What you are supposed to learn:

- What are carbonate rocks, where do they form and how.
- What are the main types of carbonate rocks
- Elements of sedimentology of carbonates
- Some notions about the geochemistry of carbonate in the oceans

DISCLAIMER

This module in just an introduction to the complex and fascinating world of carbonates. If you want to learn more, you may decide to follow a course on Carbonate Sedimentology.

Carbonate rocks.
What are they made of and where do they form (today)?

dipartimento di matematica e geoscienze

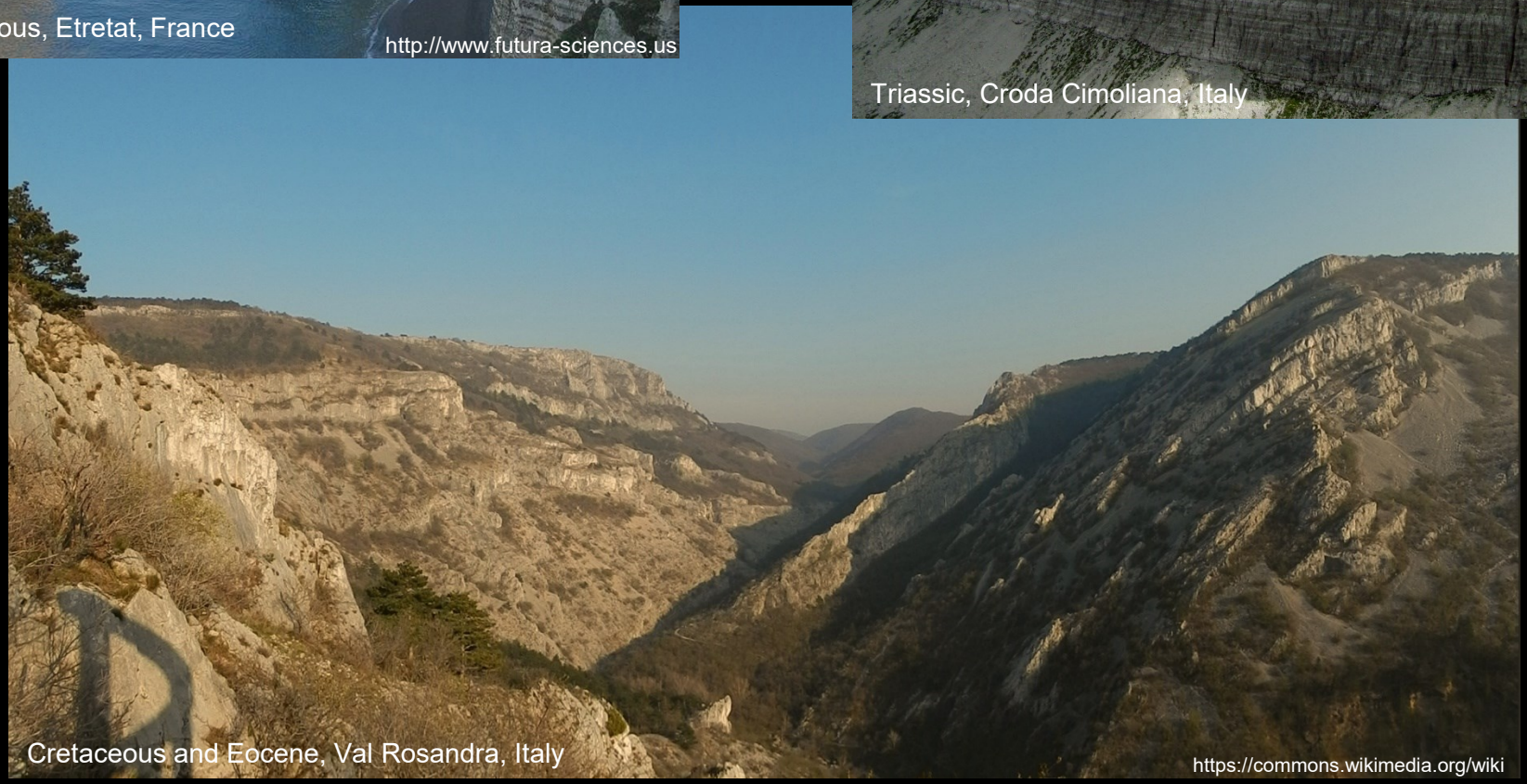
Carbonate rocks are made (predominantly) of carbonate minerals

Carbonatite
(ingeous)

Marble
(metamorphic)

Limestone
(sedimentary)

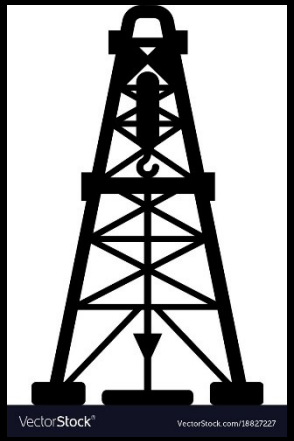
We will deal with carbonate sedimentary rocks

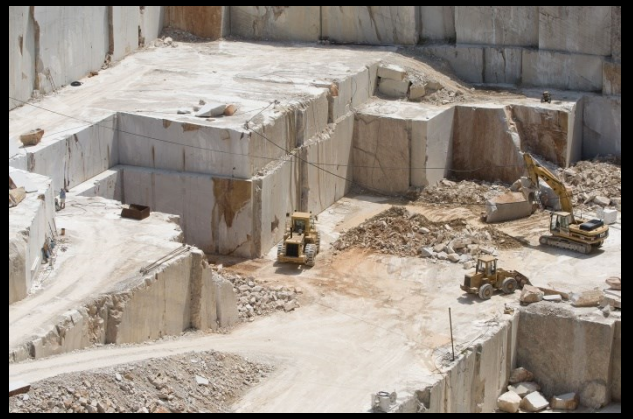


Why do we care of carbonate rocks?

- We are geologists, we know and like rocks.
- Carbonate rocks are volumetrically a most significant part of the geologic record.
- Carbonate rocks possess much of the fossil record of life on the planet.
- Carbonate rocks are a fundamental part of the global C cycle.
- Carbonate rocks possess prominent economical importance:

  - host nerarly 40% of known hydrocarbon reserves
  - host base metal deposits (e.g. Pb, Zn…)
  - groundwater reservoirs
  - raw materials for construction and chemical industries





Carbonate sedimentary rocks are composed primarily (>50%) of carbonate minerals.

There are two main types : of carbonate rock

limestone
prevailingly $CaCO_3$

dolostone (dolomite rock)
prevailingly $CaMg(CO_3)_2$

Note
In geology and mineralogy, the term "carbonate" can refer both to carbonate minerals and carbonate rock (which is made of chiefly carbonate minerals), and both are dominated by the carbonate ion, CO_2^{-3}

How can we recognize limestone and distinguish it from dolostone?

limestone

?

dolostone

This distinction by visual observation only can be sometimes difficult

How can we recognize limestone and distinguish it from dolostone?

HCl test

Limestone reacts intensely (releasing CO_2 and H_2O) when in contact with hydrochloric acid (HCl).

This peculiarity is very useful for recognizing limestone from dolostone also in the field.

HCl test can be used to qualitatively evaluate how much carbonate a rock contains. In pure limestone, the reaction can be observed with naked eye (formation of bubbles and clearly audible fizzing). In dolostone, no reaction at all takes place. In parlty dolomitized limestone or marlstone, the bubbles are tiny or not visible, the fizzing of the reaction can be heard by putting the sample close to the ear.

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limestone

dolostone

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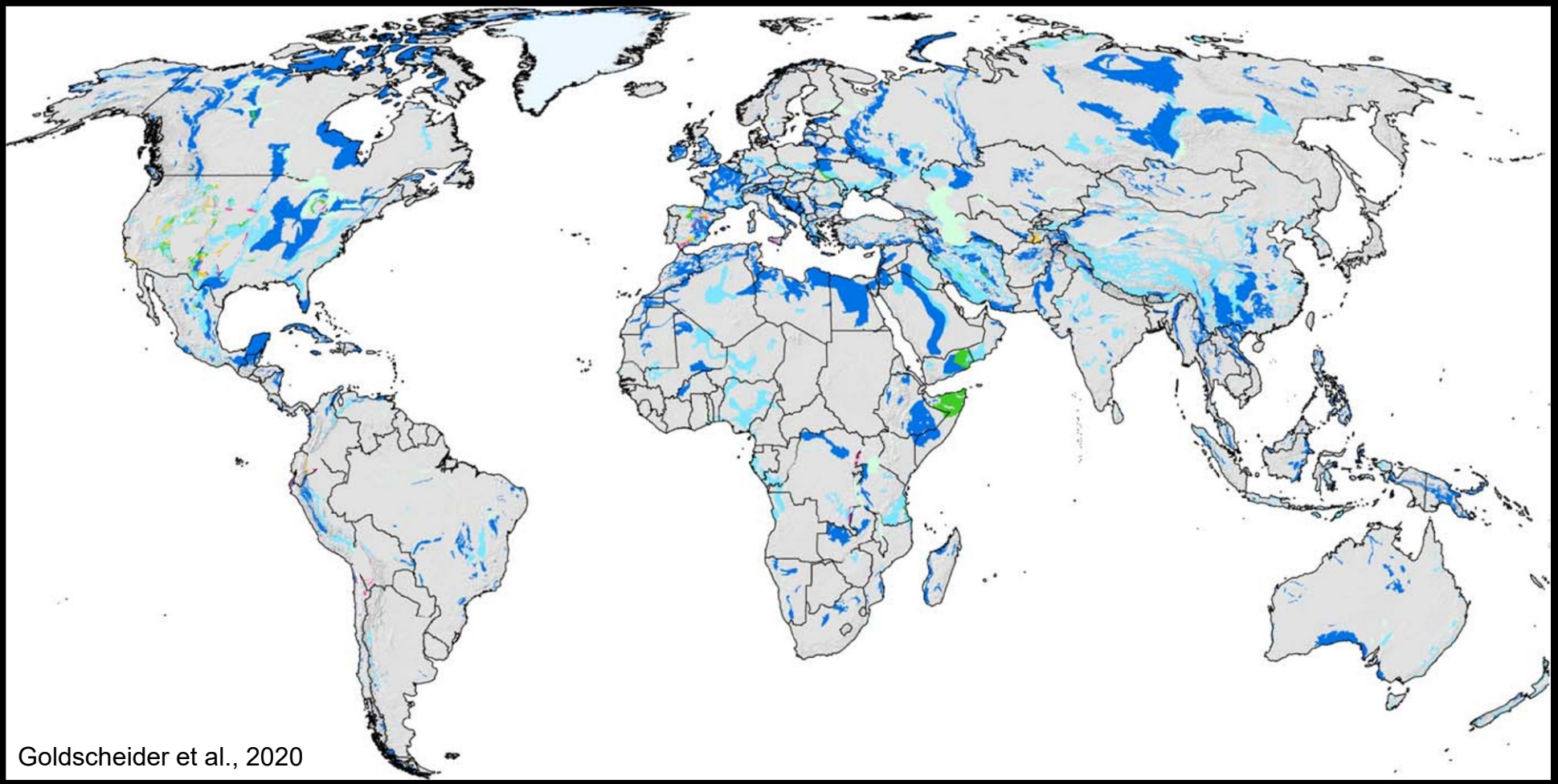
limestone

dolostone

Global distribution of carbonate rocks



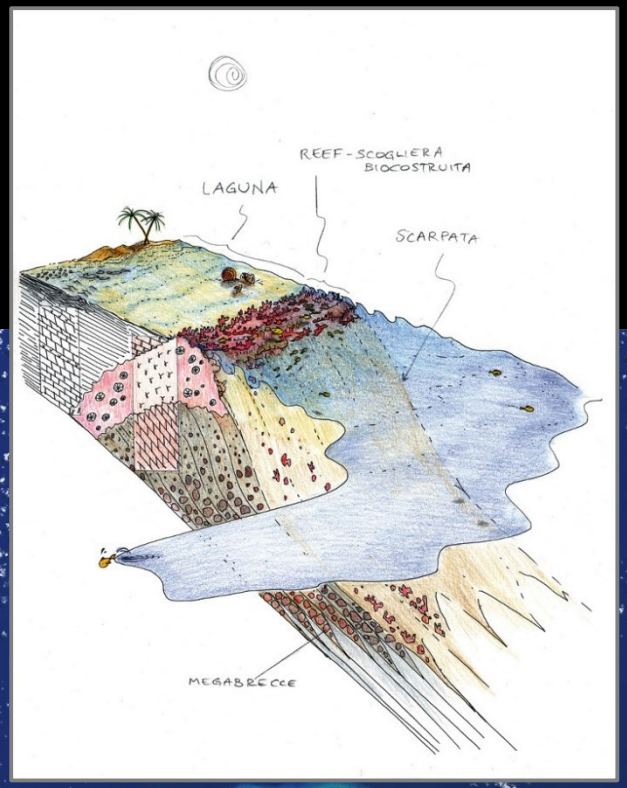
Continuous carbonate rocks

Discontinuous carbonate rocks

Mixed carbonate and evaporite rocks

Carbonate rocks are widely outcropping across the globe. They are extensively quarried as raw material for construction and chemical industries.
Large volumes of carbonate rocks also exist in the subsurface and can host important hydrocarbon and groundwater reservoirs.

