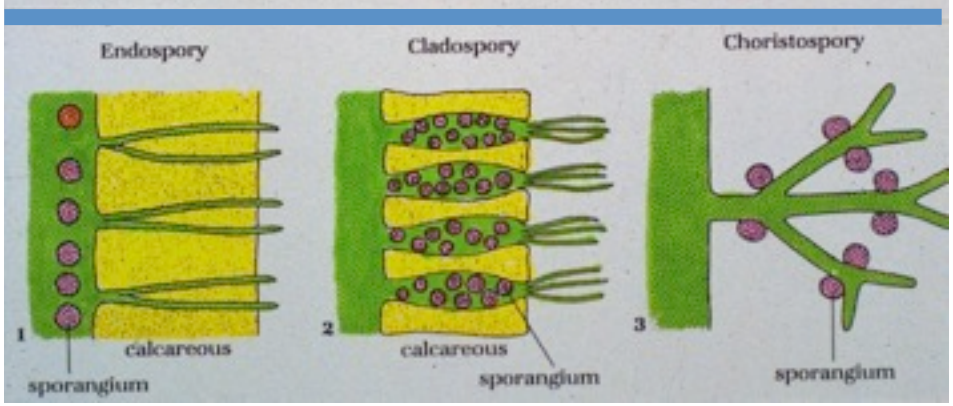


aragonite moulds



Taken from Genot (1985)



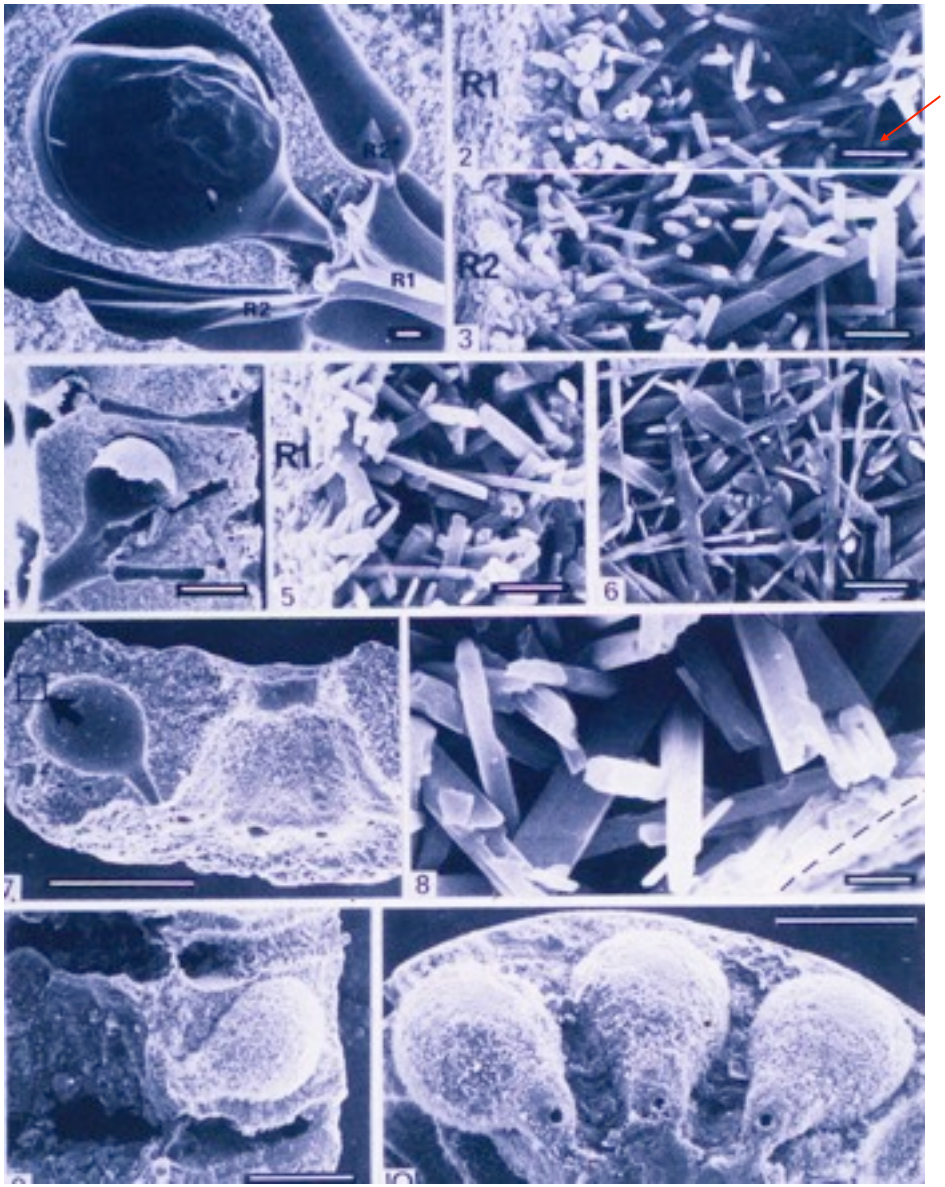


varying distribution of aragonite precipitates

varying degree of calcification

some are never calcified

location of sporangia



1 micron

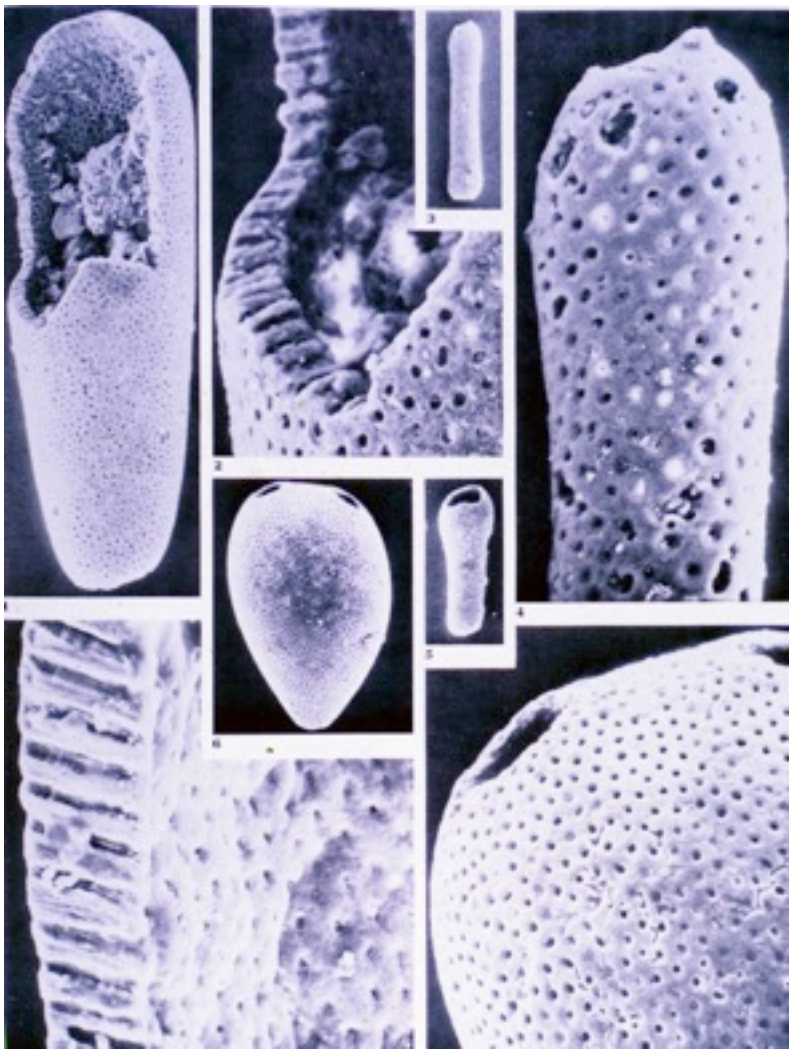
bioinduced but not fully controlled aragonite precipitation

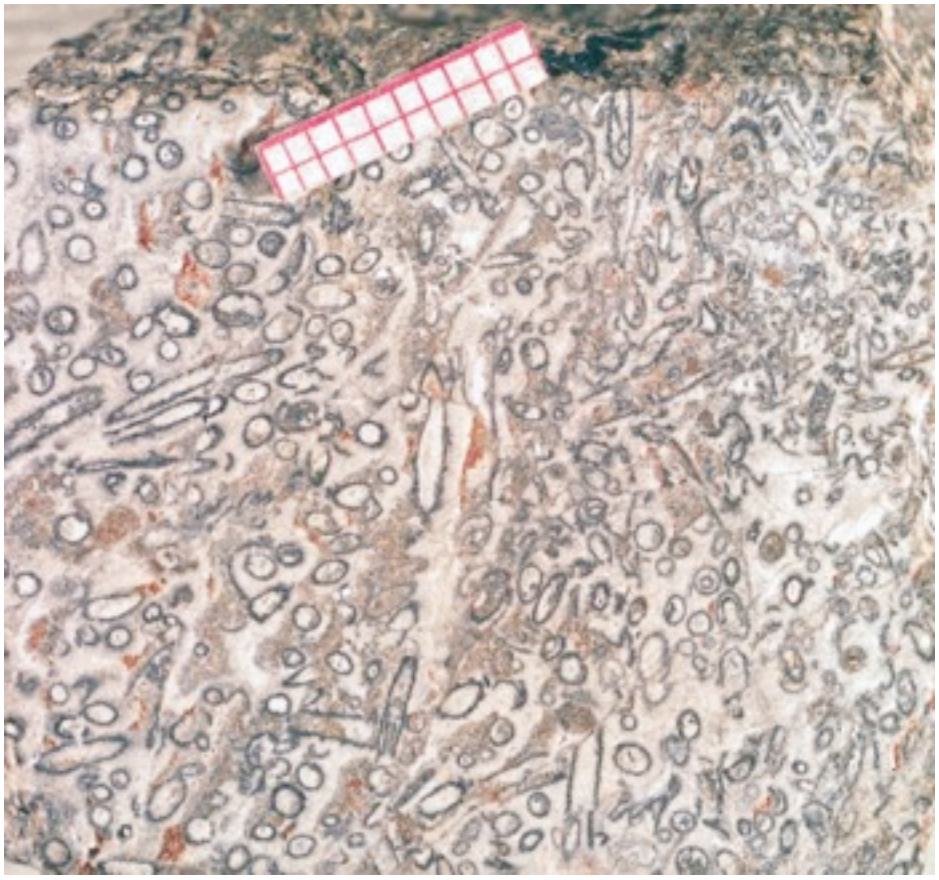
aragonite needles and prisms

calcium carbonate precipitation is regulated by the **local pH** at the calcification site and over-saturation of calcium carbonate in the seawater

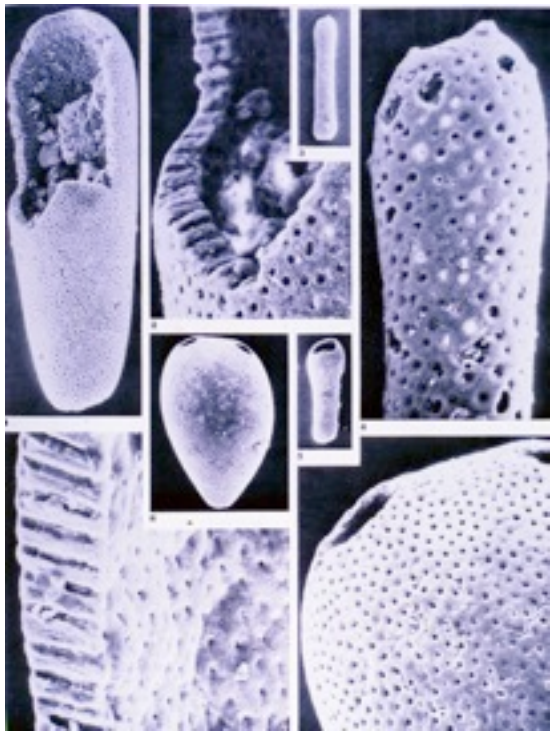
photosynthesis, respiration and a light-driven proton pump determine the local pH

Taken from Genot (1985)





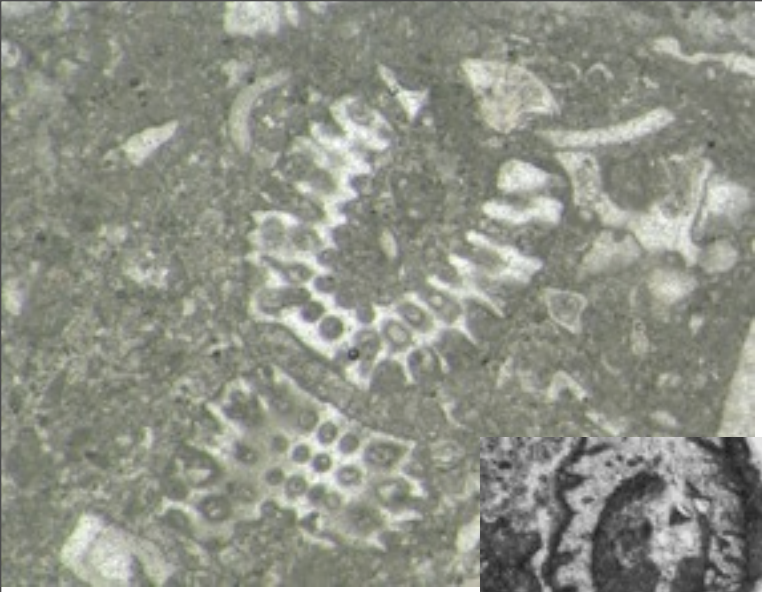
Late Triassic from SE Spain

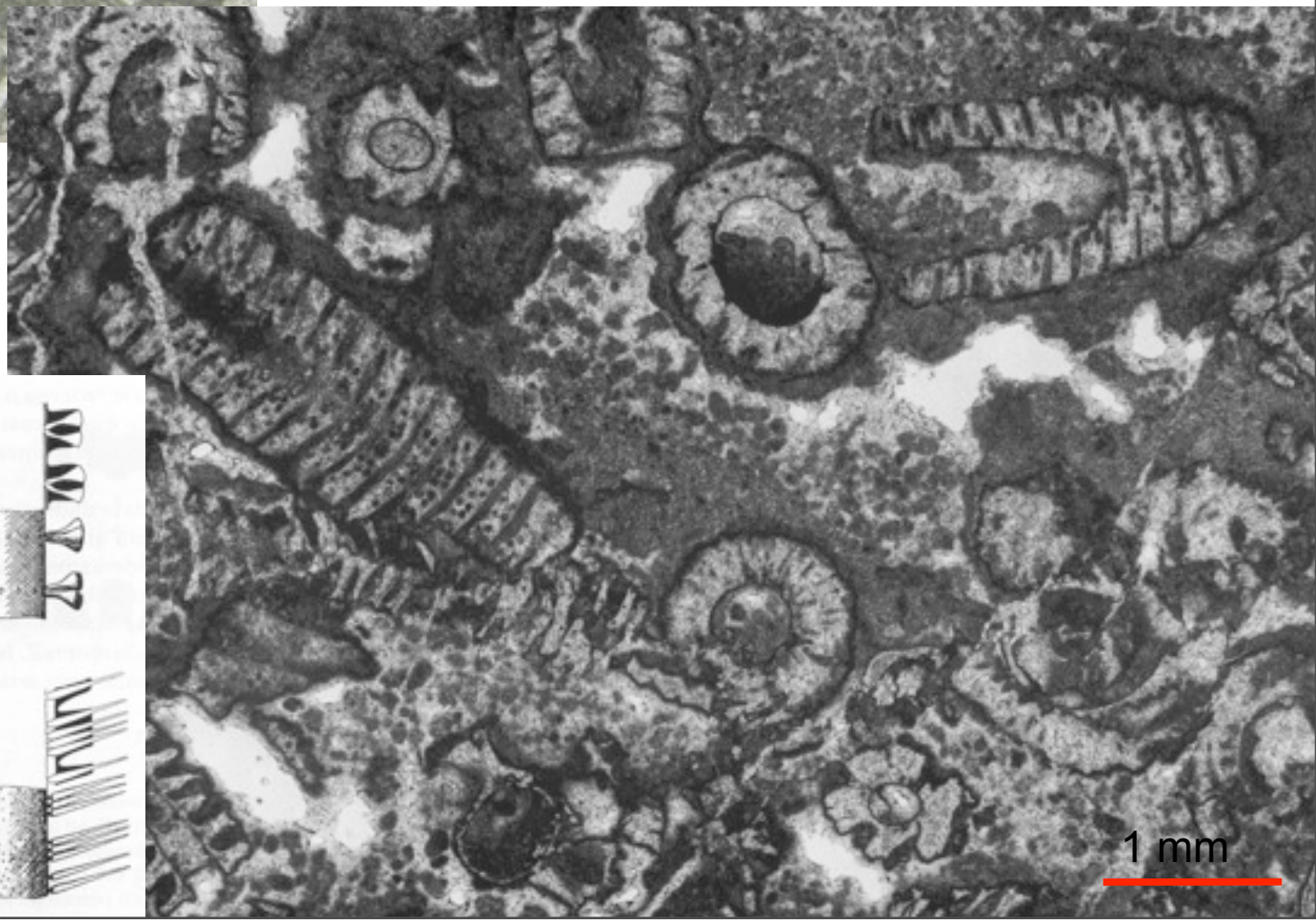


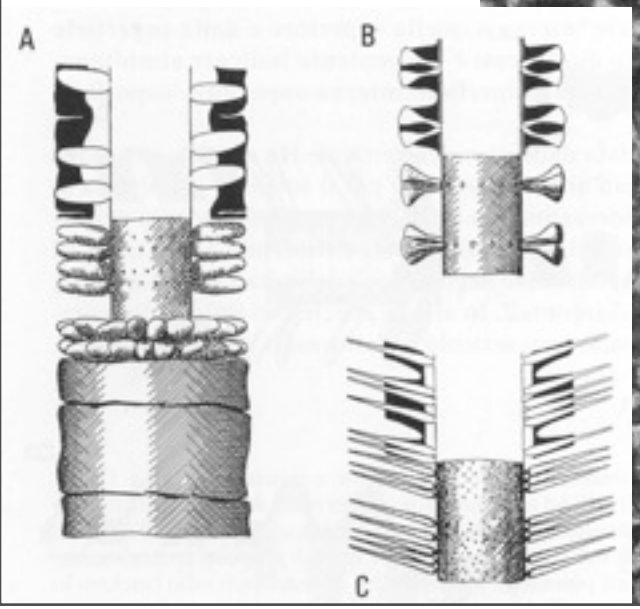
Taken from Flügel (2004)

Palaeocene, Pyrenees

Taken from Flügel (2004)



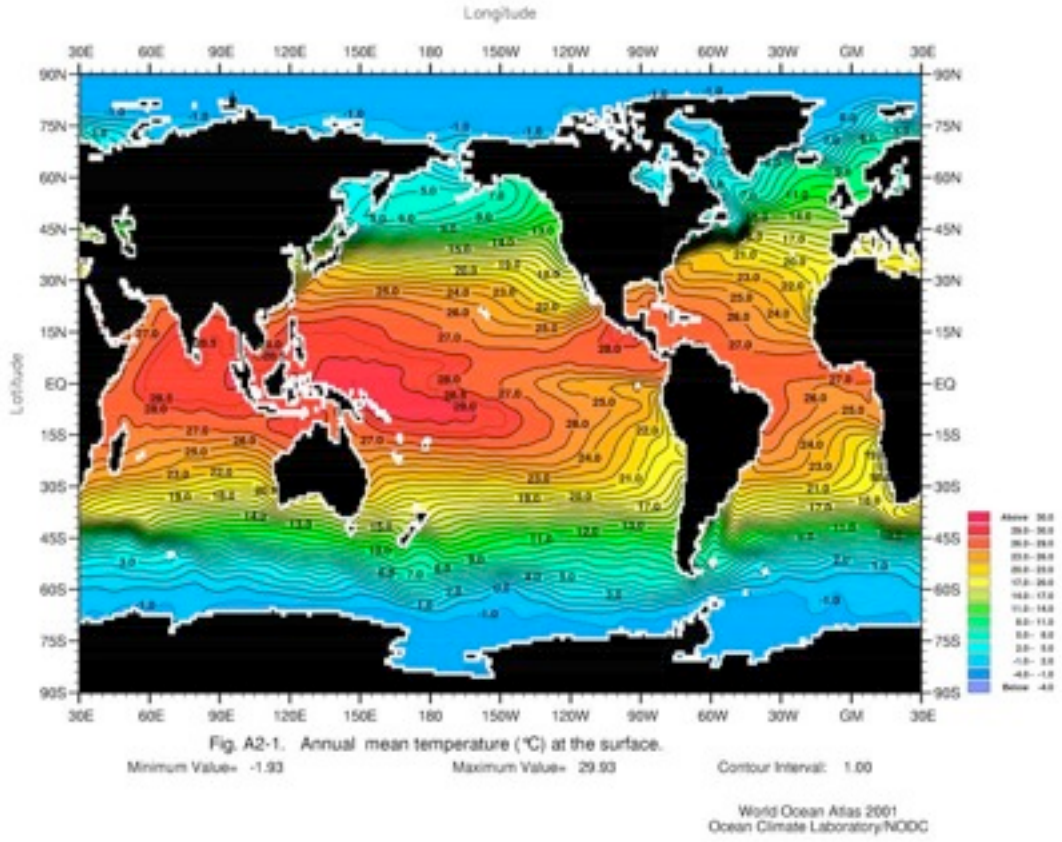


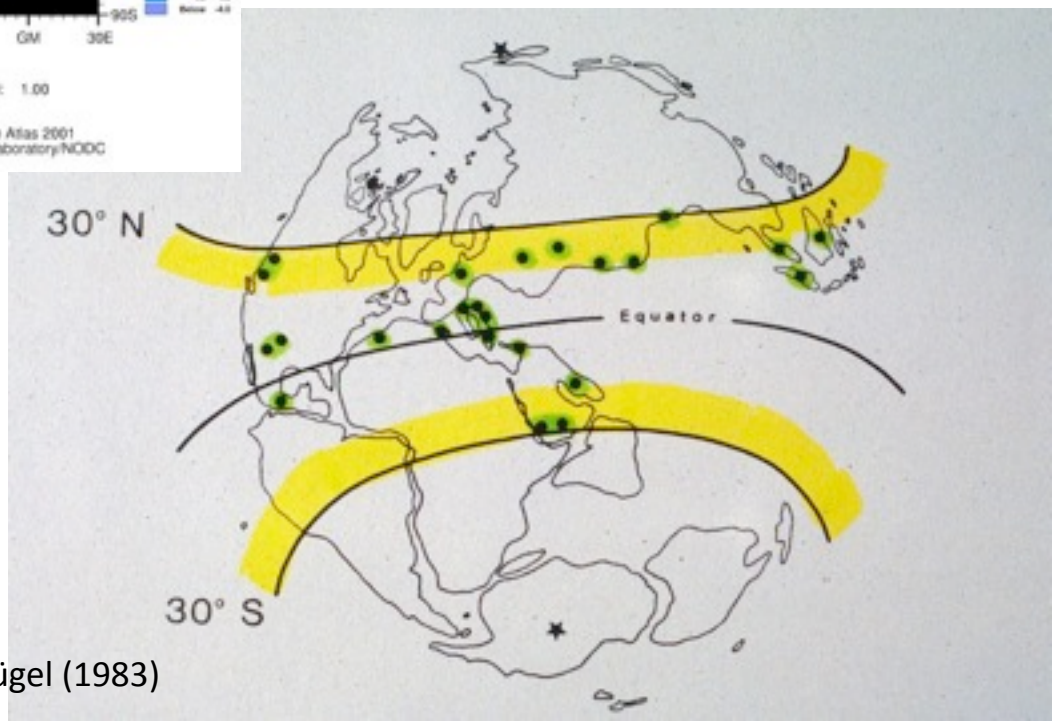


only six genera and few species

red and orange areas: calcifying

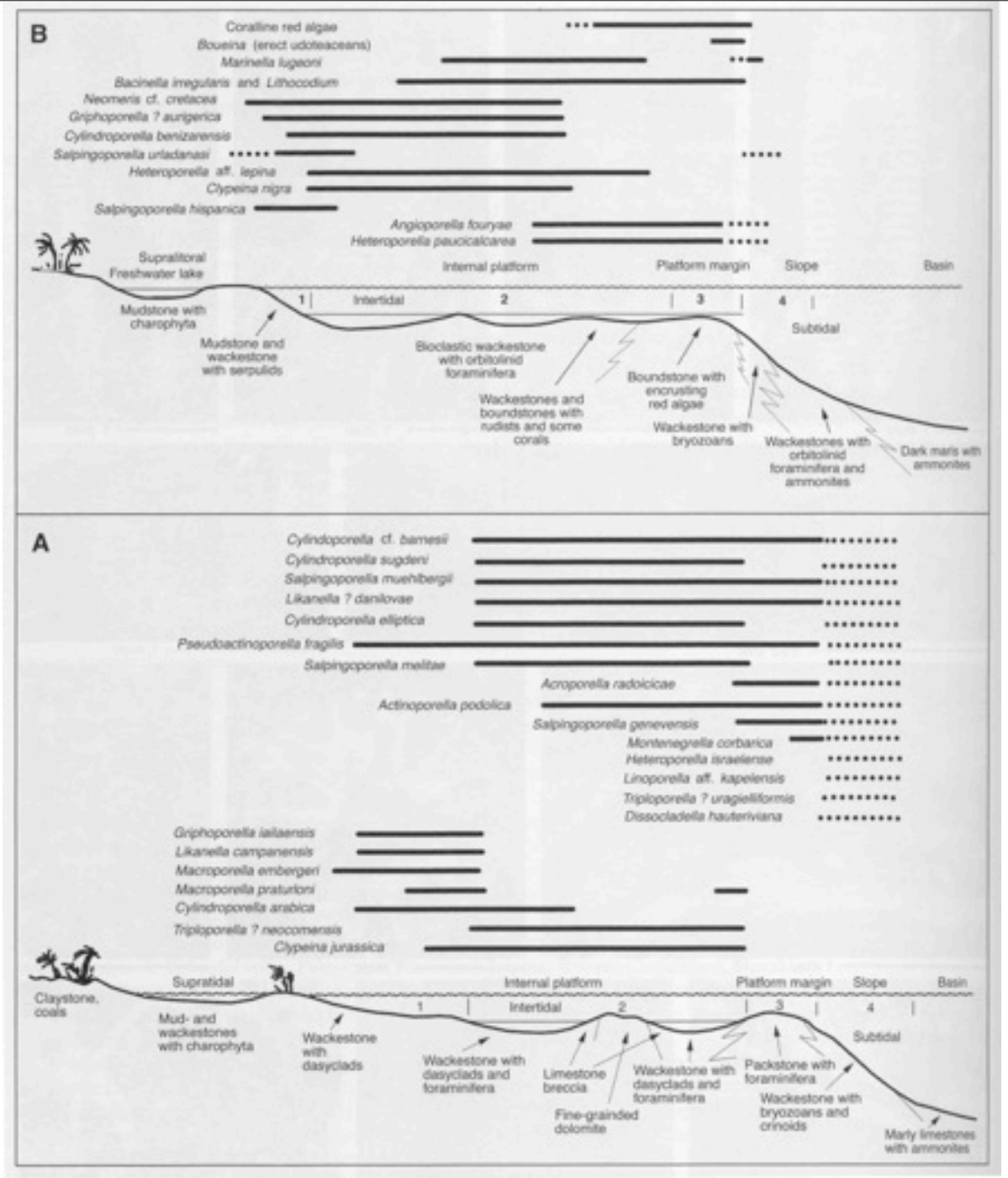
yellow: living, not calcifying





taken from Flügel (1983)

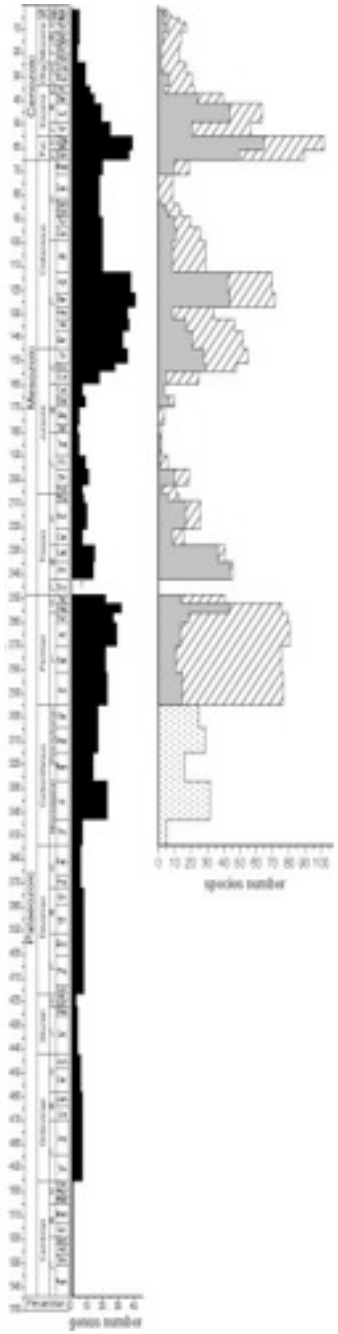
shallow-water
(usually < 10 m)
from slightly brackish to
slightly hypersaline