Carbonates rocks have mainly marine origin



Artwork: Elena Manfrè

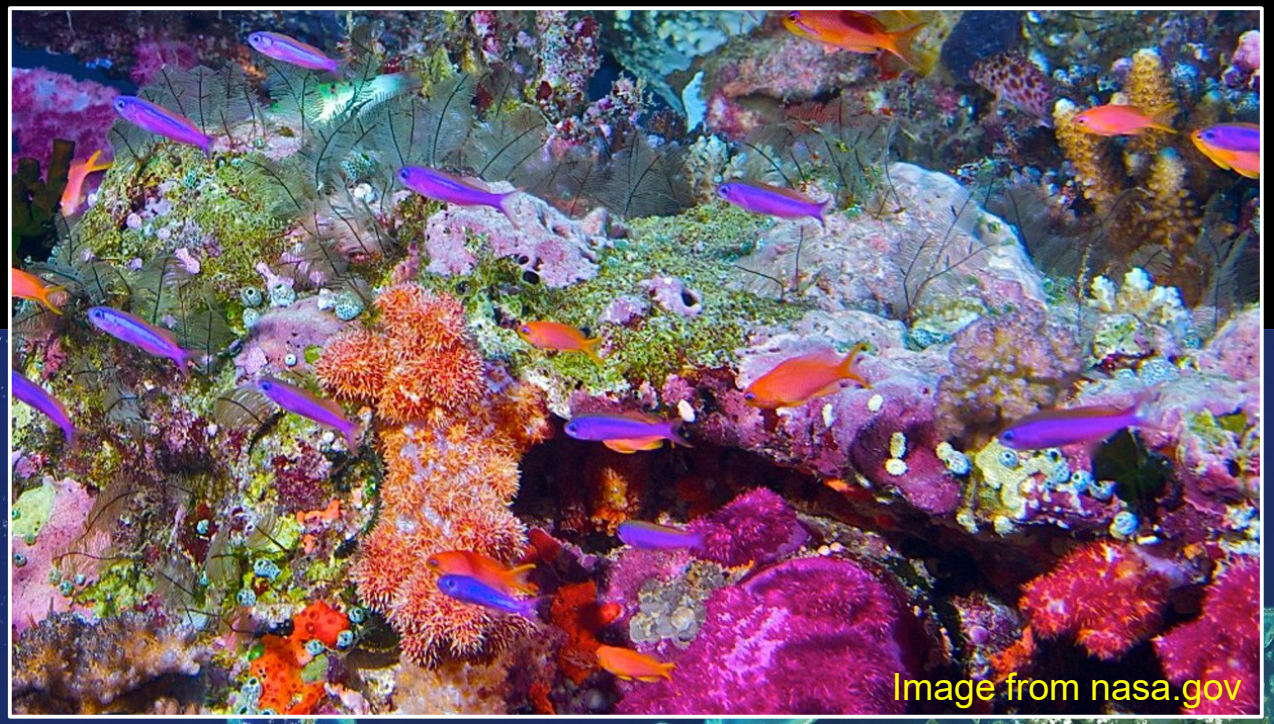
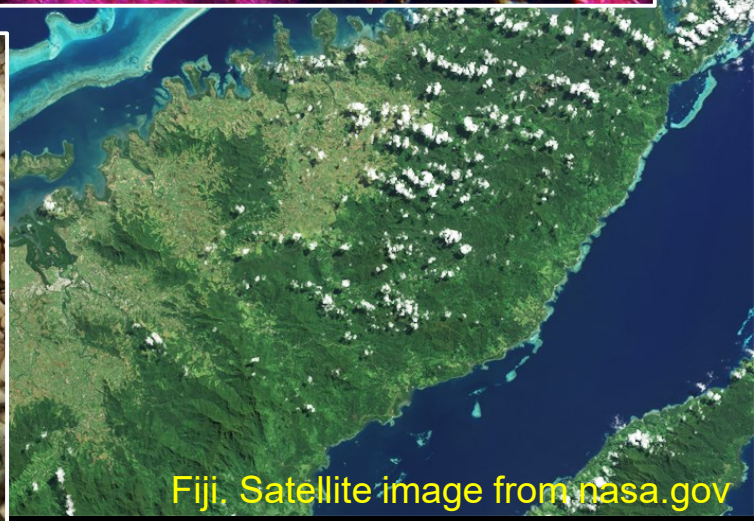


Image from nasa.gov

Image author @ commons.wikimedia.org/wiki/User:Llez



Fiji. Satellite image from nasa.gov

Nevertheless, continental carbonates also exist!


Mono Lake, California, USA

Carbonate precipitation in continental settings can occur in lakes (microbial) or around hot springs (tufa and travertine).

This type of carbonates is, however, volumetrically minor with respect to marine carbonate deposits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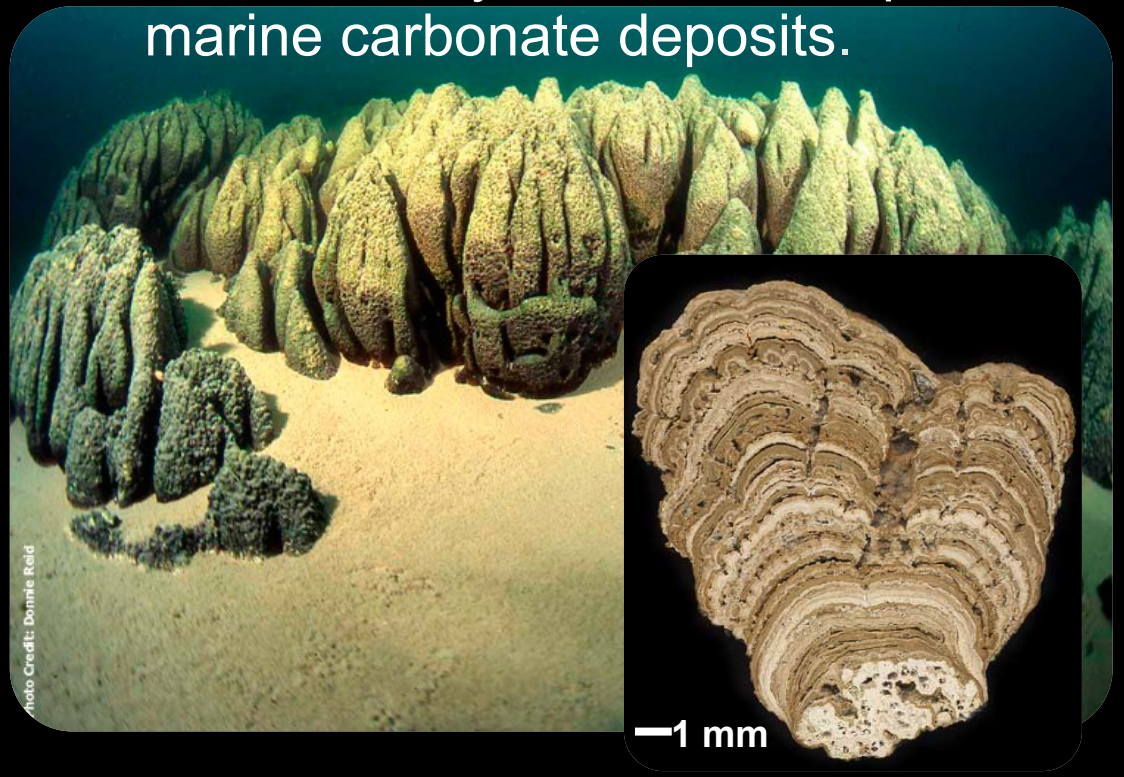


Carbonate rocks vs clastic rocks

Carbonate rocks like clastic rocks derive from sediments, but they are fundamentally different.

- Carbonates are often formed with the **mediation of living organisms** (up to 90-95% grains are biogenic in origin)
- Carbonate precipitation is a **chemical reaction**.

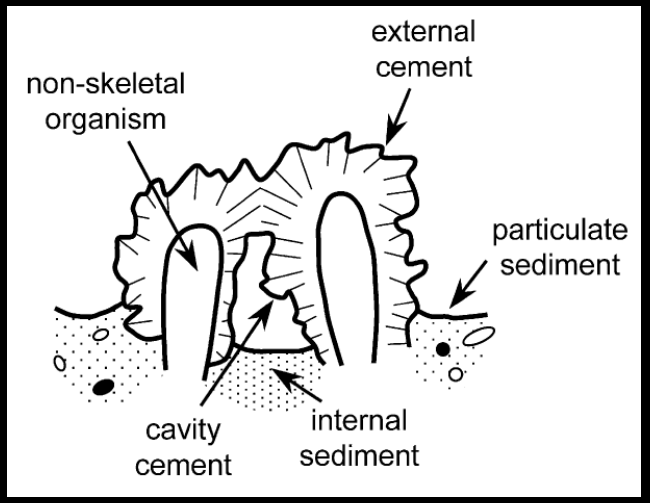
Physical, chemical and biological processes

VS

Physical (transport) processes

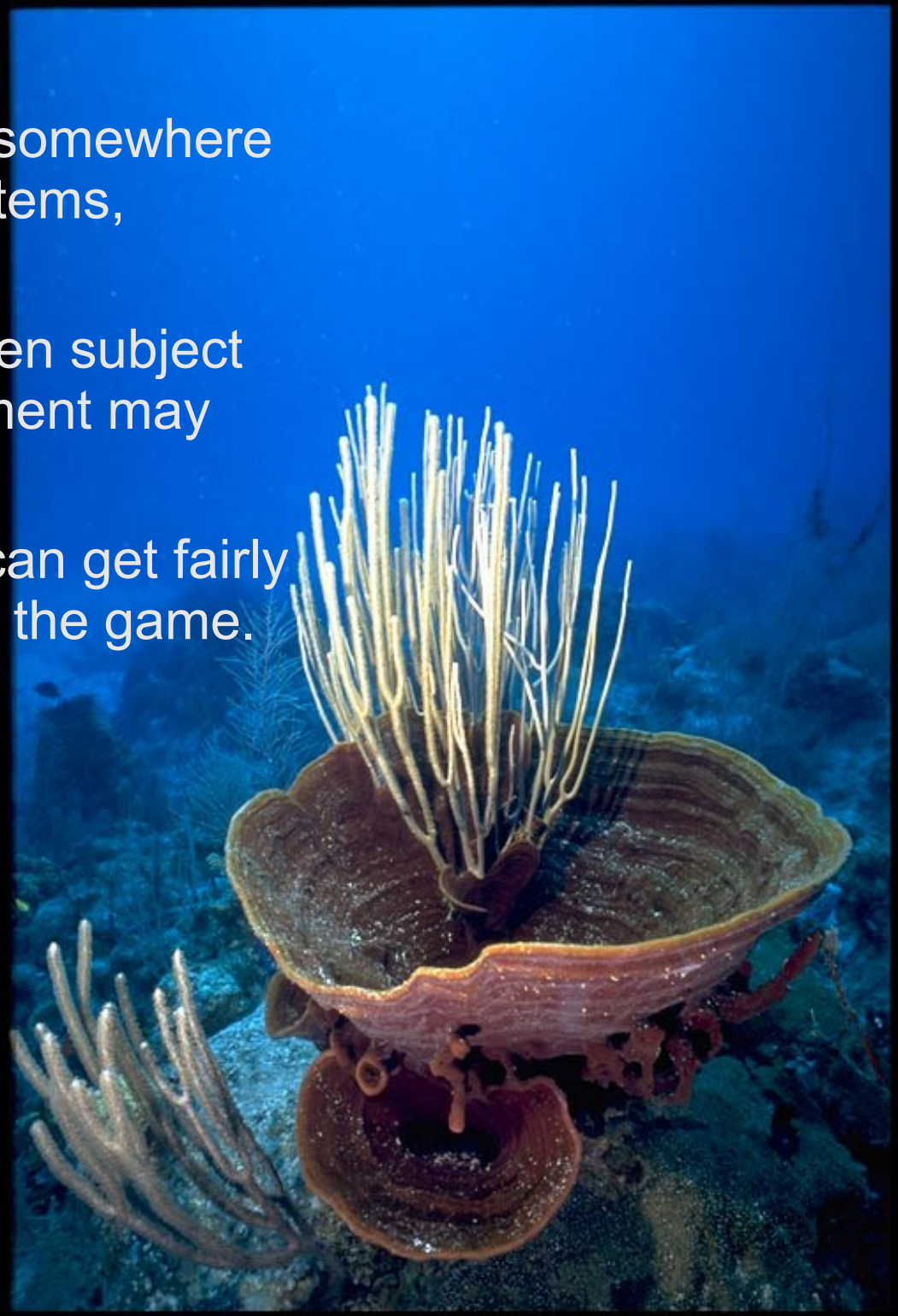
Three main consequences:

- Sediment do not come from somewhere in the hinterland: in carbonate systems, sediments are produced in situ*;
- Carbonate sediments are often subject to early lithification: carbonate cement may even form directly from seawater.
- When life is involved things can get fairly complicated as evolution is part of the game.

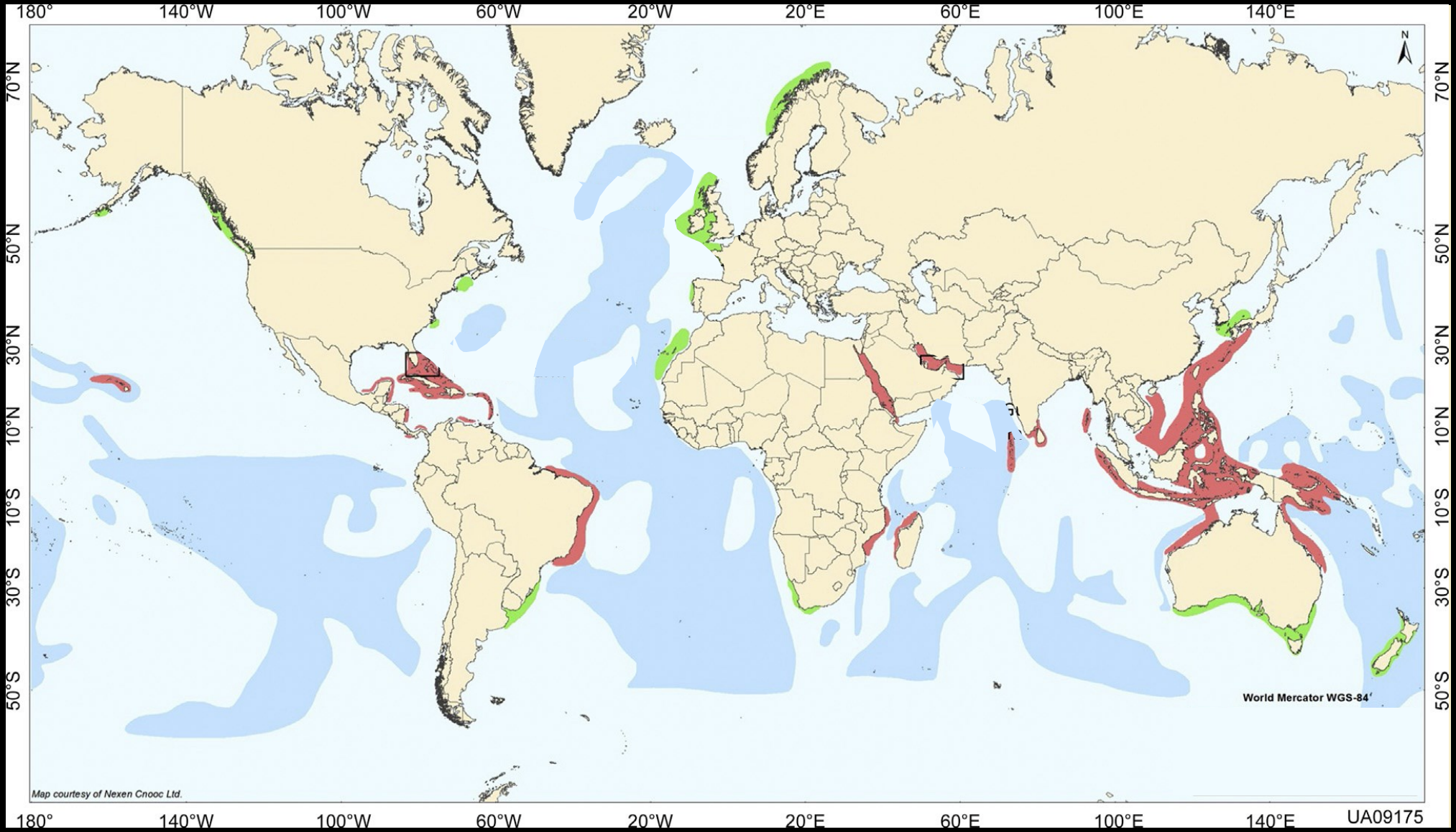


Riding, 2002

*) “Carbonates are born, not made”

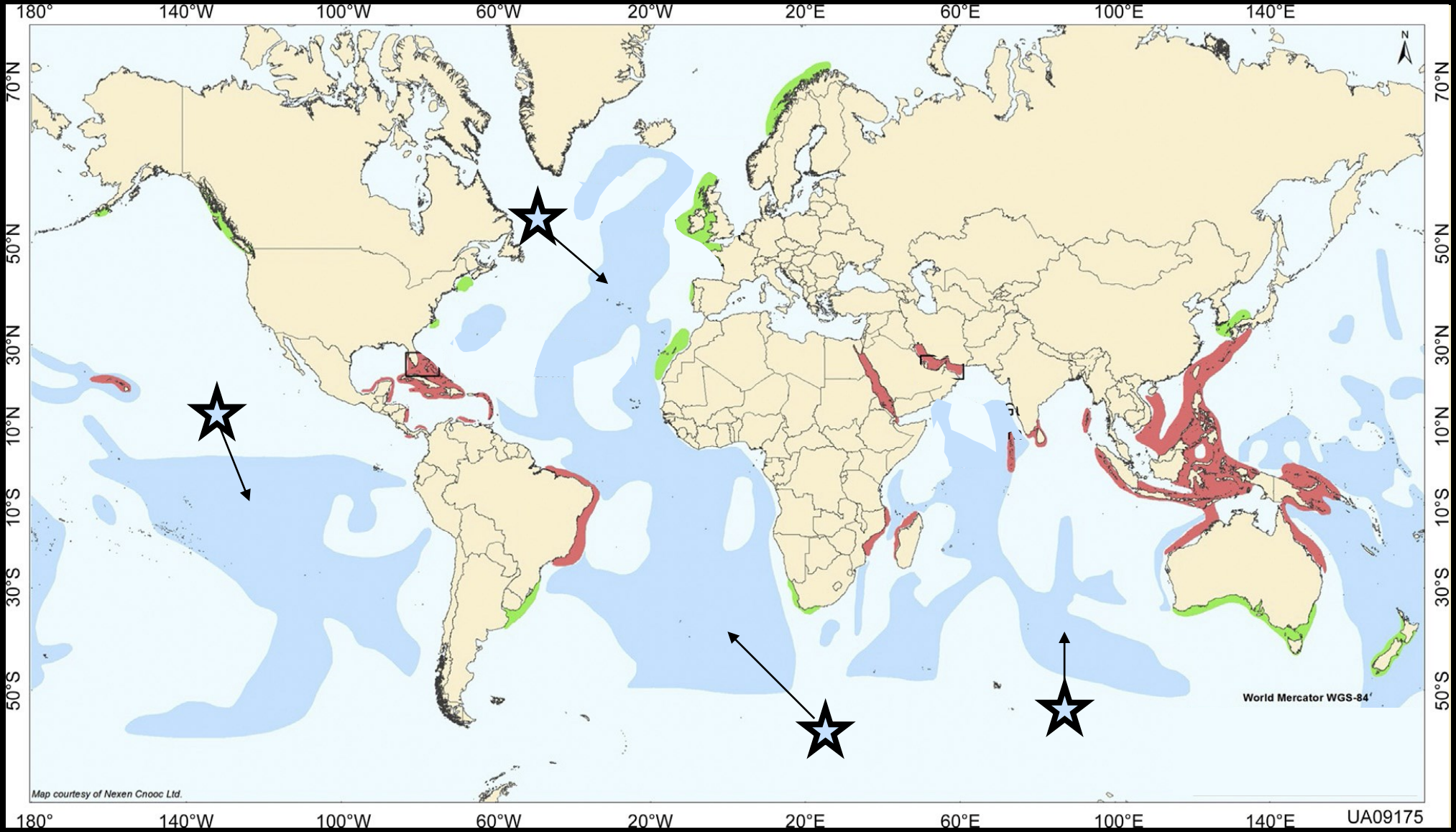


Carbonate rocks mainly derive from marine carbonate sediments



Main areas of carbonate precipitation in modern oceans:

Carbonate rocks mainly derive from marine carbonate sediments



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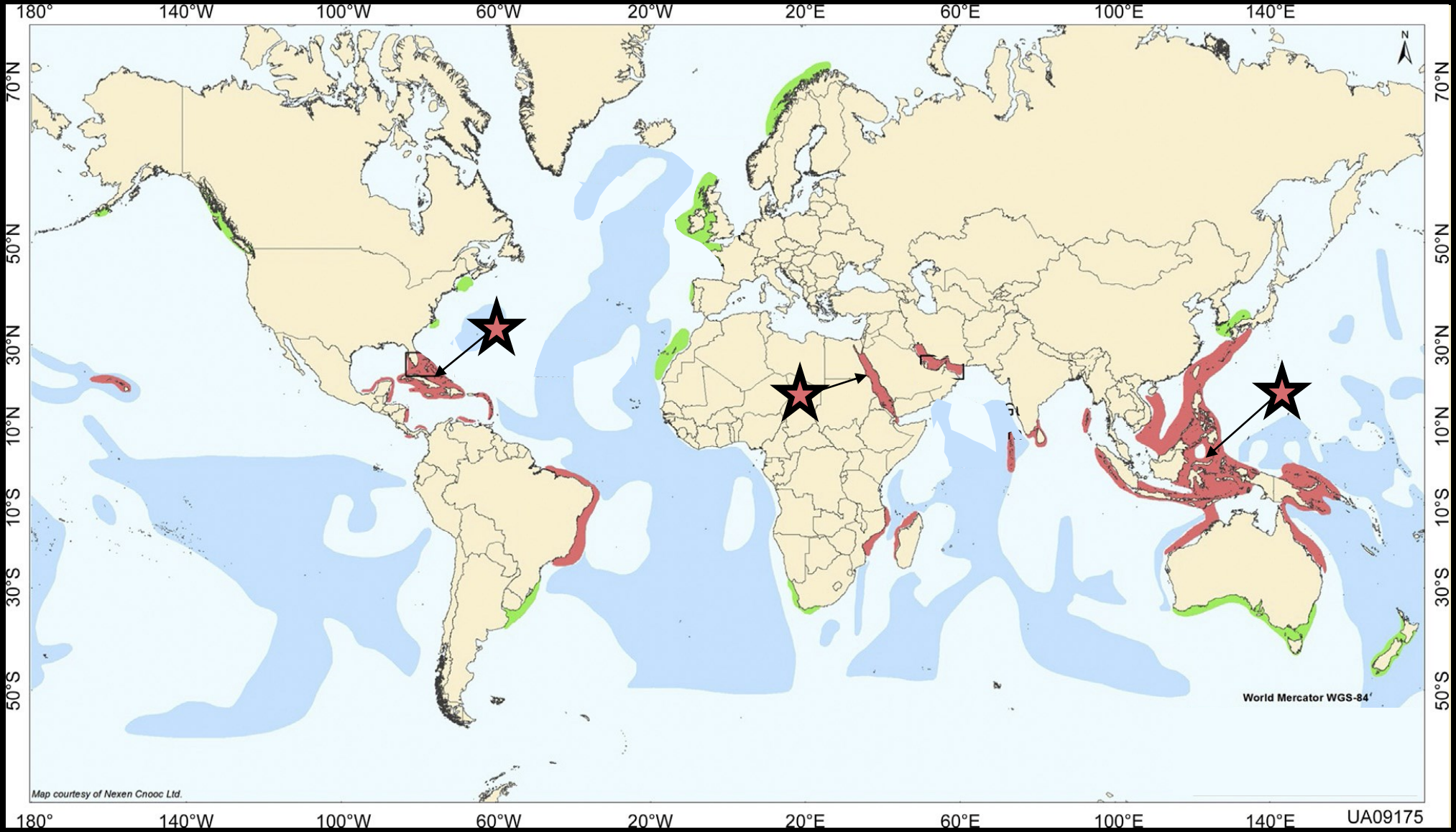