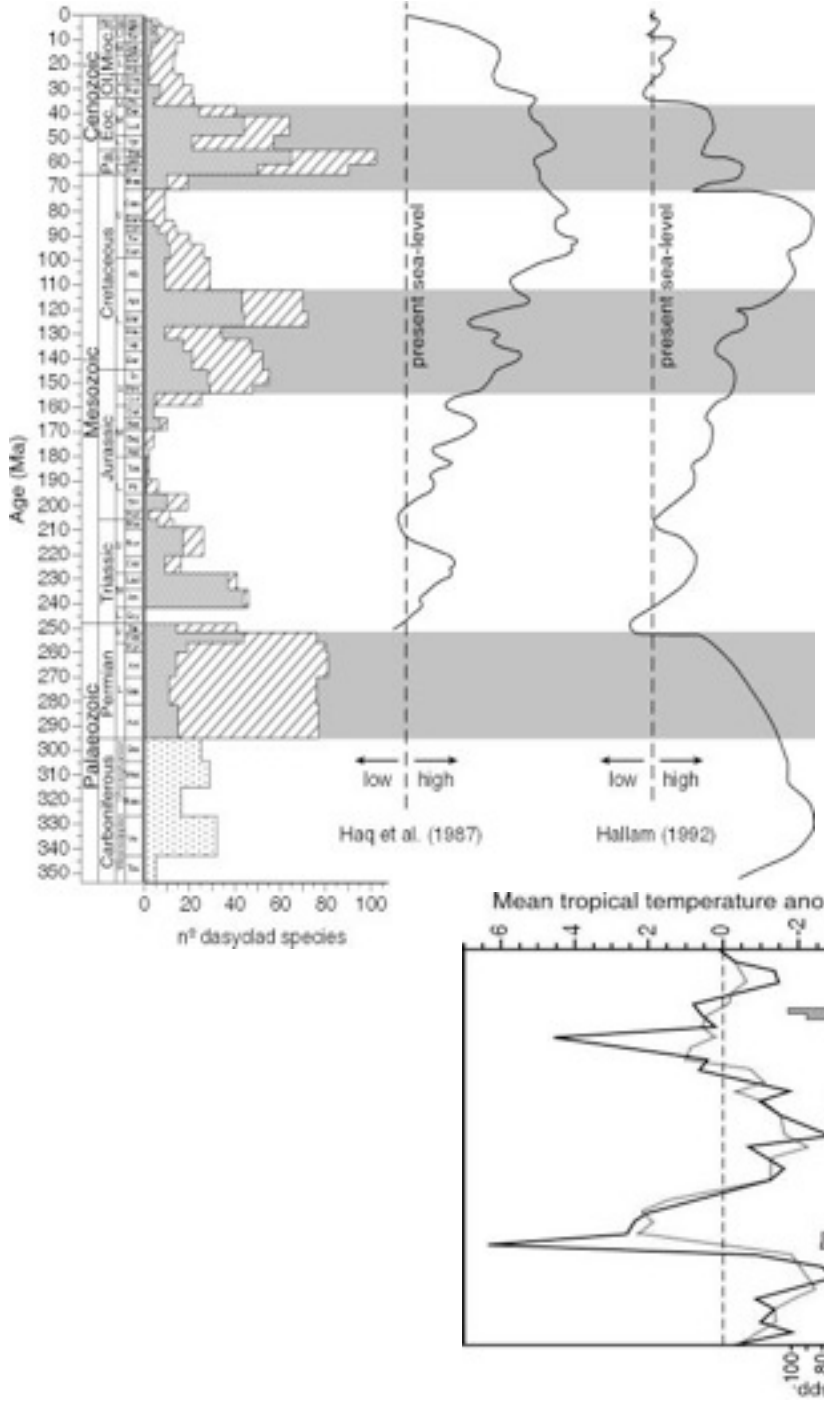


Early Cretaceous, Pyrenees

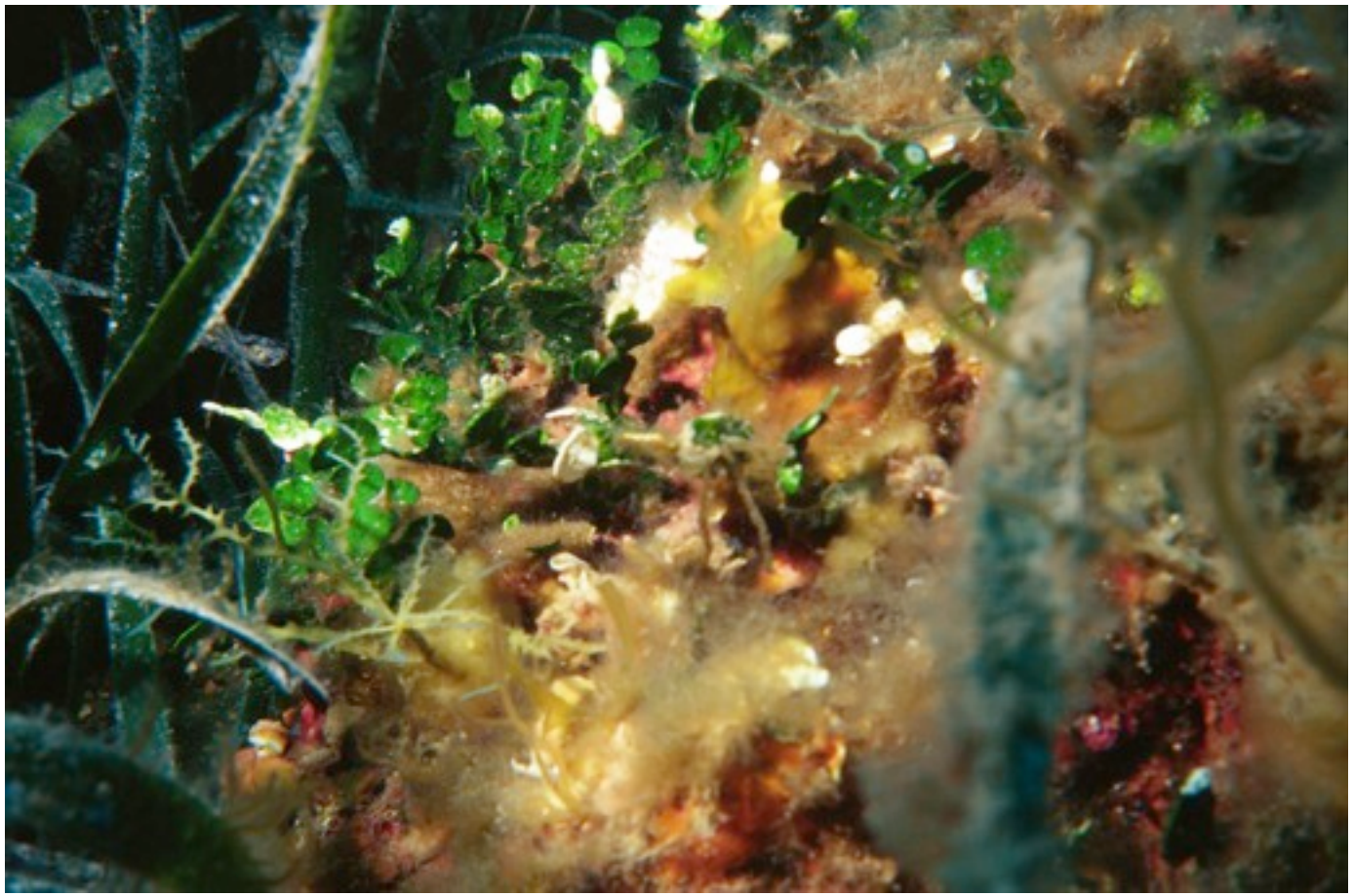
(from Flügel, 2004)

Edad (Ma)

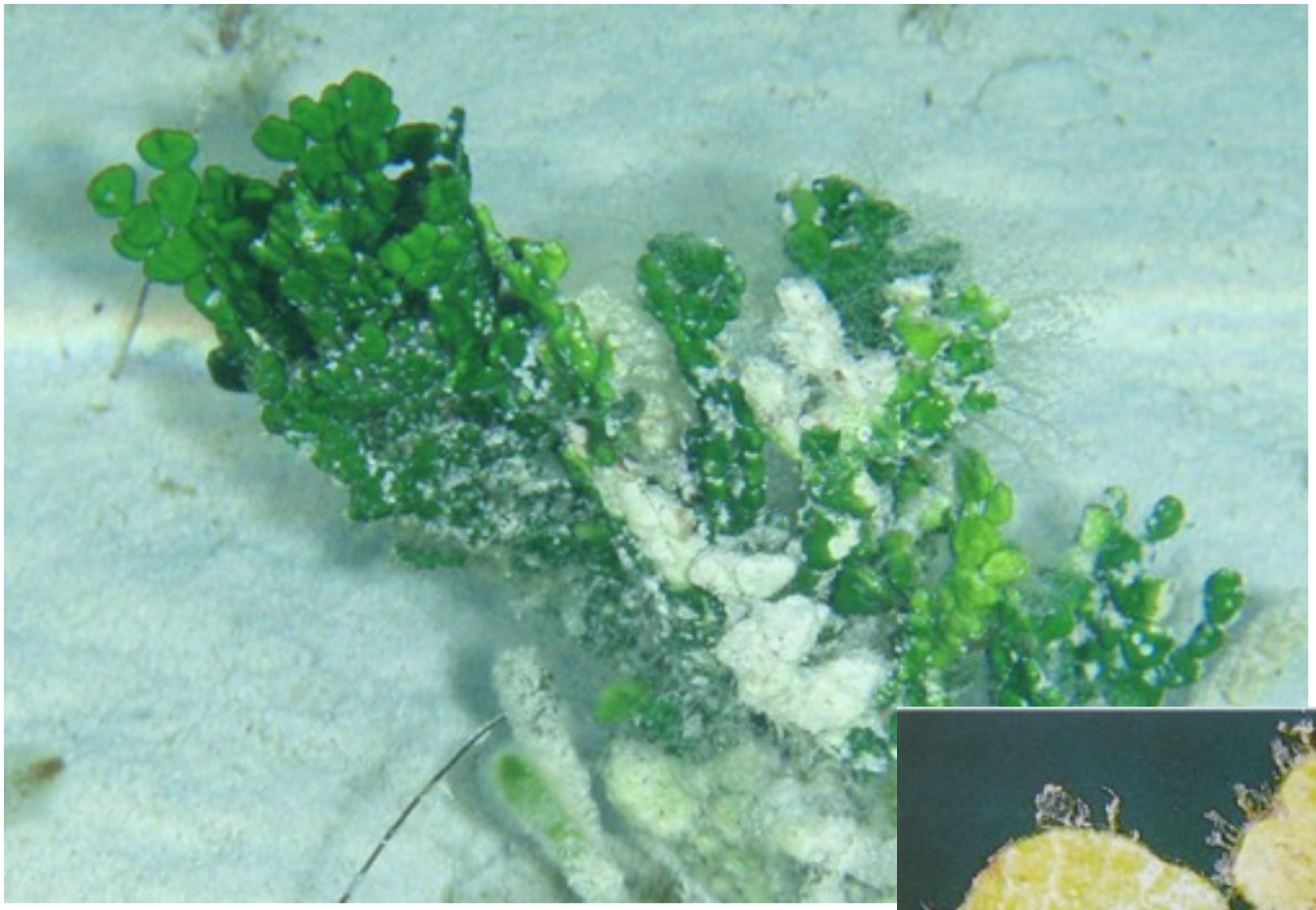



Age (Ma)
Cenozoic
Mesozoic
Palaeozoic
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
present sea-level
present sea-level
low
high
low
high
Haq et al. (1987)
Hallam (1992)
n° dasyclad species
Mean tropical temperature anomaly (°C)
Carb.
Per.
Tr.
Juras.
Cretac.
Pal.
N.
Age (Ma)
dasyclad spp.

BRYOPSIDALES
(or HALIMEDALES)

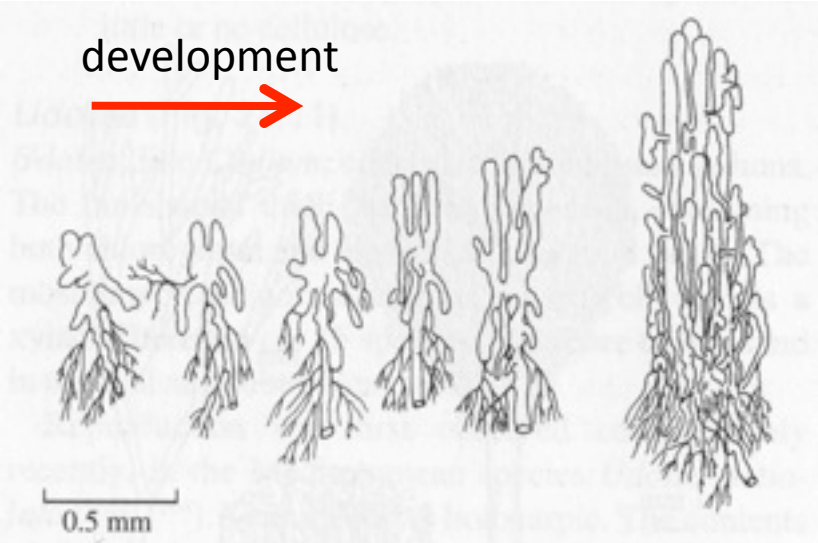


Halimeda



calcified segments

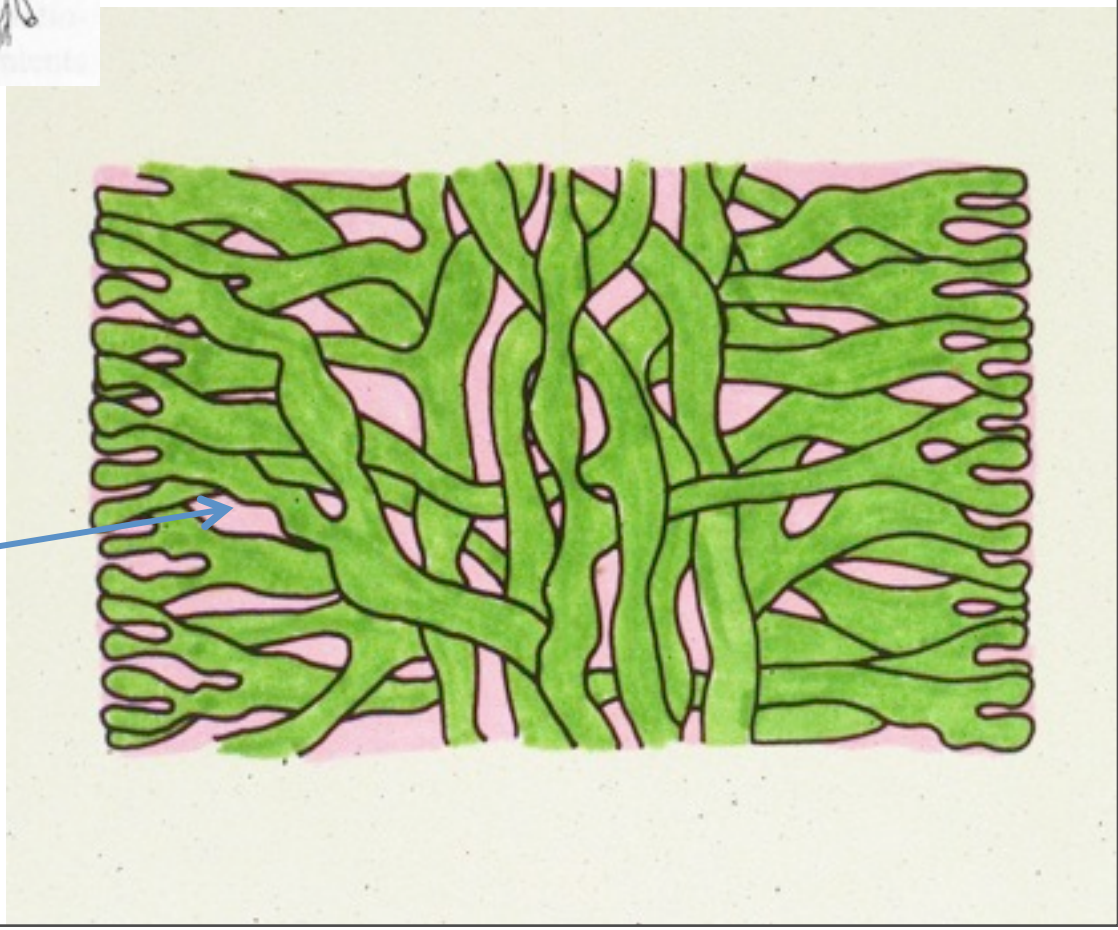
uncalcified junctions

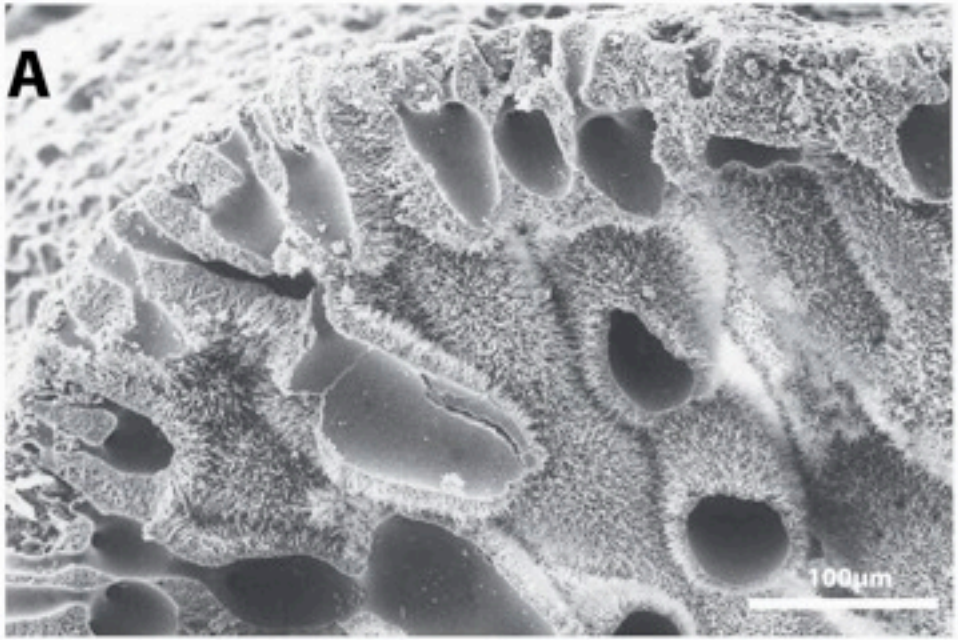


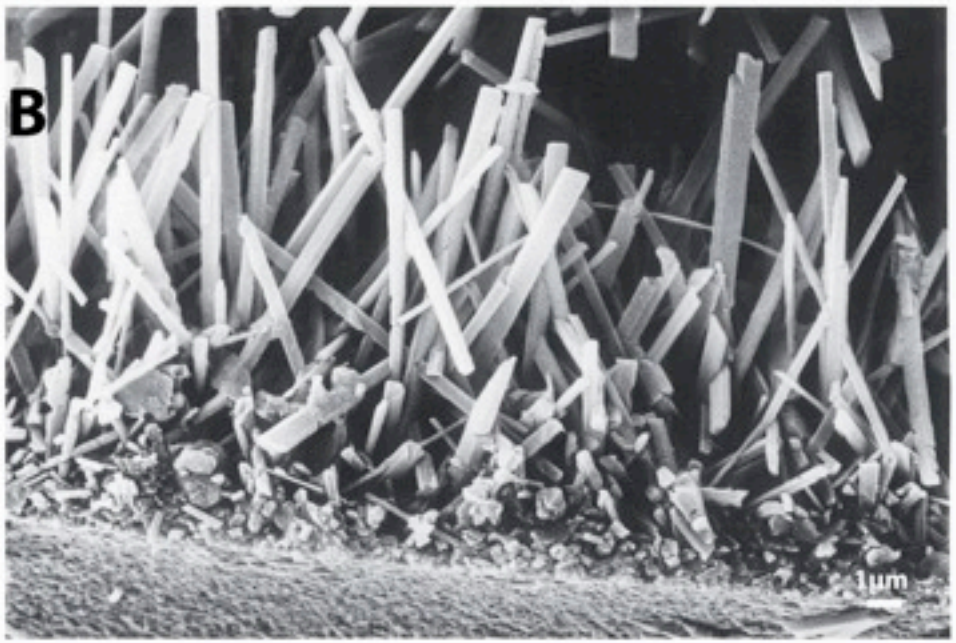
(Van den Hoek et al., 2003)

single giant, multinucleate cell, forming a branching tube (siphon) complexly interwoven

fine-grained aragonite







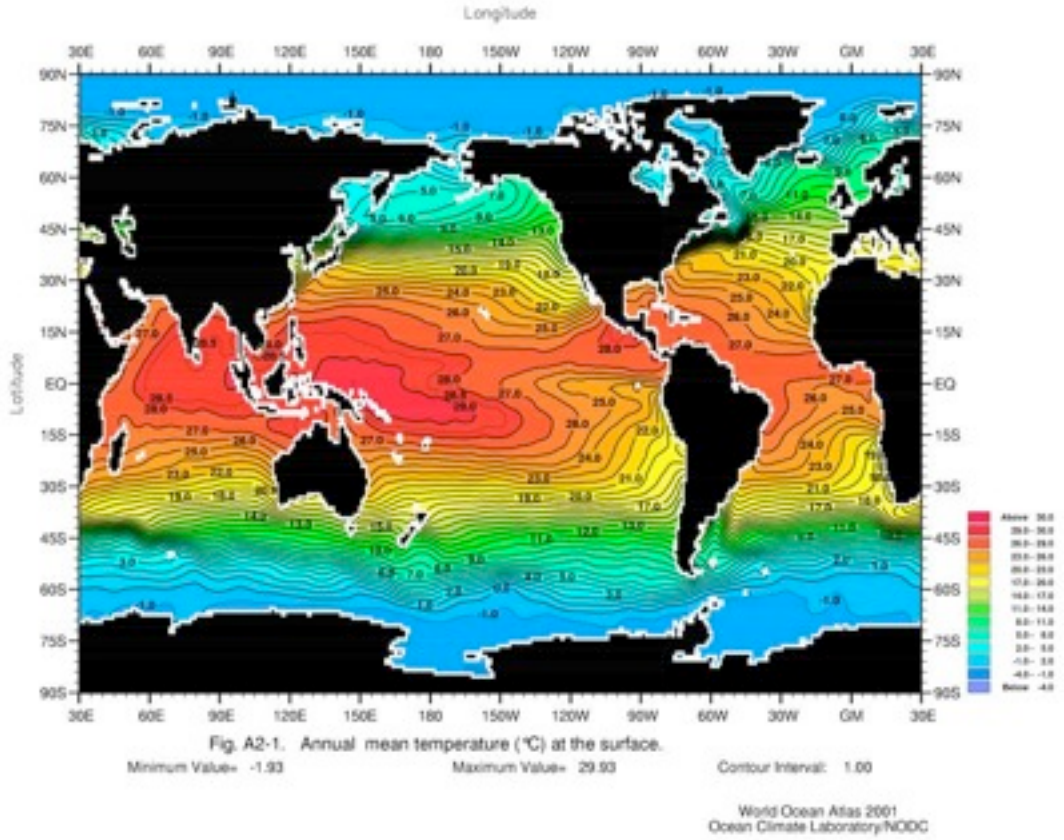
bioinduced aragonite precipitation

aragonite needles and prisms

calcium carbonate precipitation is regulated by the **local pH** and over-saturation of calcium carbonate in the seawater

photosynthesis, respiration and a light-driven proton pump determine the local pH

(taken from Granier, 2011)

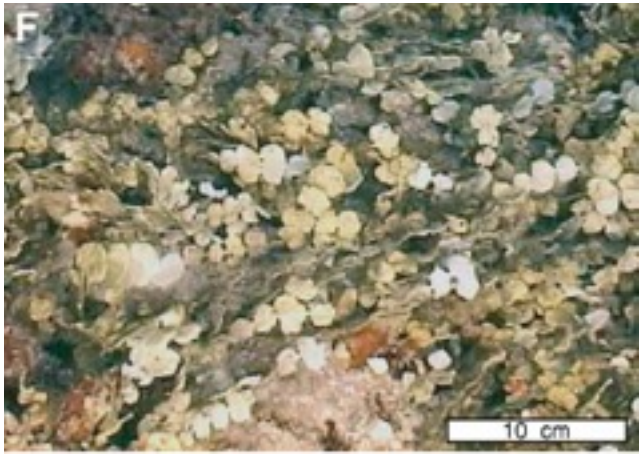


tens of species

red and orange areas: calcifying

yellow: weakly calcifying

From 0 to 130-140 m water depth

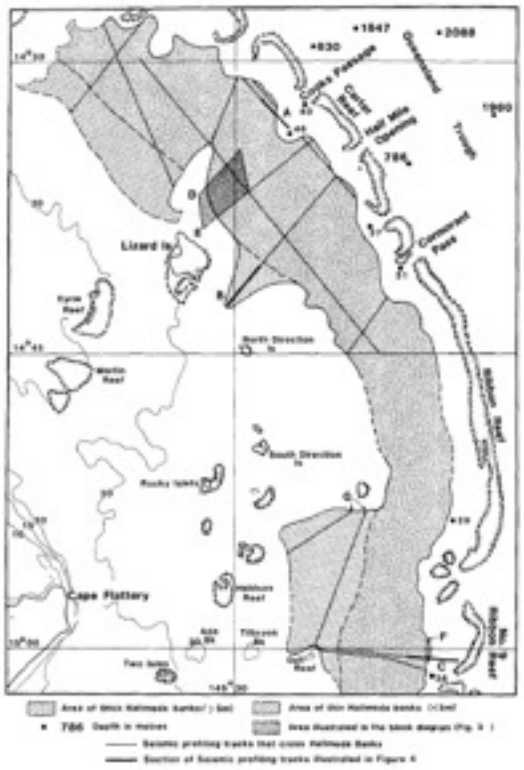


living *Halimeda distorta* community at - 74 m, Penguin Bank, off East Molokai, Hawaiian Is. (Webster et al., 2006)

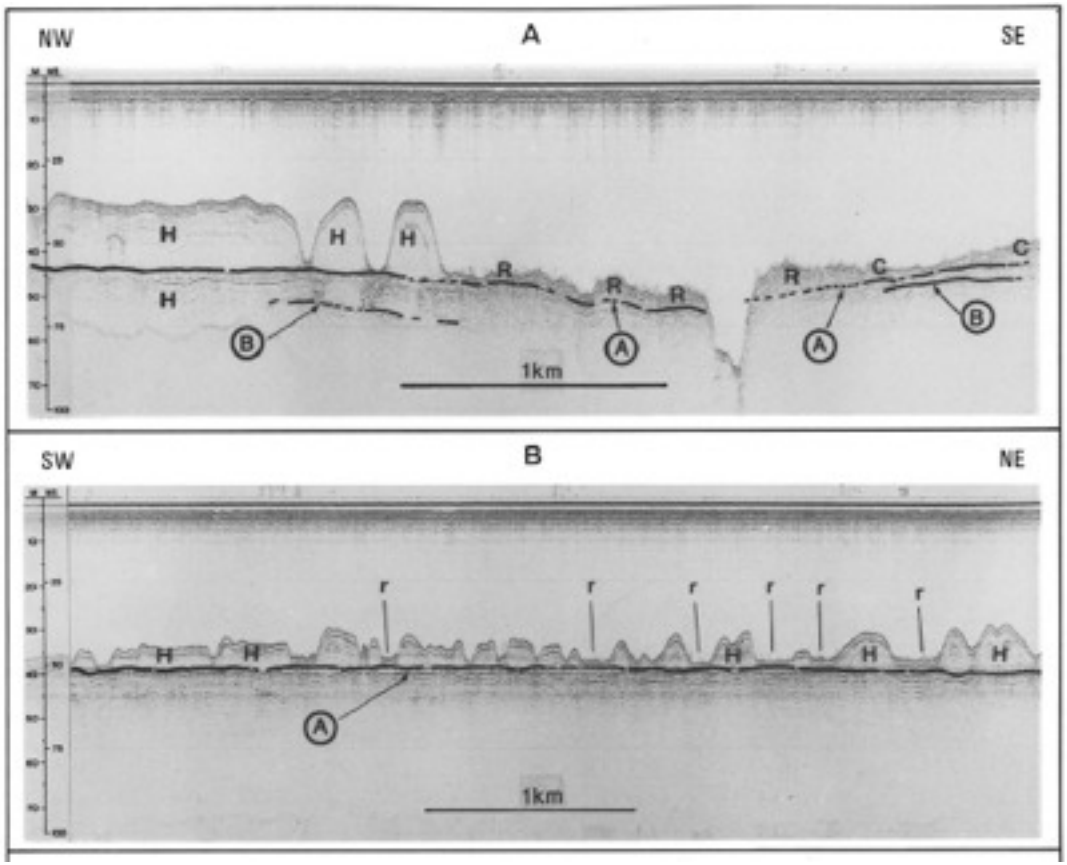
Halimeda is a common component in shallow-water carbonate deposits

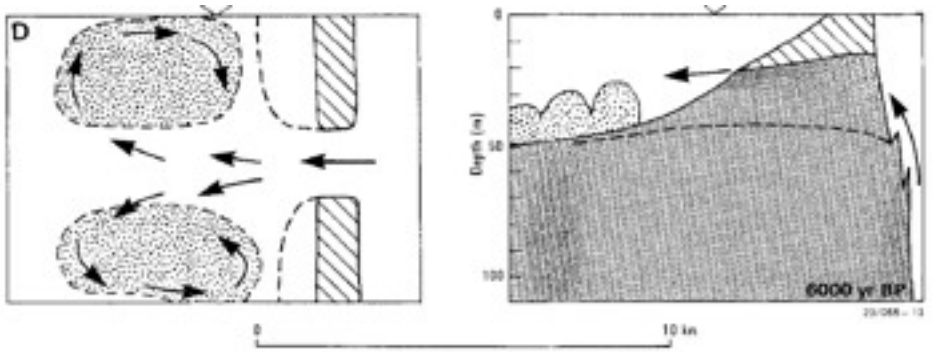
Halimeda segments on a beach (northern Dominican Republic)

Halimeda bioherms



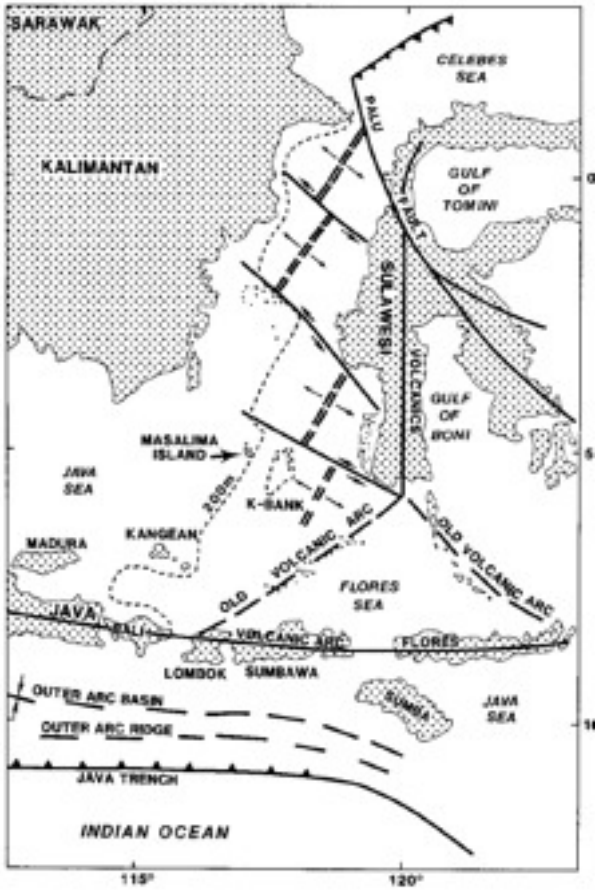
Taken from Orme and Salama (1988)