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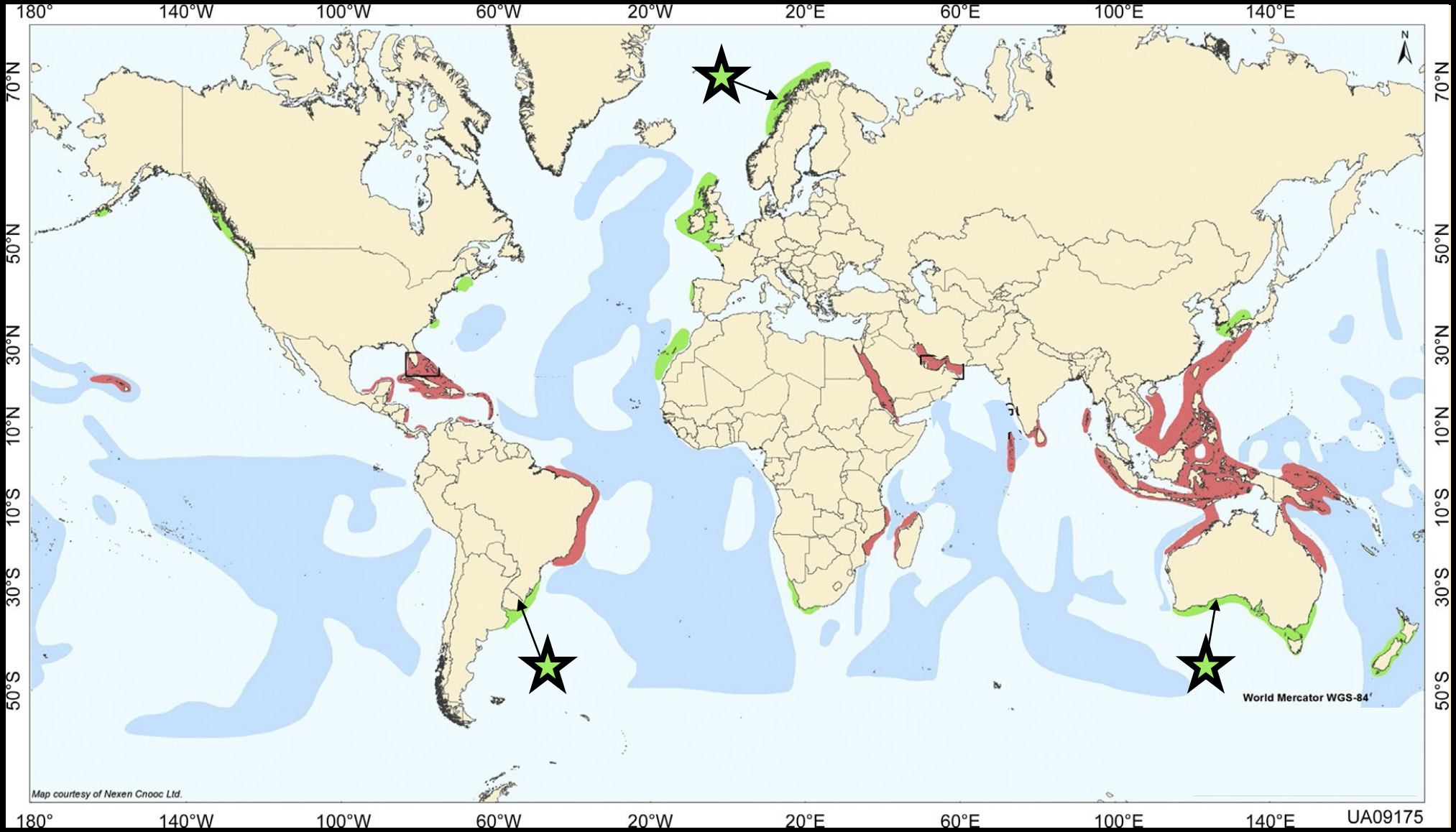

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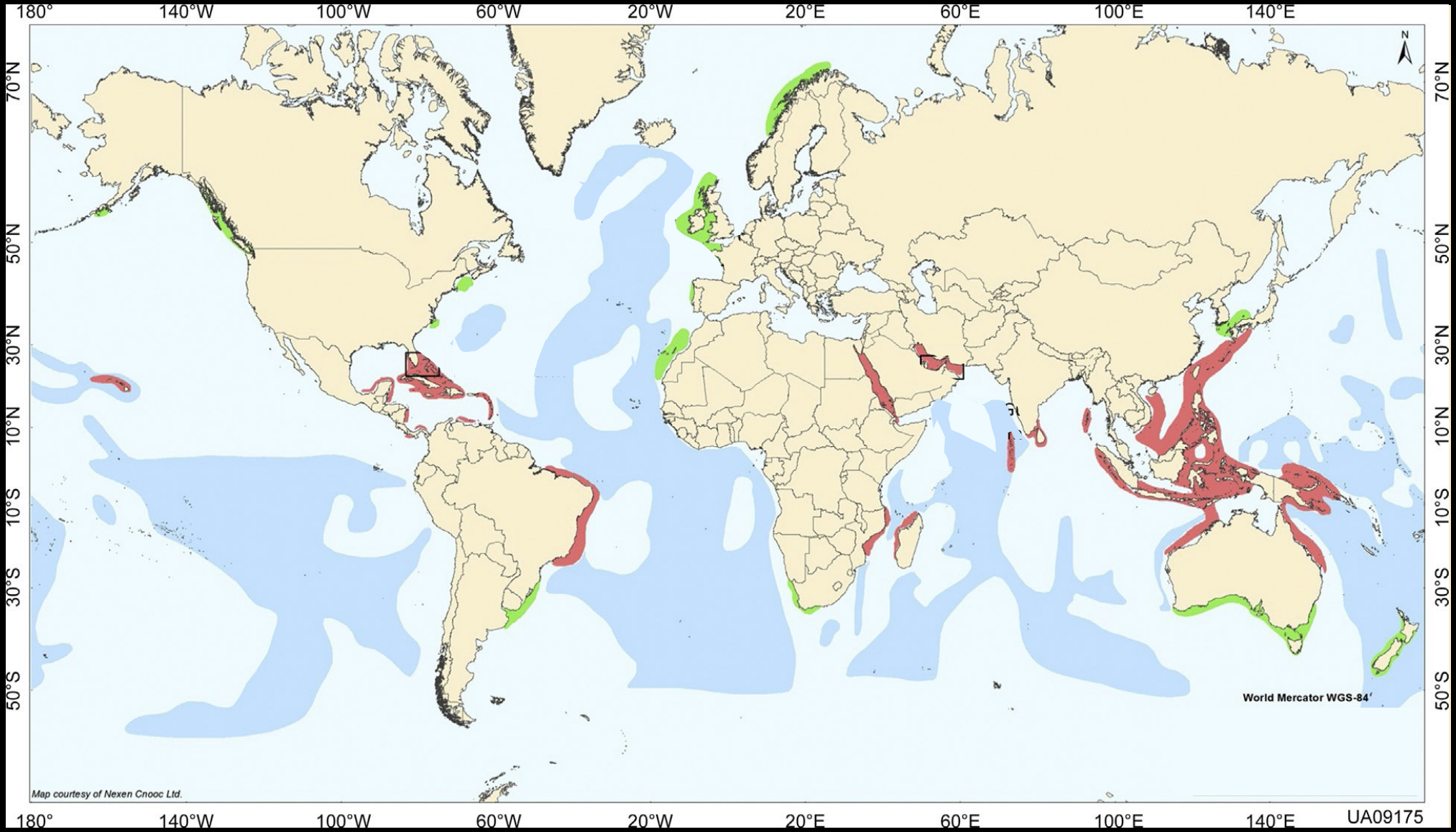


Main areas of carbonate precipitation in modern oceans:

- **DEEP WATER**
- **SHALLOW WATER** (warm water, cool water)

Precipitation today

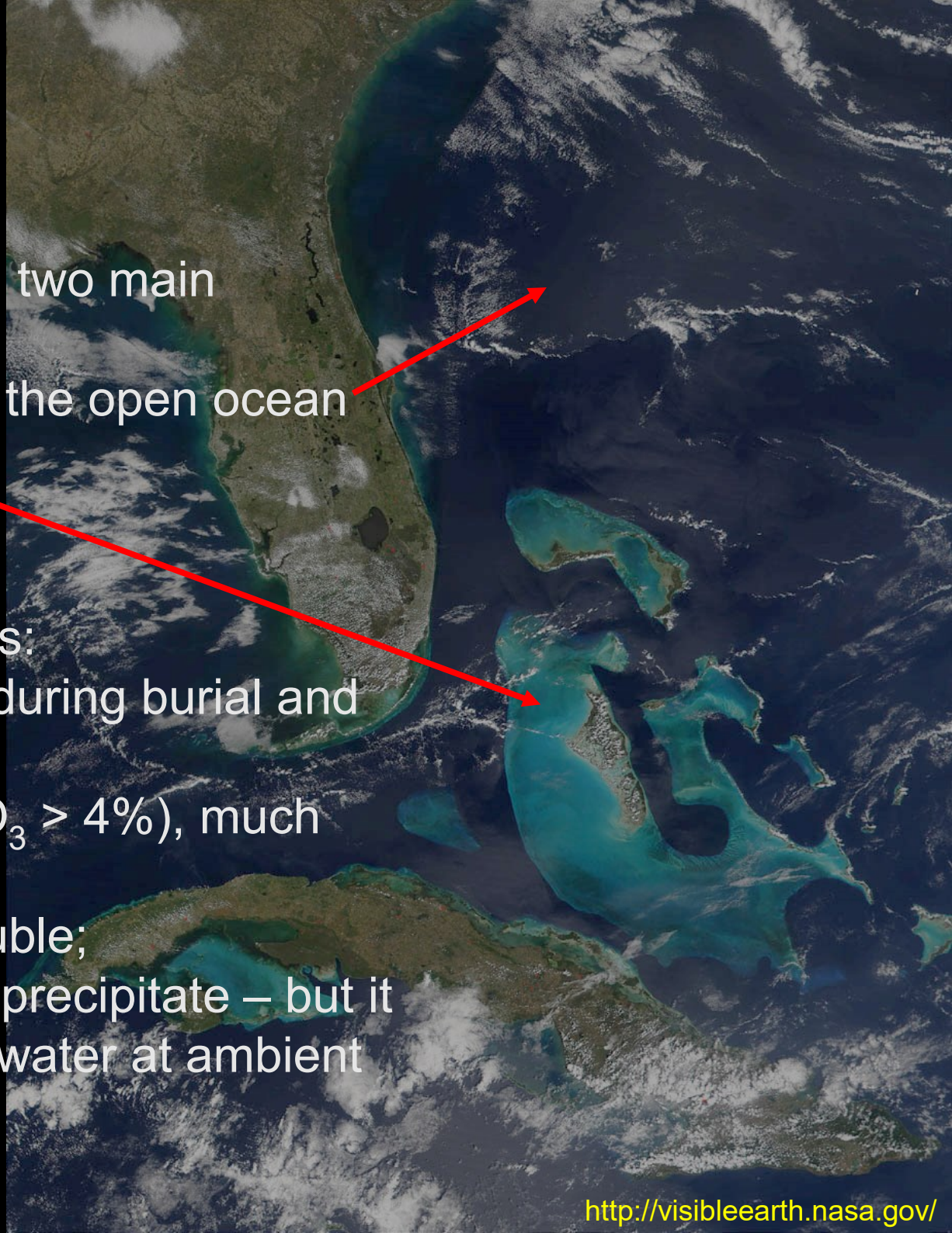
Precipitation occurs today in two main settings, ca. 50 / 50%:

- in superficial waters of the open ocean
- in shallow waters

Three common minerals.
calcite occurs in two species:

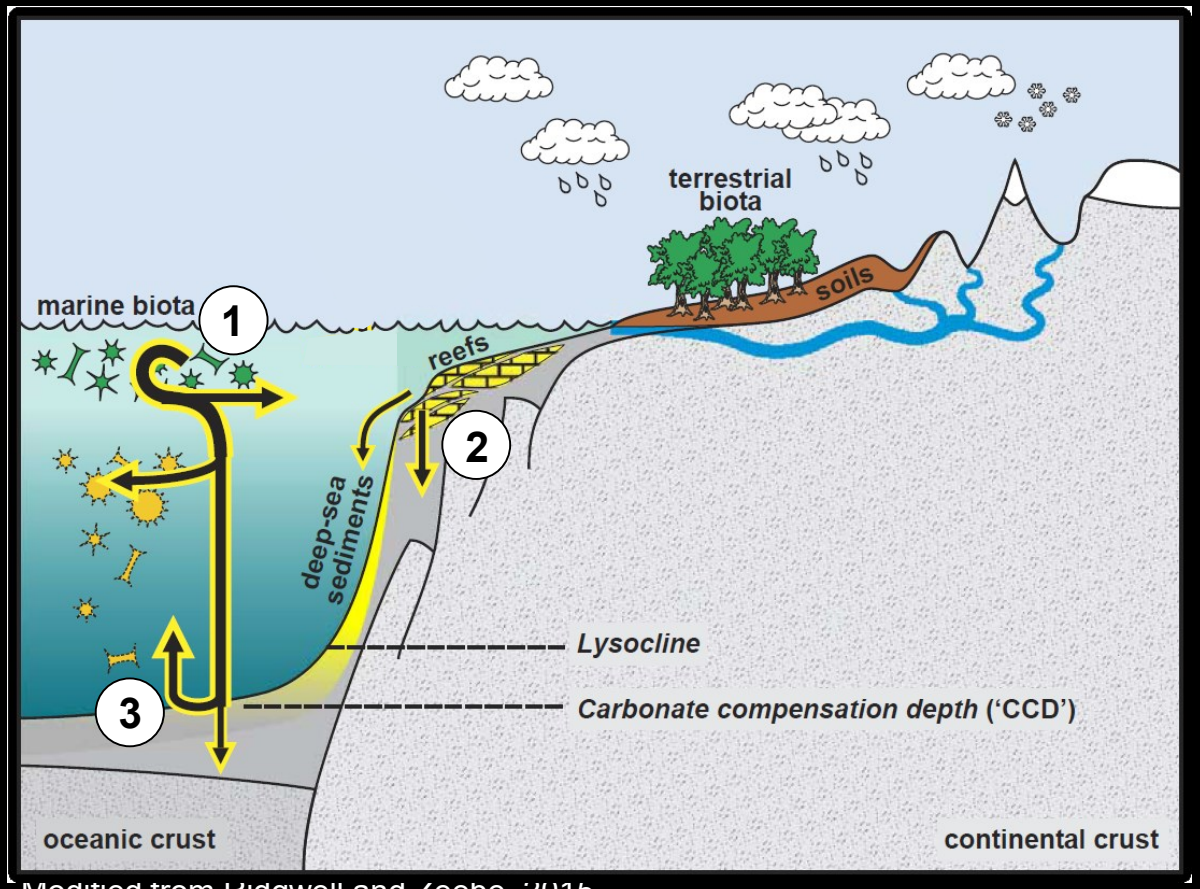
- low-Mg calcite, stable during burial and resistant to dissolution
- high-Mg calcite ($MgCO_3$ > 4%), much more soluble (metastable);

aragonite also is highly soluble;
dolomite is rare as primary precipitate – but it would be most stable in seawater at ambient conditions.



http://visibleearth.nasa.gov/

Precipitation of carbonate in seawater (today)



Modified from Ridgwell and Zeebe, 2015

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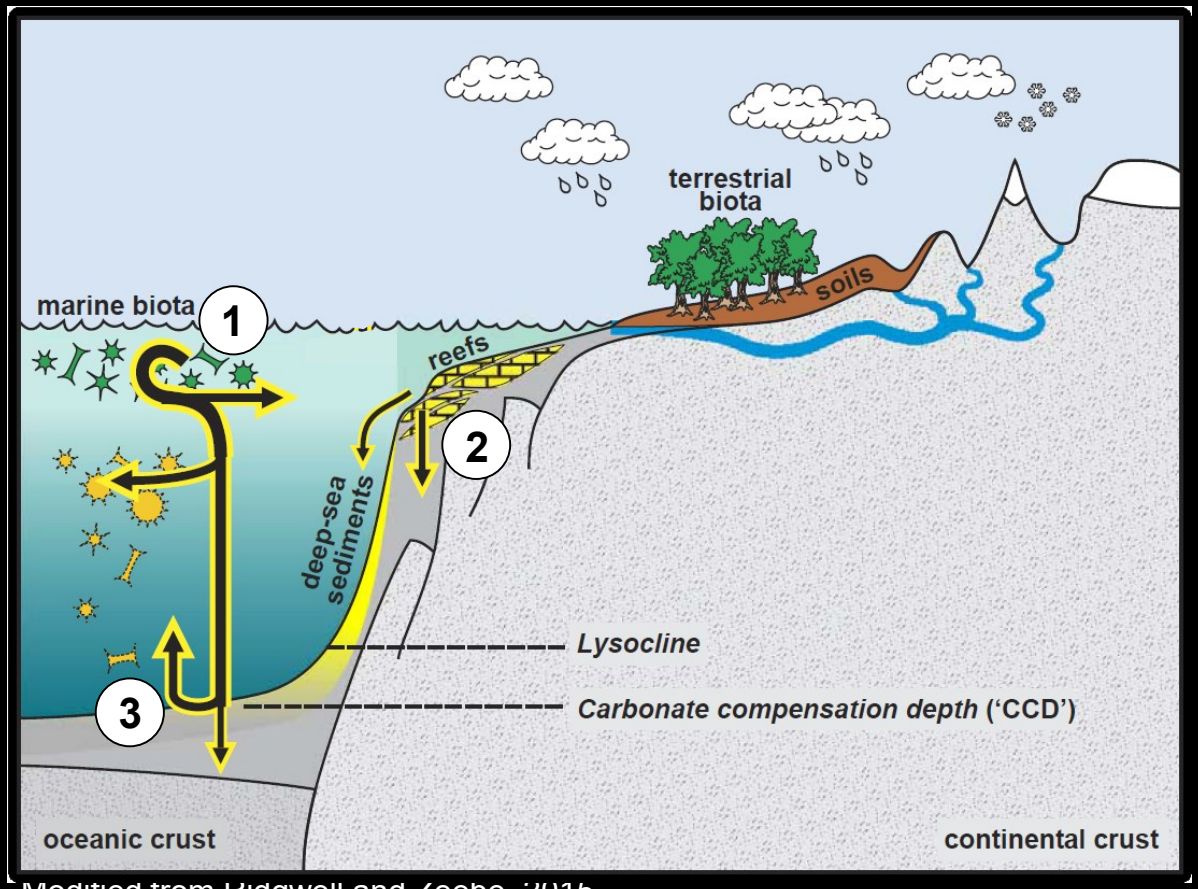
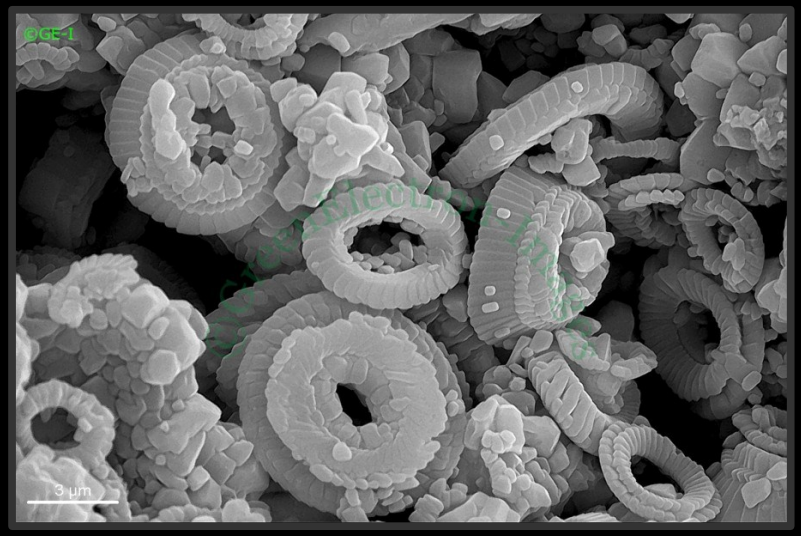


Modified from Ridgwell and Zeebe, 2015

① Precipitation by **coccolitophores** and **foraminifera***

* also pteropods pracipitate carbonate but their contribution is minor with respect to cocoolithofores and forams



coccolithophores

foraminifera

Precipitation of carbonate in seawater (today)

COCCOLITHOPHORES

Unicellular, eucaryotic algae. They are charcaterized by calcium carbonate plates called **coccoliths**.