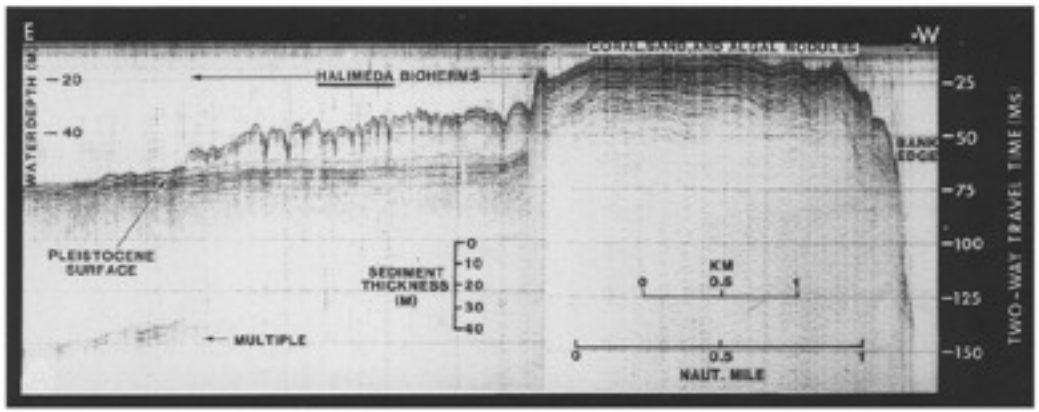


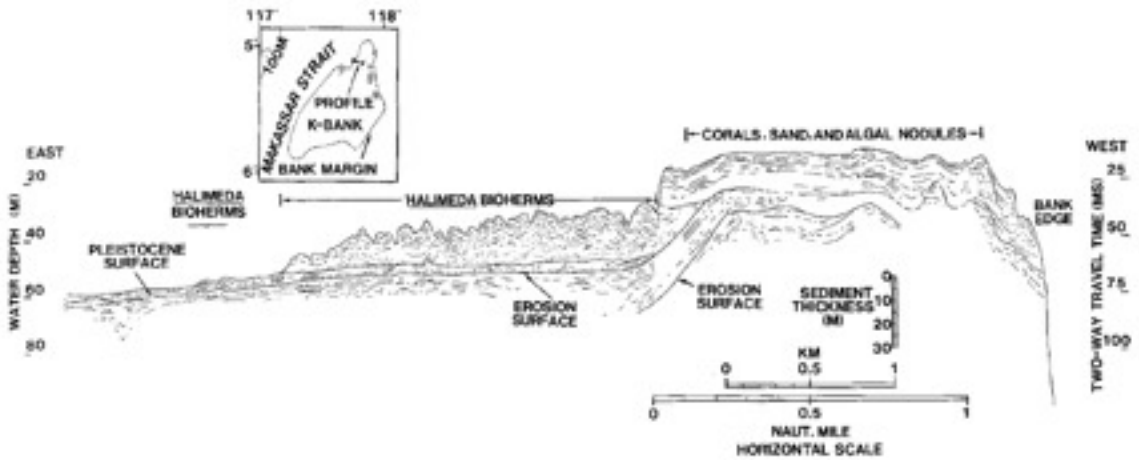


nutrient supply by jets of upwelled oceanic water

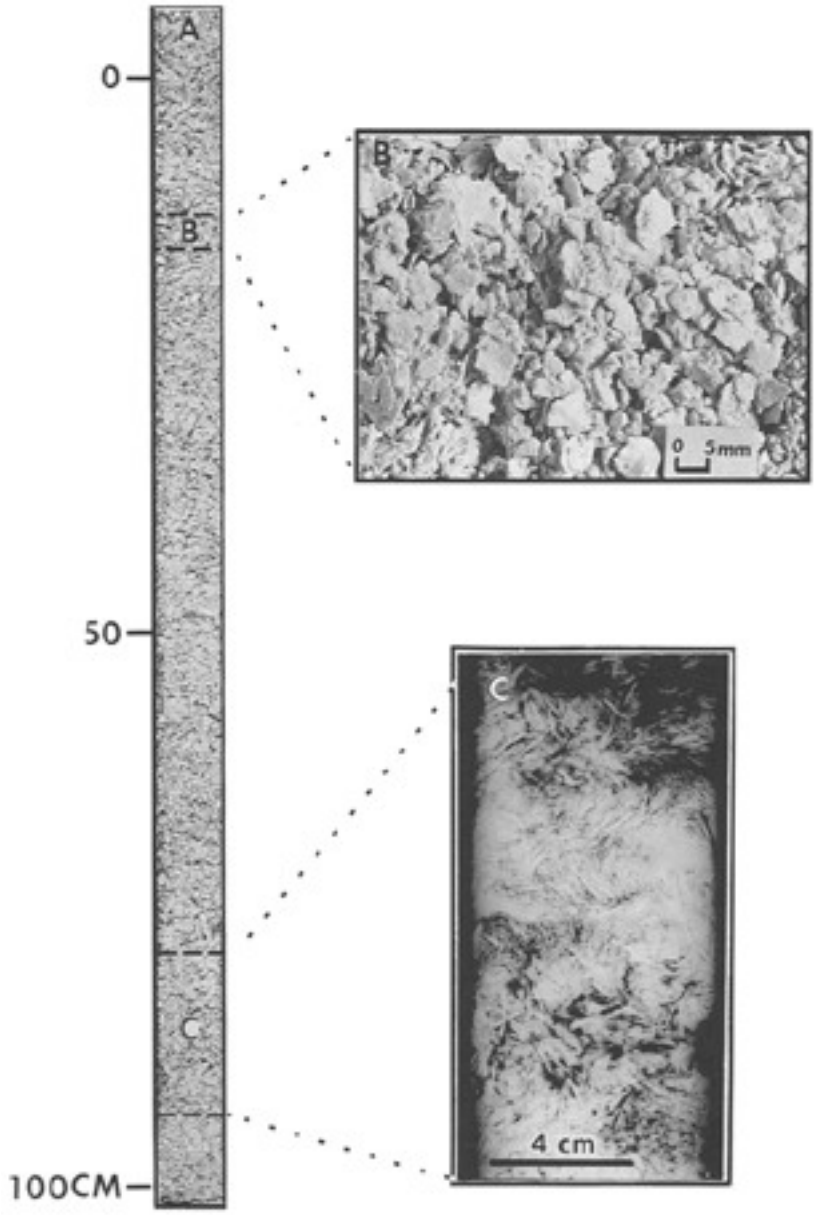
Taken from Marshall and Davies (1988)







Taken from Phipps and Roberts (1988)



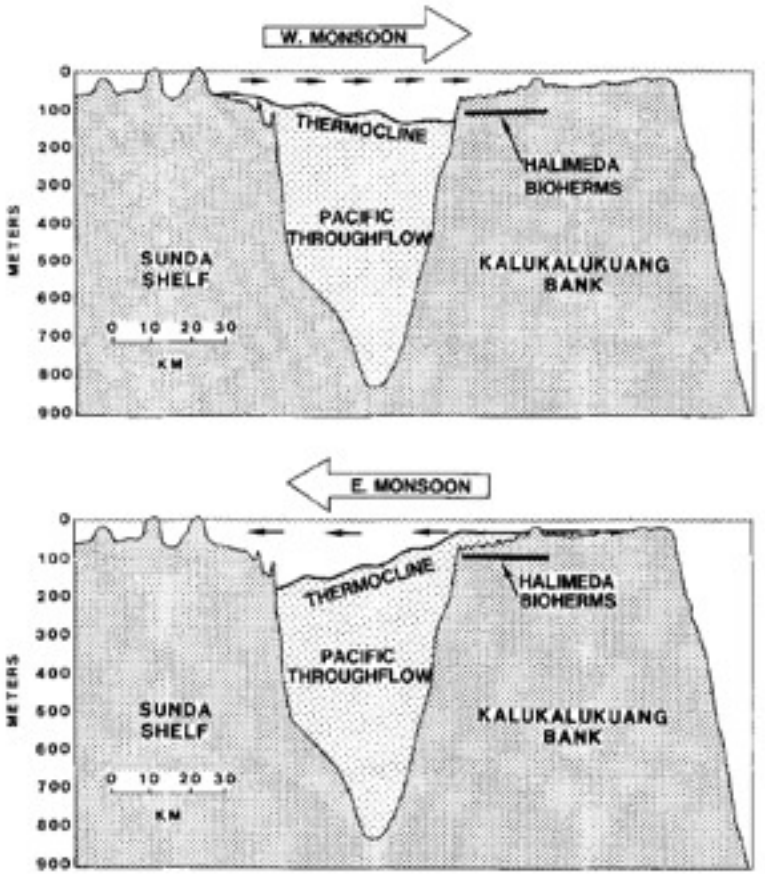


Fig. 19. Schematic diagram showing the upwelling of Pacific throughflow water along the western margin of K-Bank in response to the strong eastern monsoon

Taken from Roberts et al. (1988)

Accretion rate up to 0.6 m/100 yr

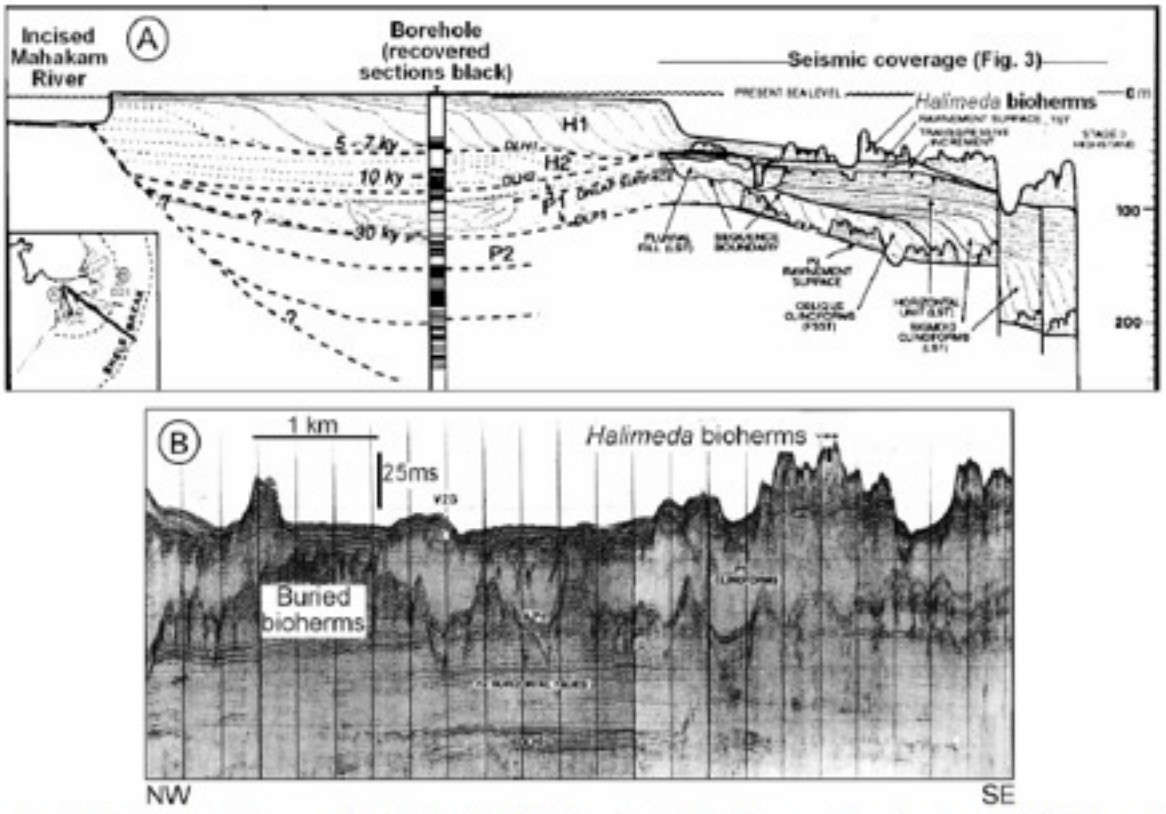
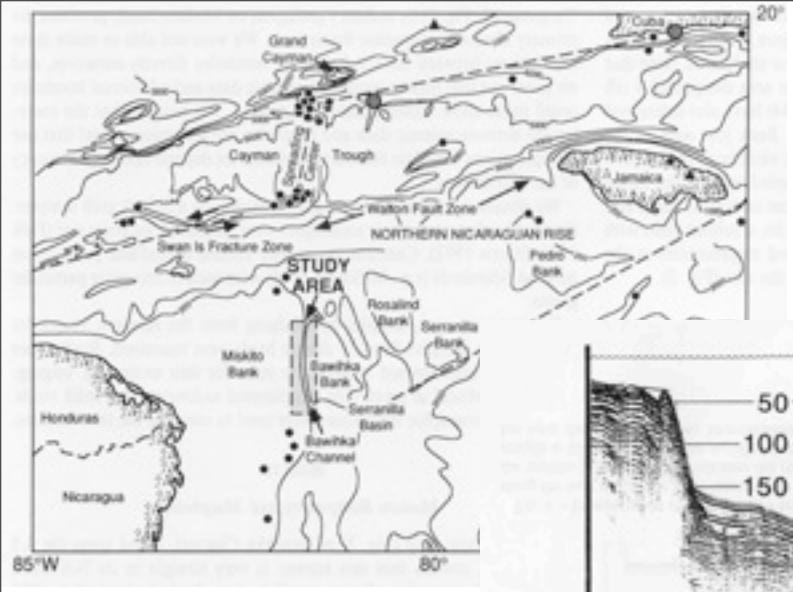
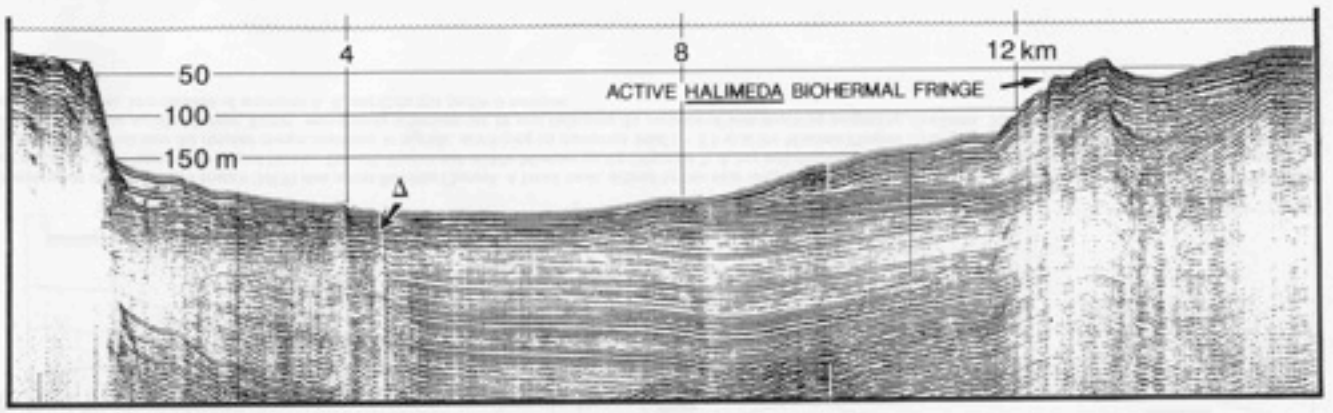