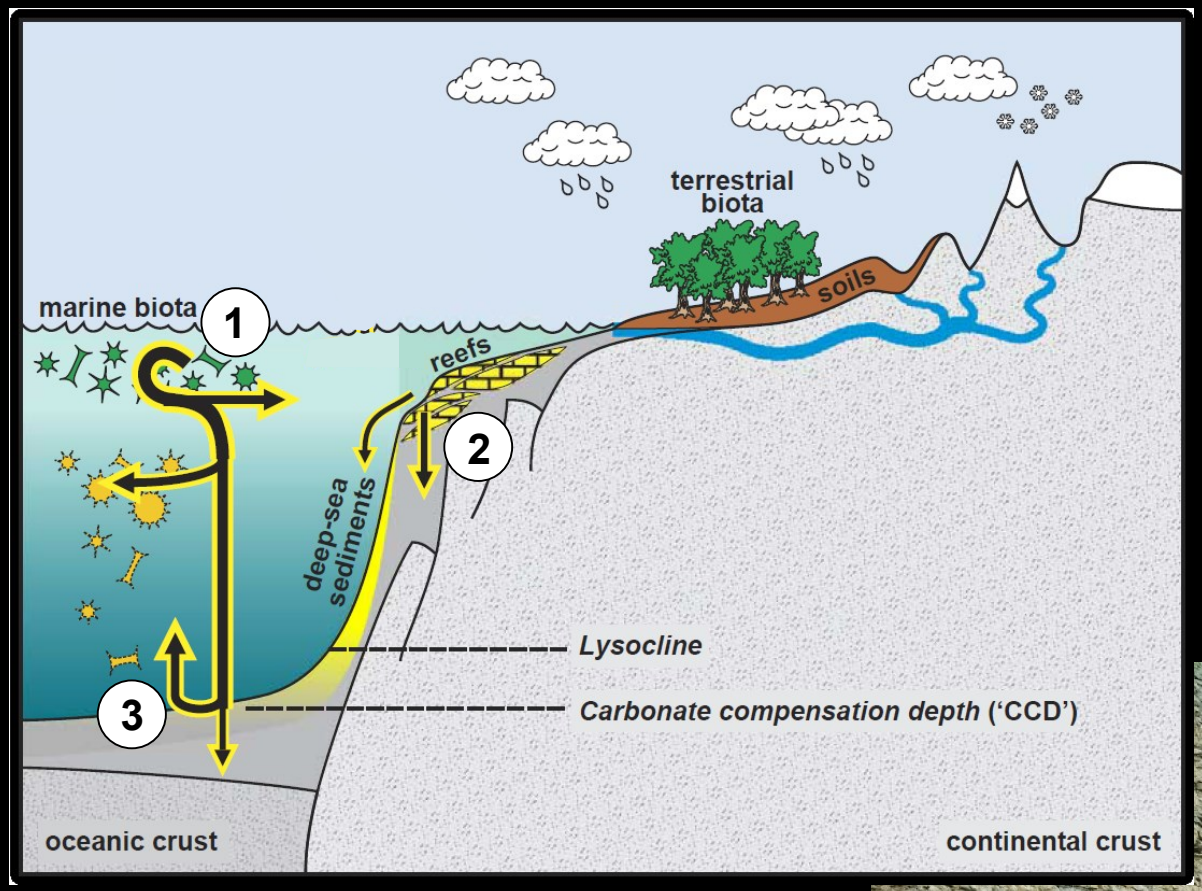
FORAMINIFERA

Unicellular animals (ameboid protists). They have an **external shell** that can be made of different materials, but mostly calcium carbonate.

*pteropods are gastropods

http://www.ucl.ac.uk/GeolSci/micropal/

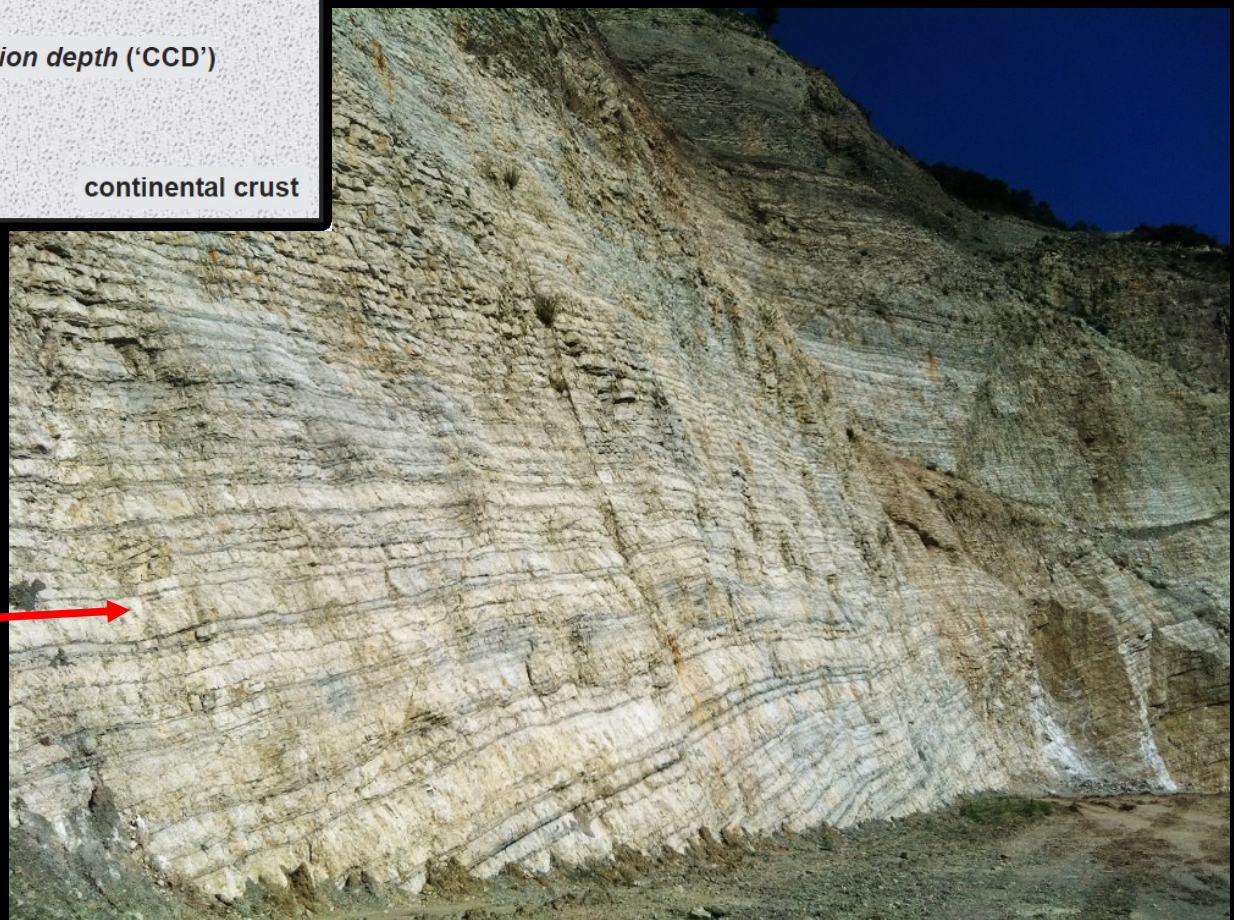
Precipitation of carbonate in seawater (today)



① Precipitation by coccolitophores and planktonic foraminifera

Carbonate production by coccolithophores and foraminifera can be lithogenic.

Pelagic carbonate deposits made mainly of tiny fossils called nannoliths (= coccolith) (Maiolica, Cretaceous, Central Italy)



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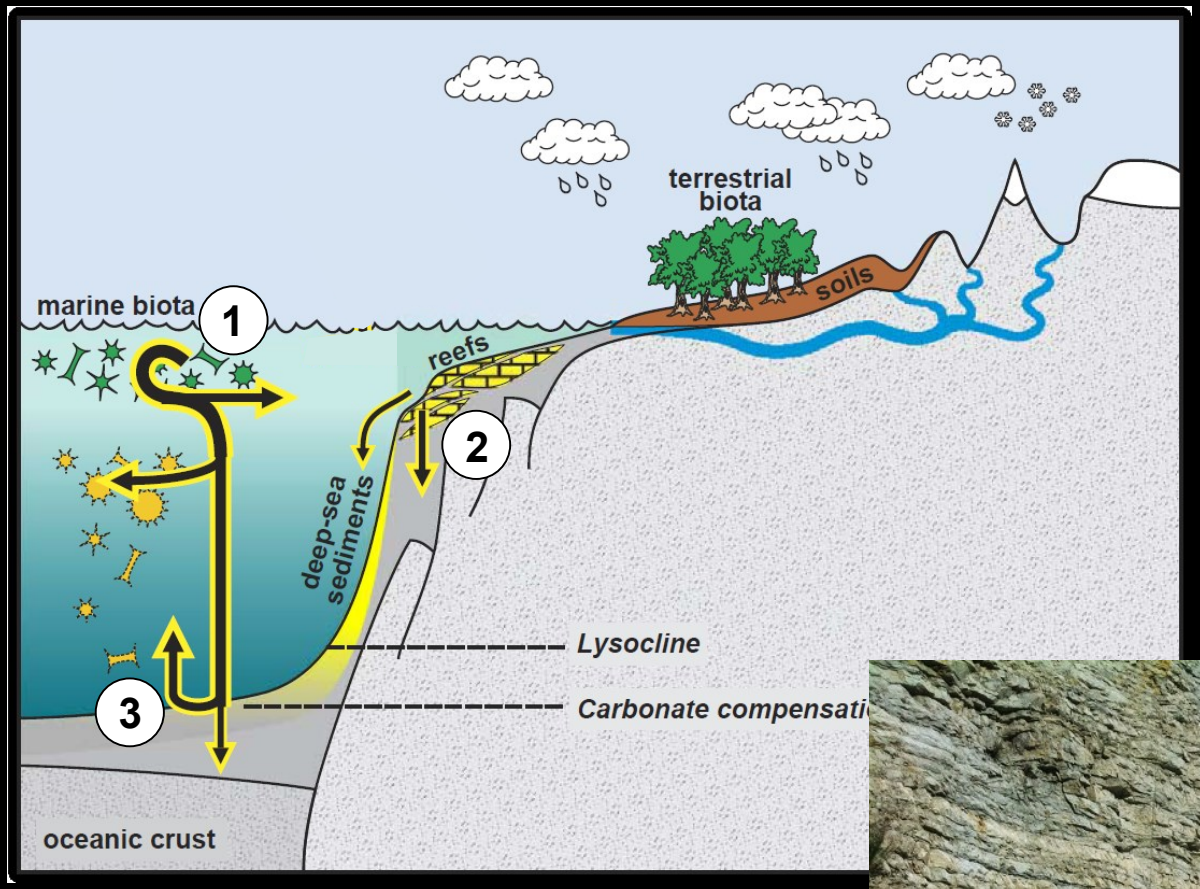