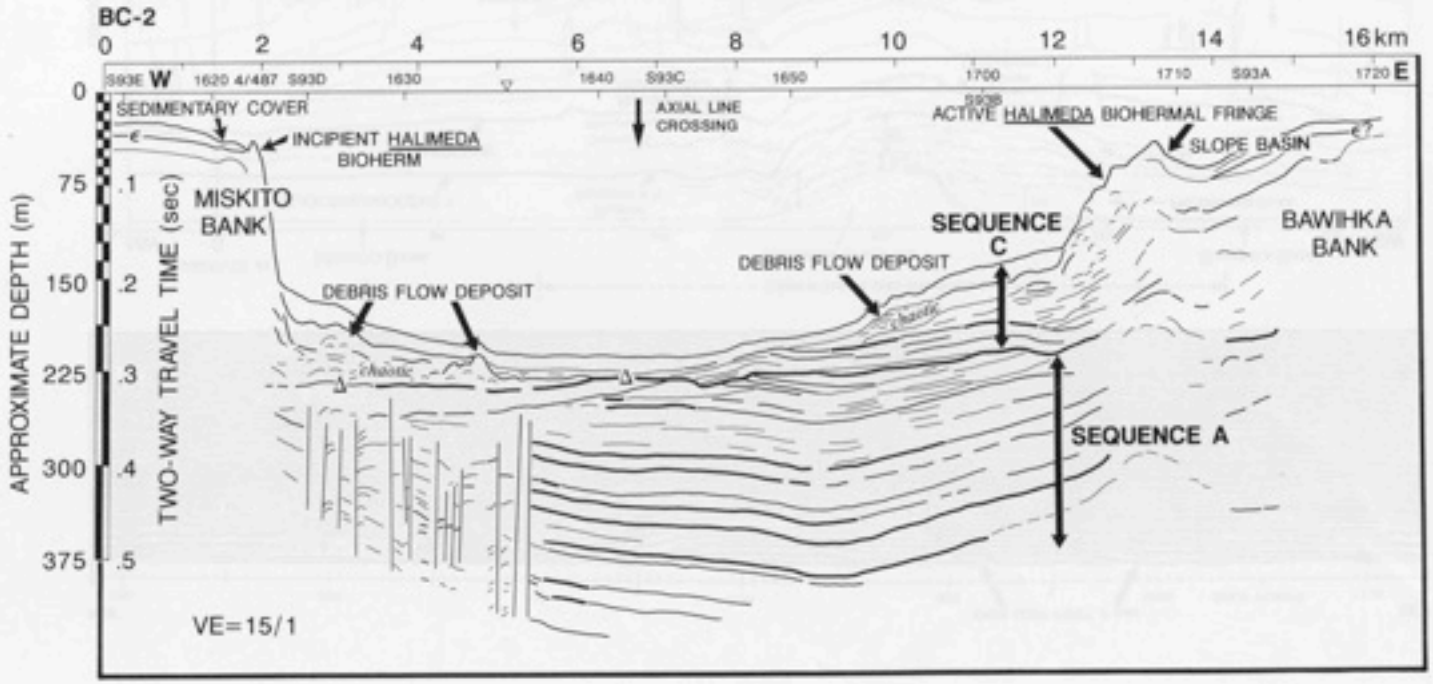
FIG. 4.—A) Schematic stratigraphic summary of the Mahakam shelf and B) high-resolution D21 seismic line across bioherms from the mid-shelf (from Roberts and Sydow 1996). Seismic facies, important units of Holocene (H) and Pleistocene (P) ages, and surfaces (DL—Downlap) are shown together with the locations of shallow vibracores V25 and V26. Inset map shows lines of section.

Taken from Wilson (2005, after Roberts and Sydow, 1996)

topographic upwelling



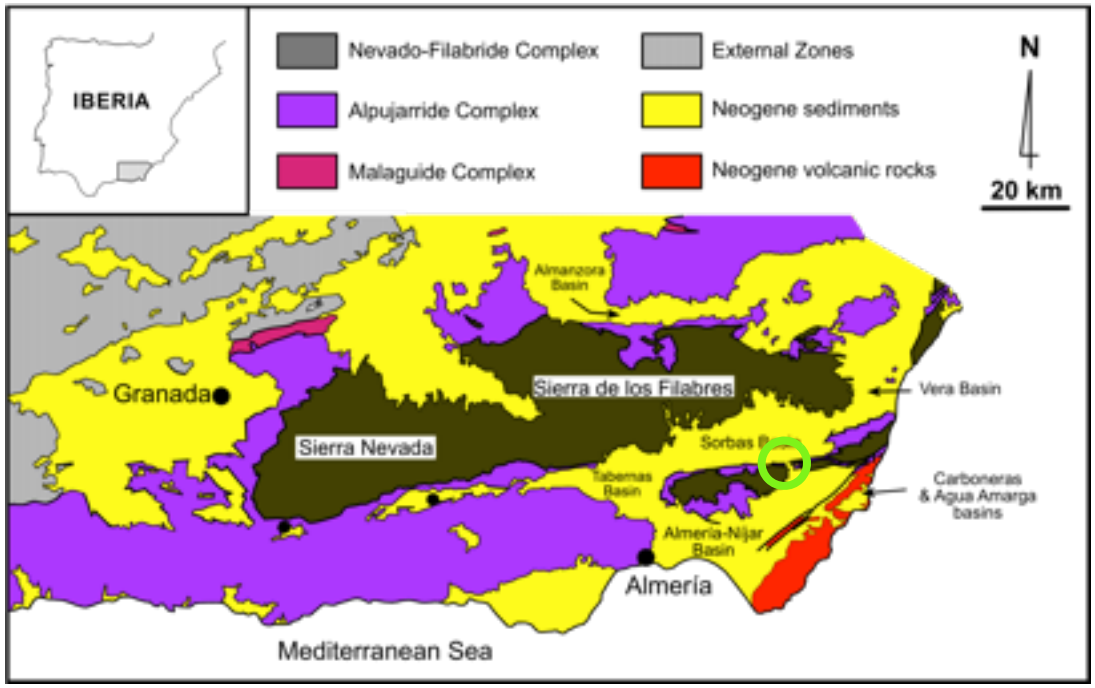


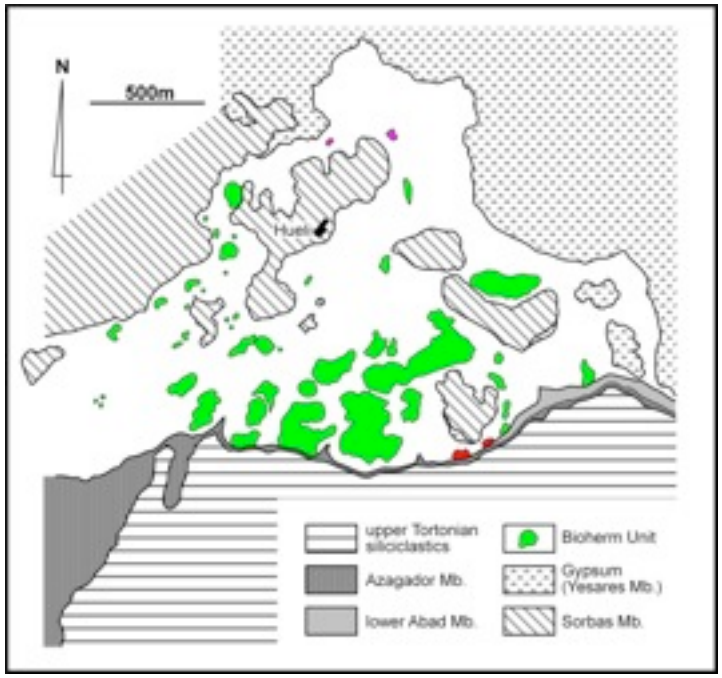


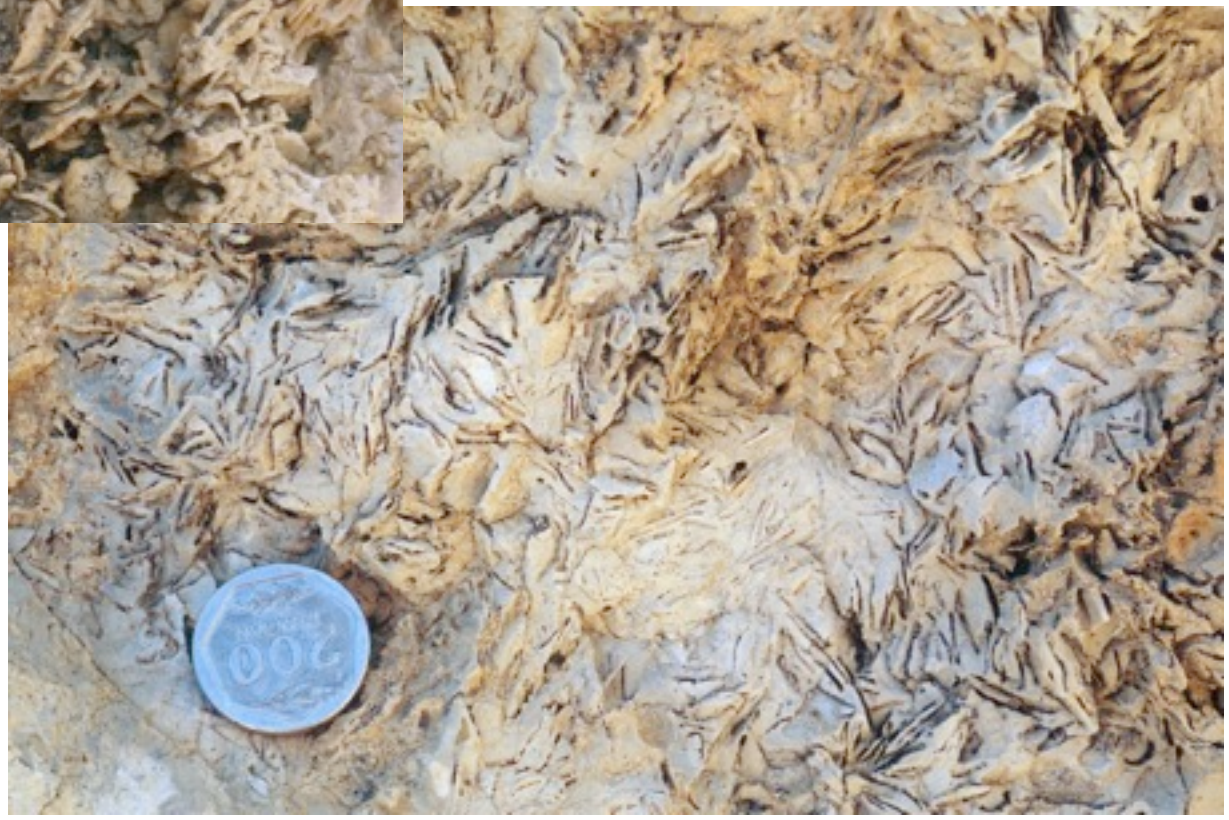
Hine et al. (1994)