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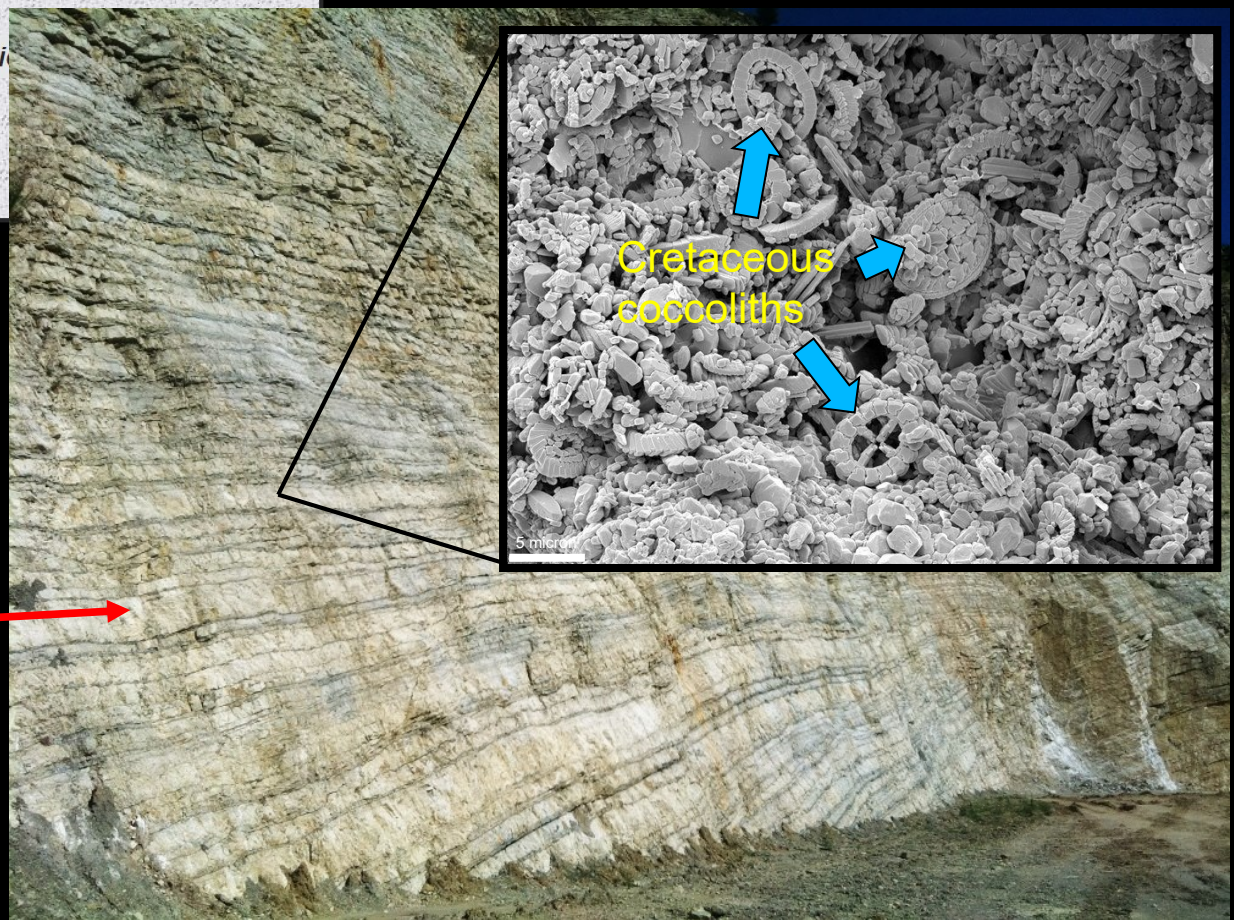
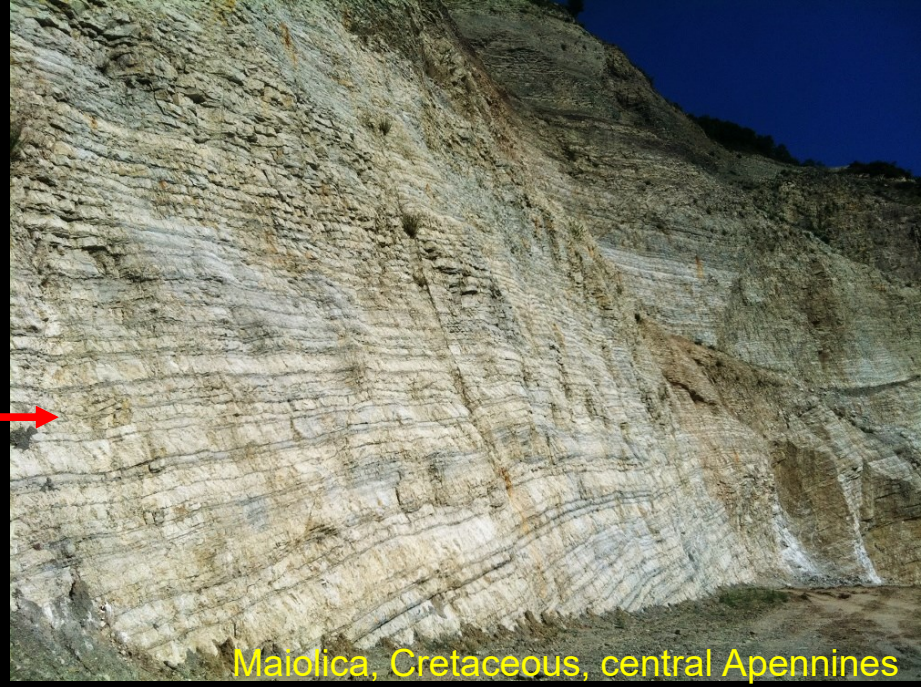


Two types of deep-water sediments

- **Pelagic**: sediment deposited without influence (supply) from shallow water and continental sources

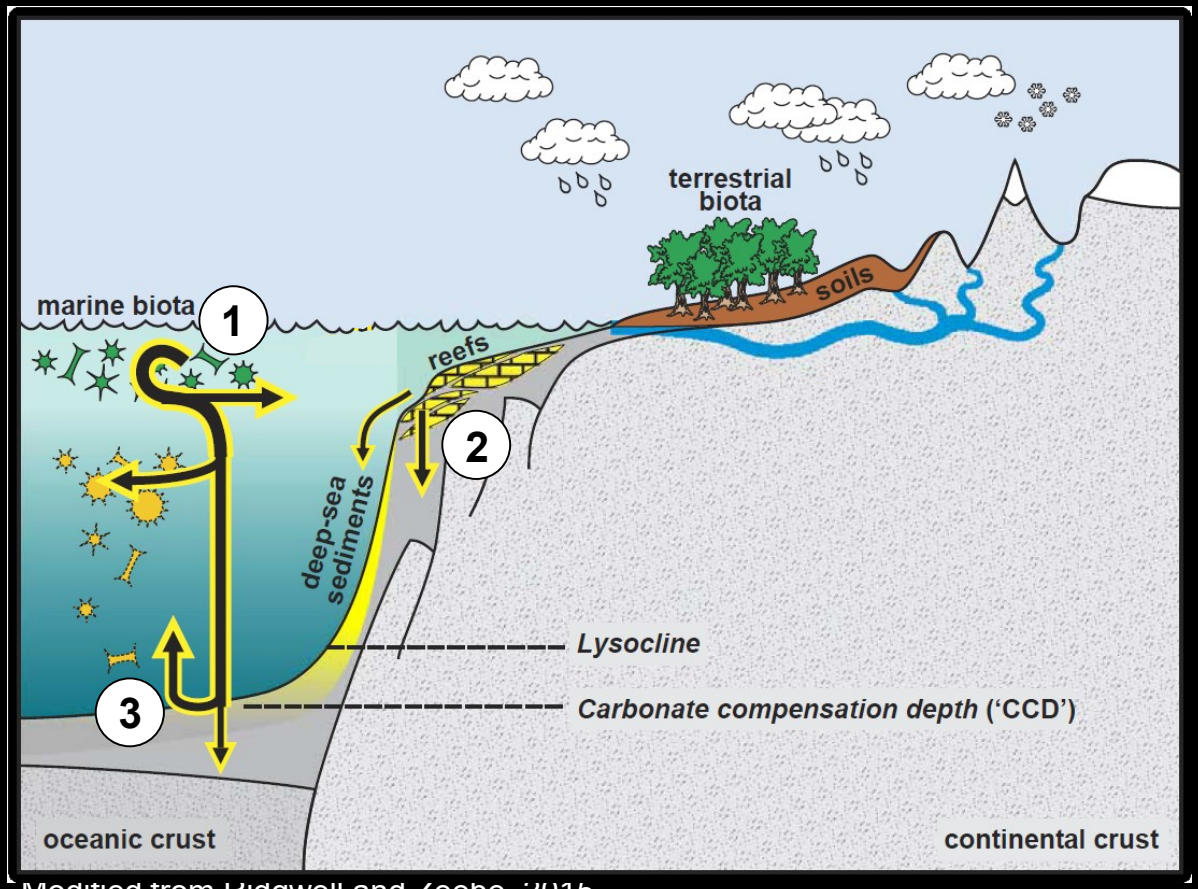
- **Hemipelagic**: mostly pelagic sediment, that includes, however, a component supplied from adjacent emerged lands or neritic platforms.



Maiolica, Cretaceous, central Apennines

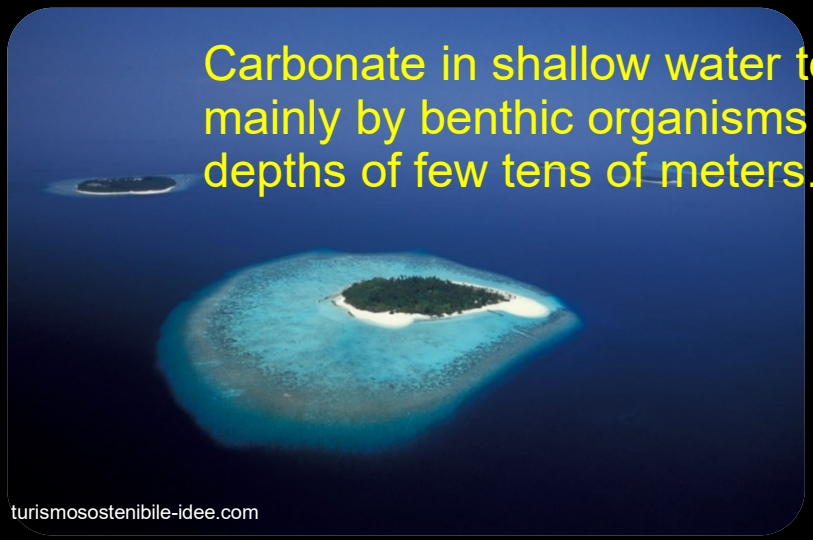
Scisti a Fucoidi, Cretaceous, central Apennines

Precipitation of carbonate in seawater (today)

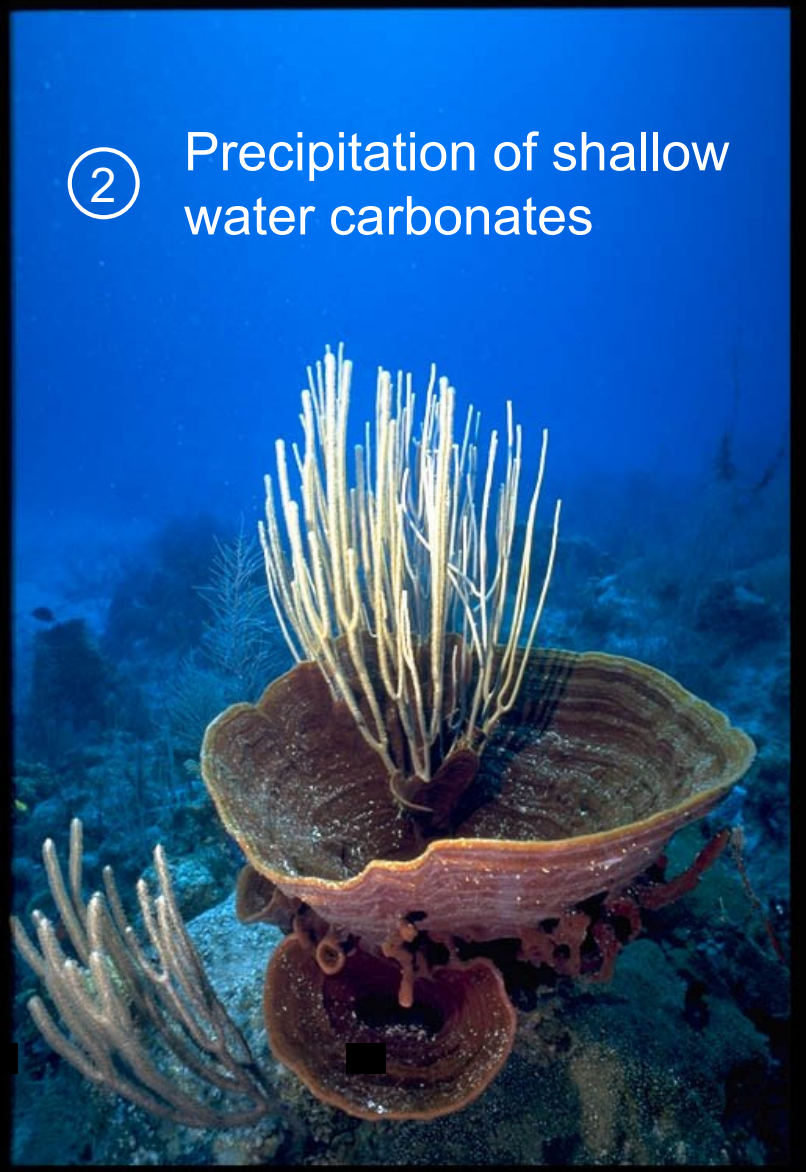


Modified from Ridgwell and Zeebe, 2015

Carbonate in shallow water today is precipitated mainly by benthic organisms that thrive up to depths of few tens of meters.



turismosostenibile-idee.com

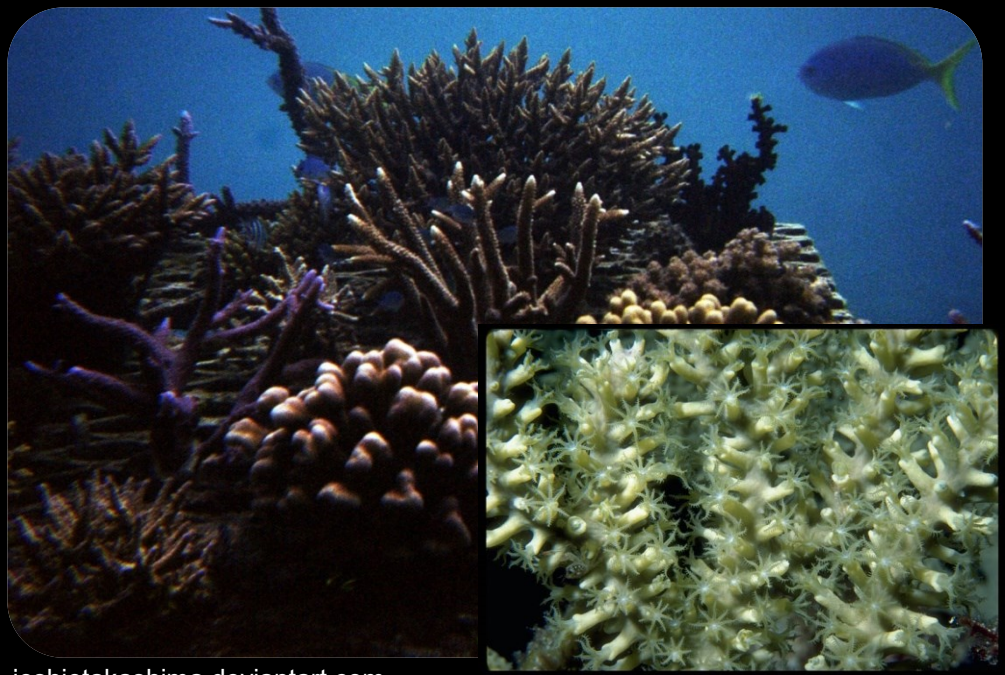


Shallow water precipitation by authotrophs

Corals: heterotrophic, but symbiontic with photosynthesizing zooxanthellae (autotrophs).