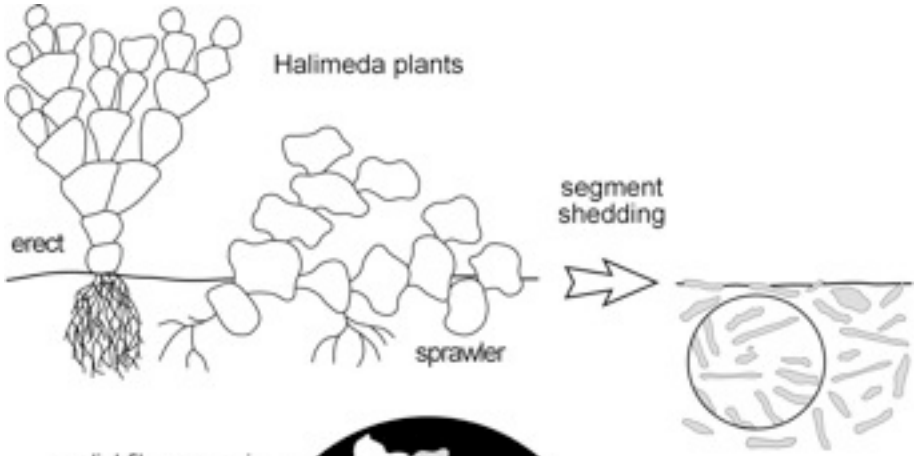
Messinian *Halimeda* bioherms

Sorbas Basin, SE Spain

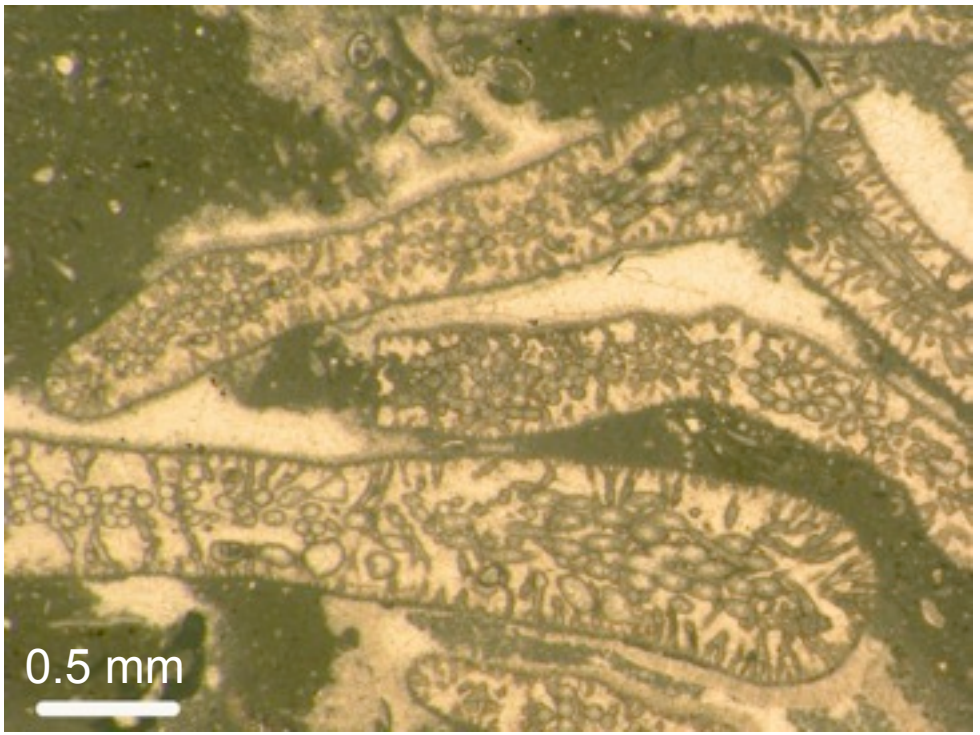


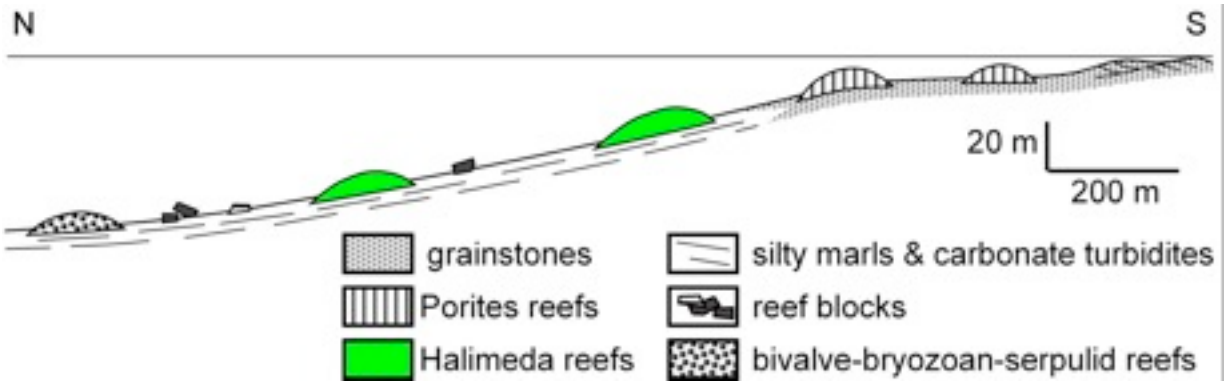


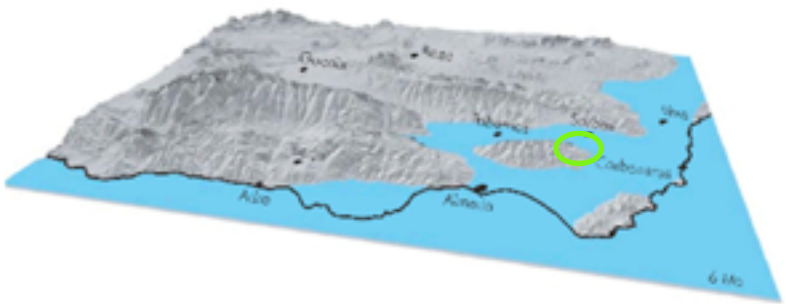



Halimeda plants
erect
sprawler
segment
shedding

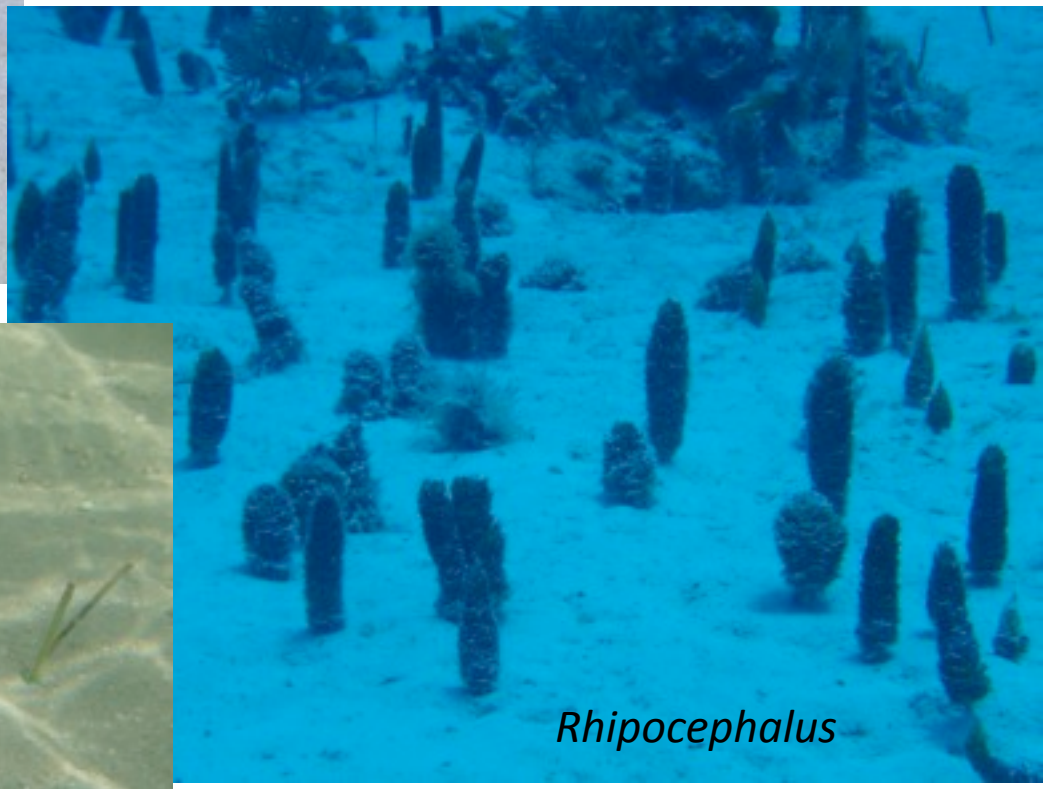

radial-fibrous marine
cement
micritic & peloidal crust
Halimeda segments
sparry cement
& voids

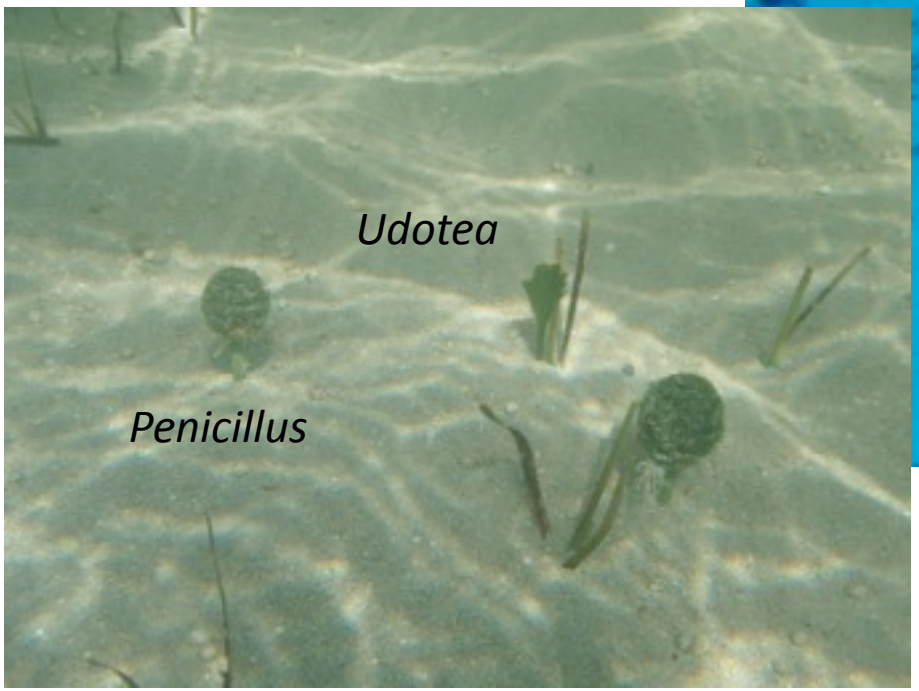

0.5 mm


N
S
20 m
200 m
grainstones
Porites reefs
Halimeda reefs
silty marls & carbonate turbidites
reef blocks
bivalve-bryozoan-serpulid reefs



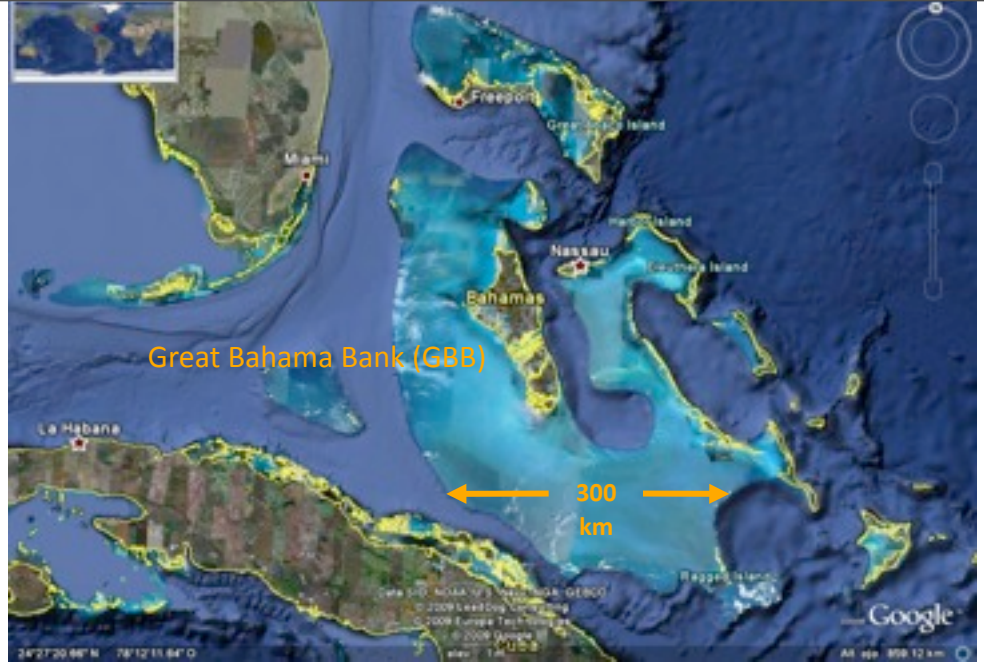
more BRYOPSIDALES





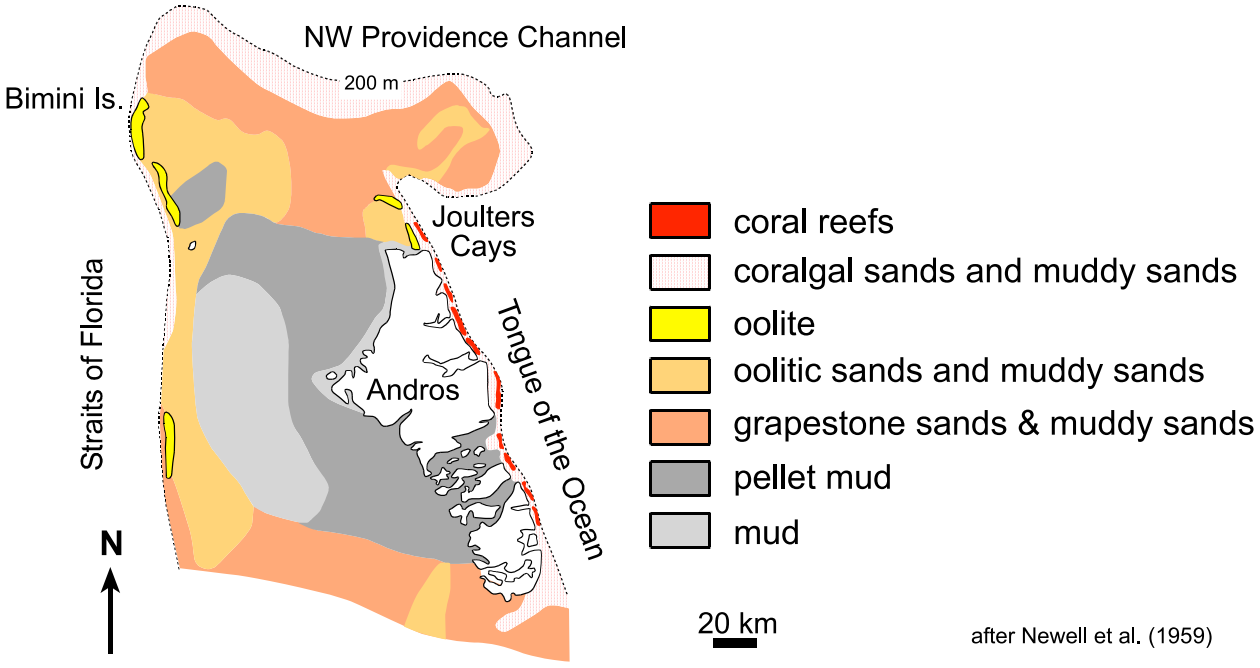
they all produce fine-grained aragonite skeletons that desintegrate after death

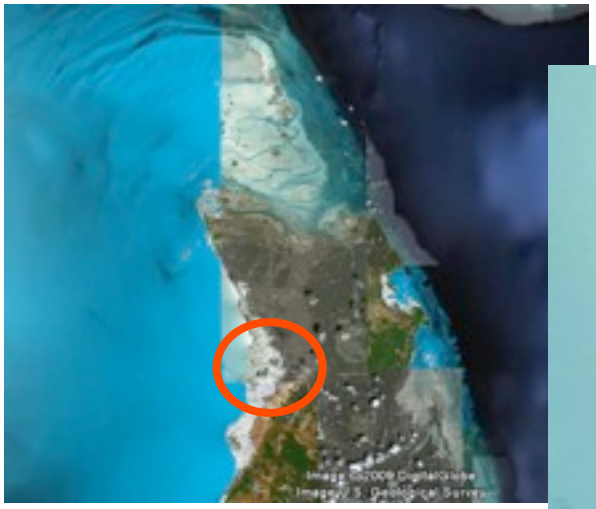
poor preservation potential but high carbonate mud production

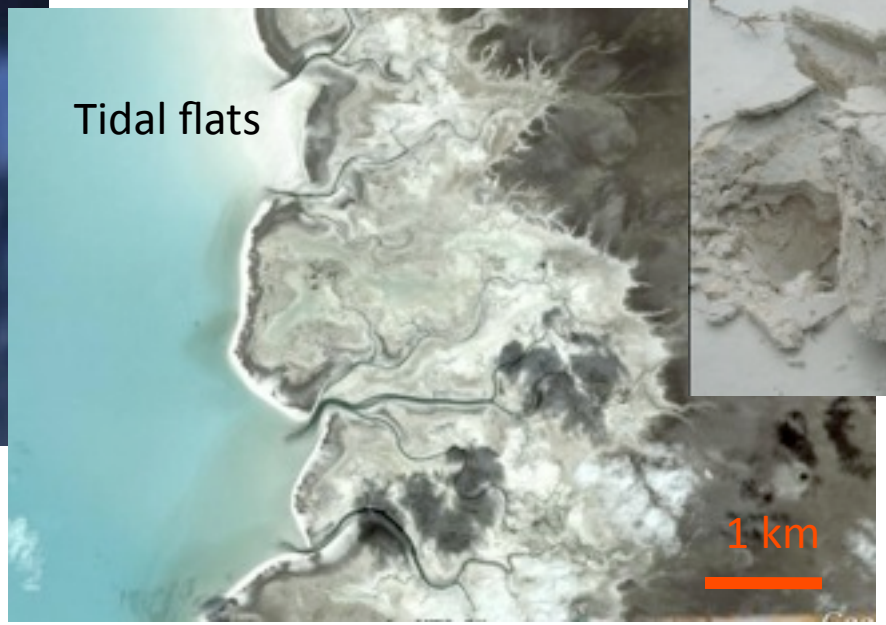


The micrite question

most carbonate accumulating in shallow-water tropical shelfs is mud



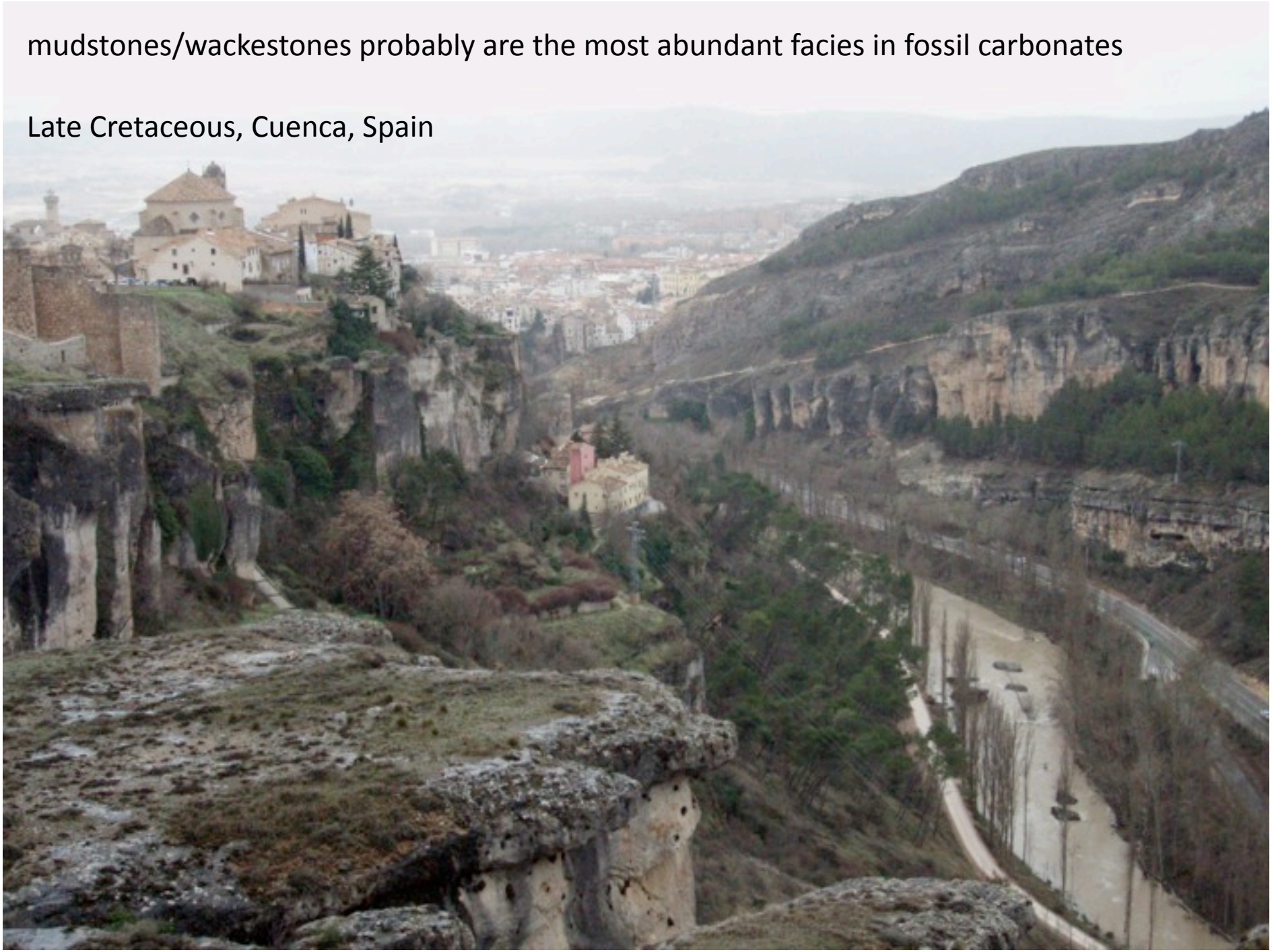




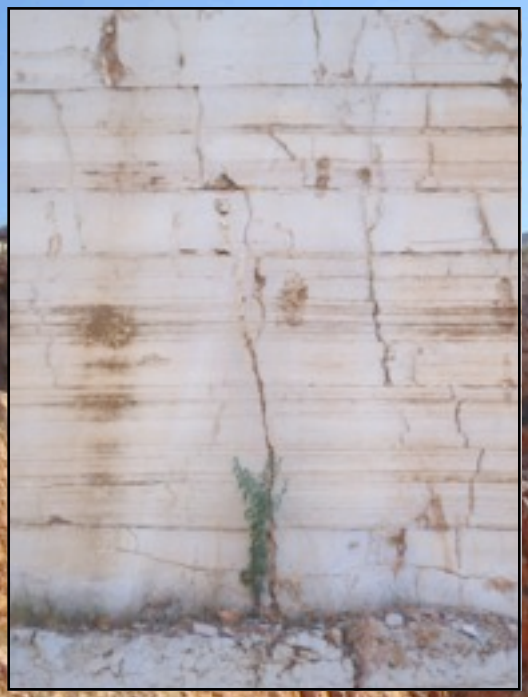
…. and most of the mud (> 90%) is fine-grained aragonite

mudstones/wackestones probably are the most abundant facies in fossil carbonates

Late Cretaceous, Cuenca, Spain



Early Cretaceous, Gargano Peninsula, Puglia, Italy



tidal-flat and inner platform deposits

Which is the origin of aragonite mud?

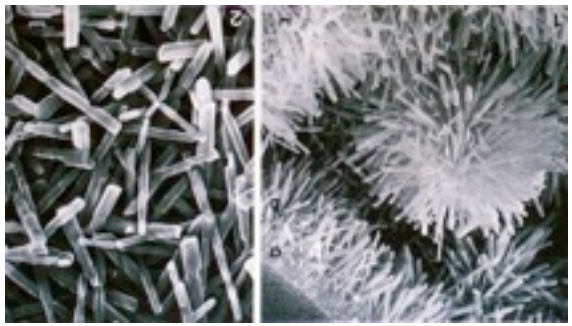
- largely algal **Lowenstam** (**1955**)

  Bryposidales and Dasycladales (Green Algae)

- whitings (clouds of carbonate mud in the water column)

  Loreau (1982)

5 micron



Which is the origin of whitings?

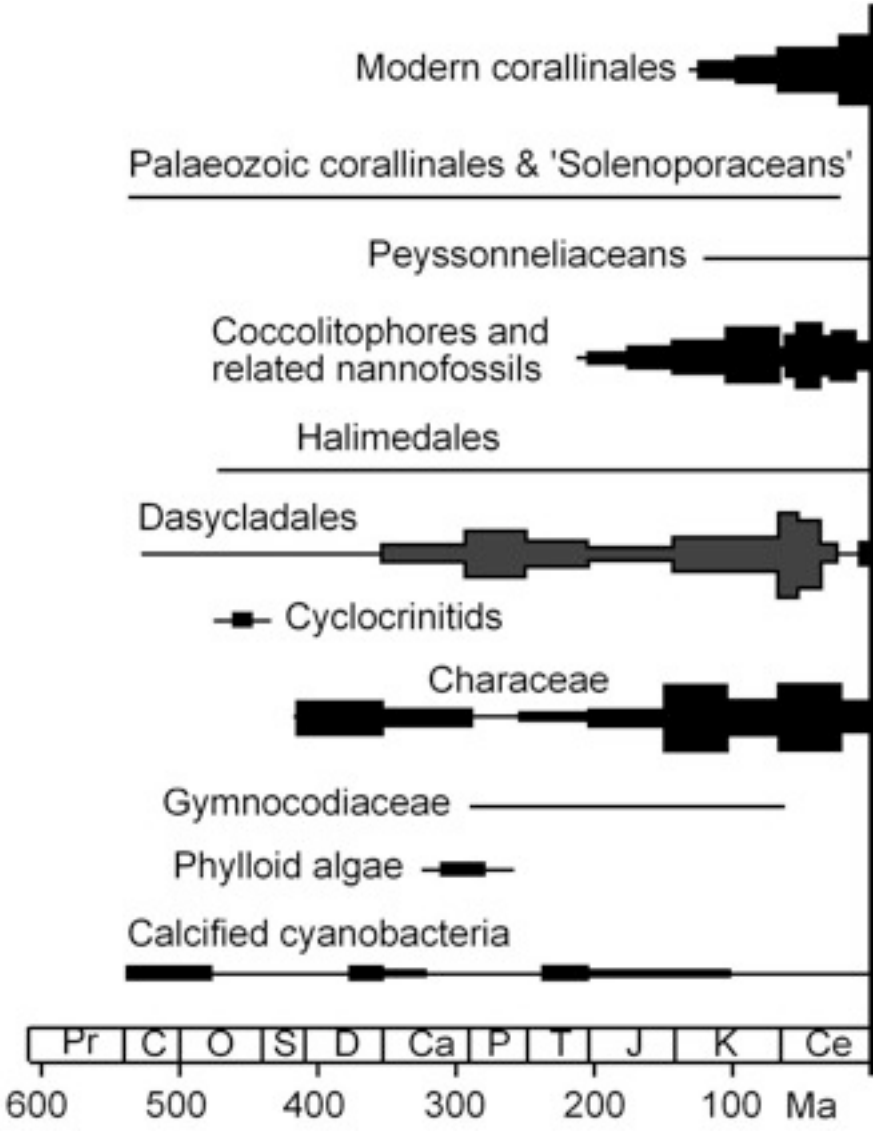
- Resuspended seafloor mud (of algal origin)

- Water column precipitates

  - Inorganic precipitation (high oversaturation required)

  - Bioinduced by phytoplankton

No conclusive evidence. Geochemistry tends to support the algal origin
(for example Broecker et al. 2001, 14C/C ratio)



Braga and Riding (2004)

Taken from Flügel (2004)

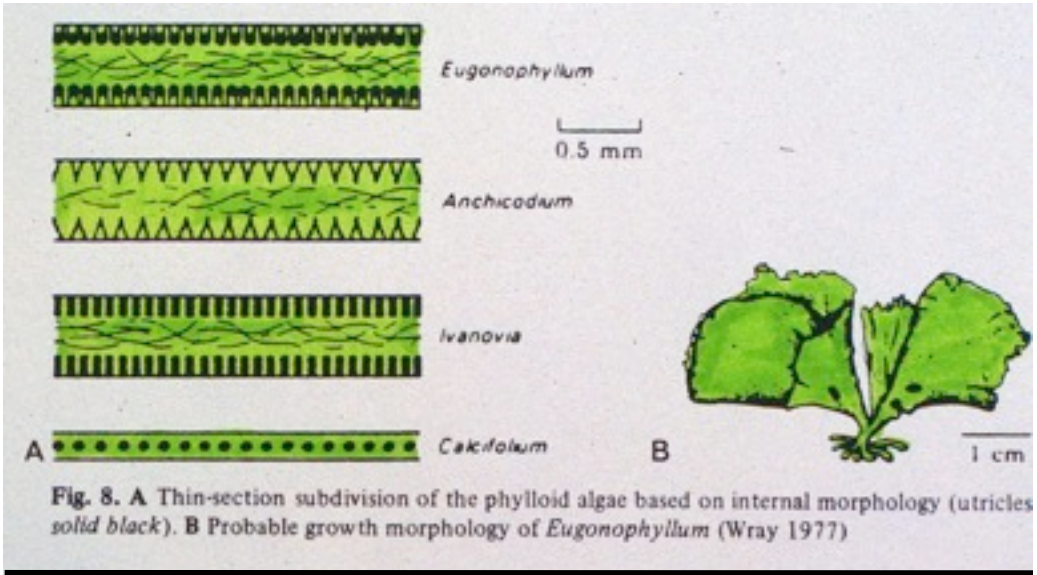
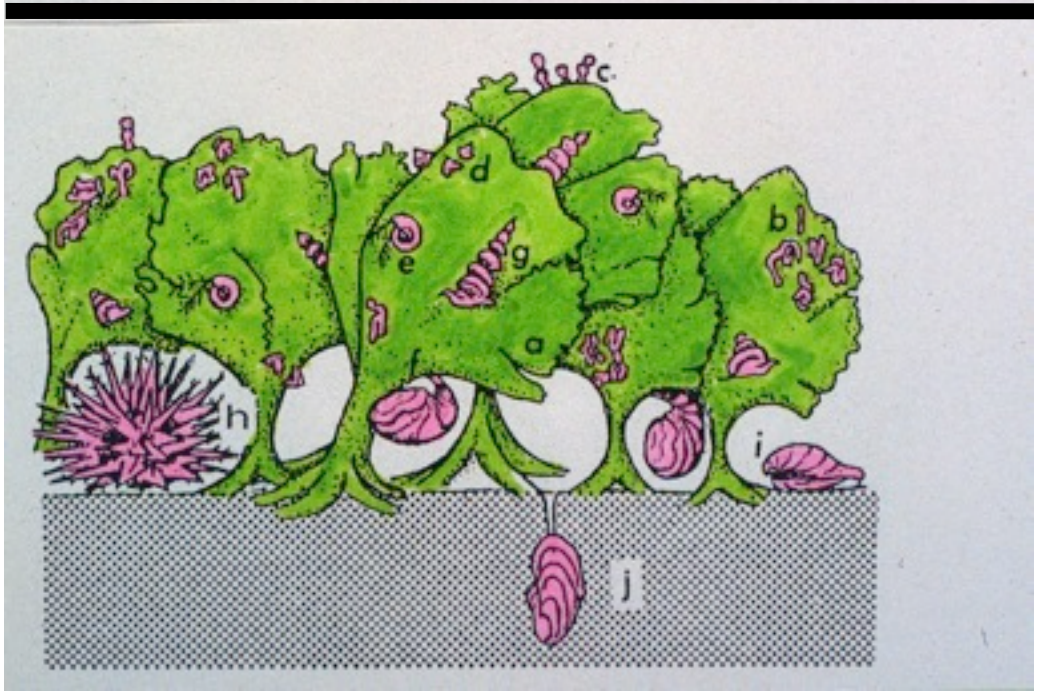
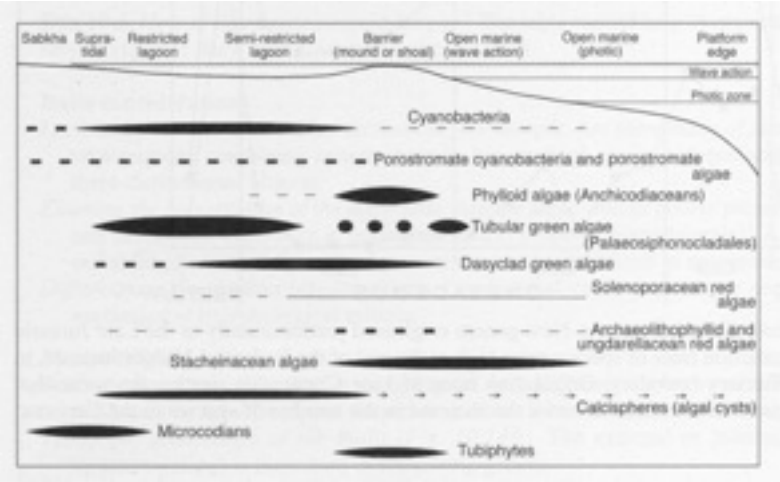


Fig. 8. A Thin-section subdivision of the phylloid algae based on internal morphology (utricles *solid black*). **B** Probable growth morphology of *Eugonophyllum* (Wray 1977)




Sabkha
Supra-tidal
Restricted lagoon
Semi-restricted lagoon
Barrier (mound or shoal)
Open marine (wave action)
Open marine (photic)
Platform edge
Wave action
Photic zone
Cyanobacteria
Porostromate cyanobacteria and porostromate algae
Phylloid algae (Anchicodiaceans)
Tubular green algae (Palaeosiphonocladales)
Dasyclad green algae
Solenoporacean red algae
Archaeolithophyllid and ungdarellacean red algae
Stacheinacean algae
Calcispheres (algal cysts)
Microcodians
Tubiphytes