Dasycladacean algae: are authotroph organisms

Main shallow water carbonate producers in tropical envirnonments



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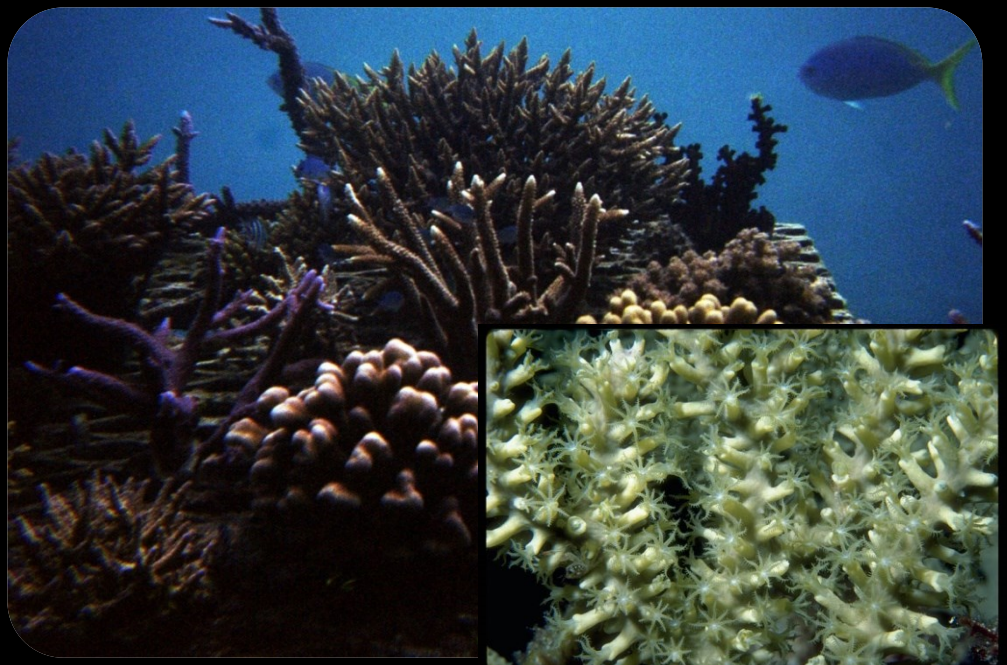

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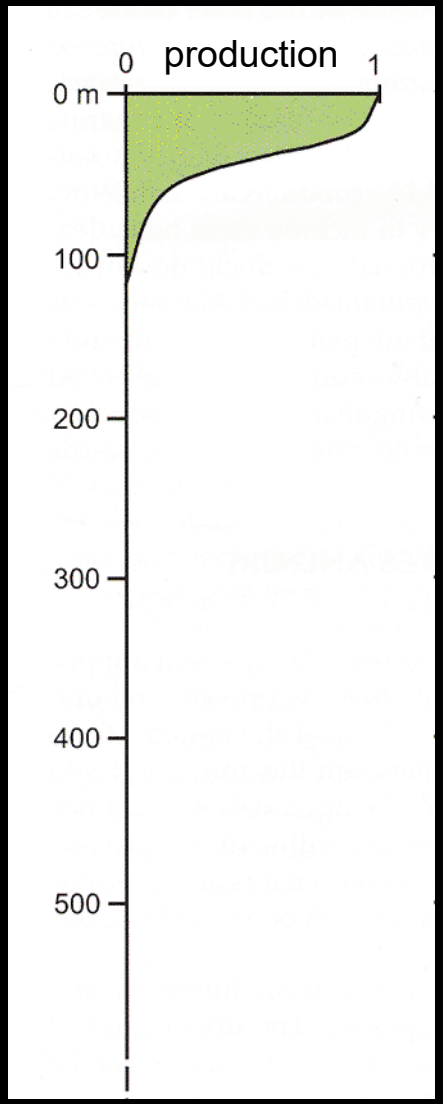
Corals

Production/depth profile in a modern tropical carbonate platform



Shallow water precipitation today - authotrophs

…they can be found in the fossil record too

Corals (Triassic)

Dasycladacean algae (Triassic)

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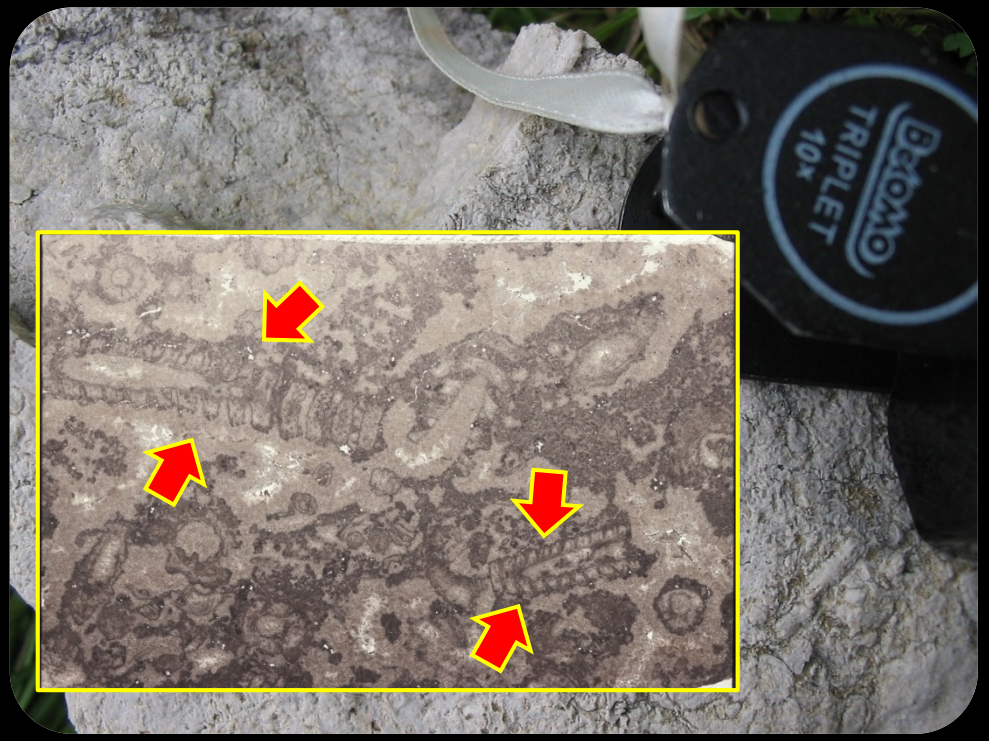
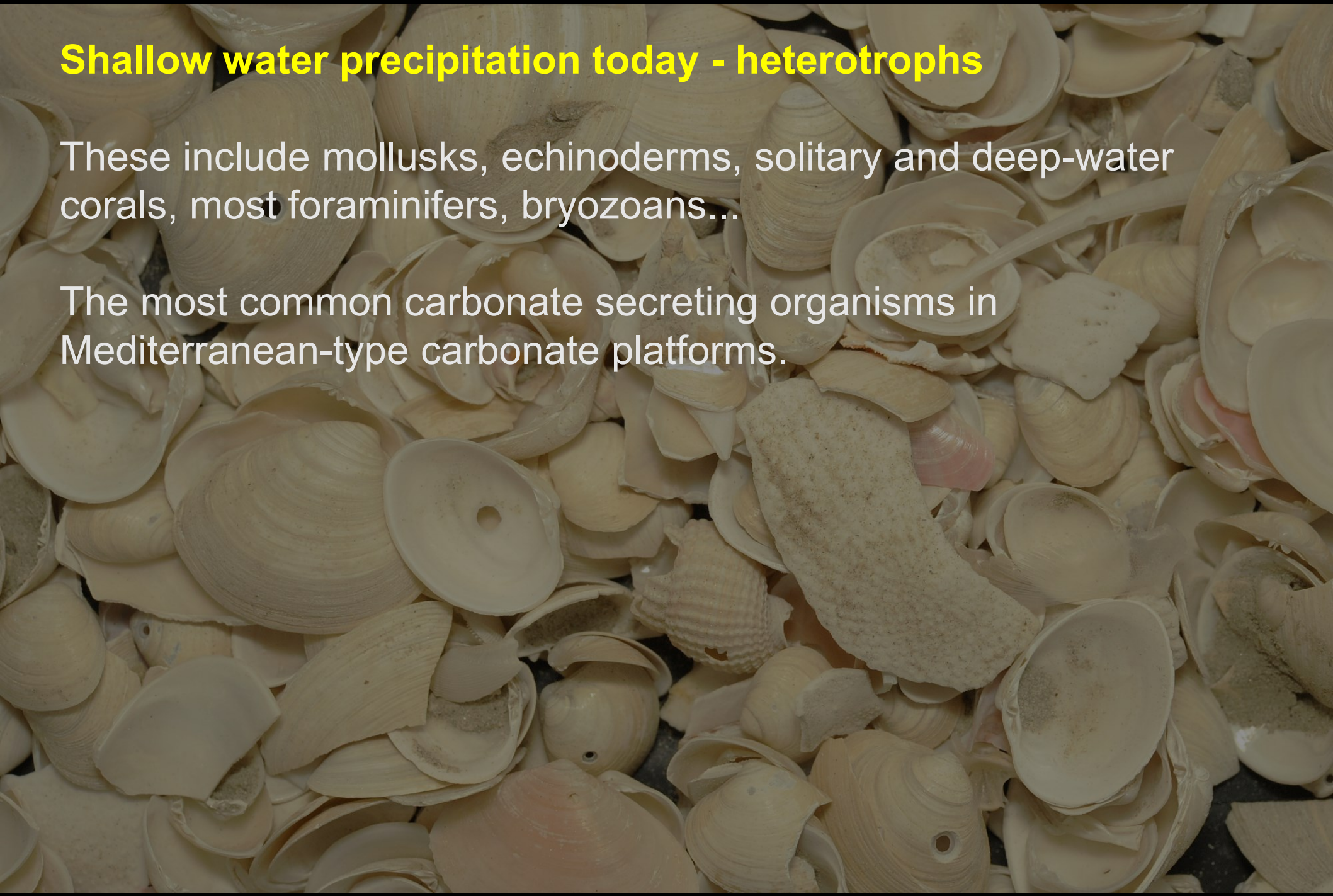


Dasycladacean algae (Triassic)



Shallow water precipitation today - heterotrophs

These include mollusks, echinoderms, solitary and deep-water corals, most foraminifers, bryozoans...

The most common carbonate secreting organisms in Mediterranean-type carbonate platforms.

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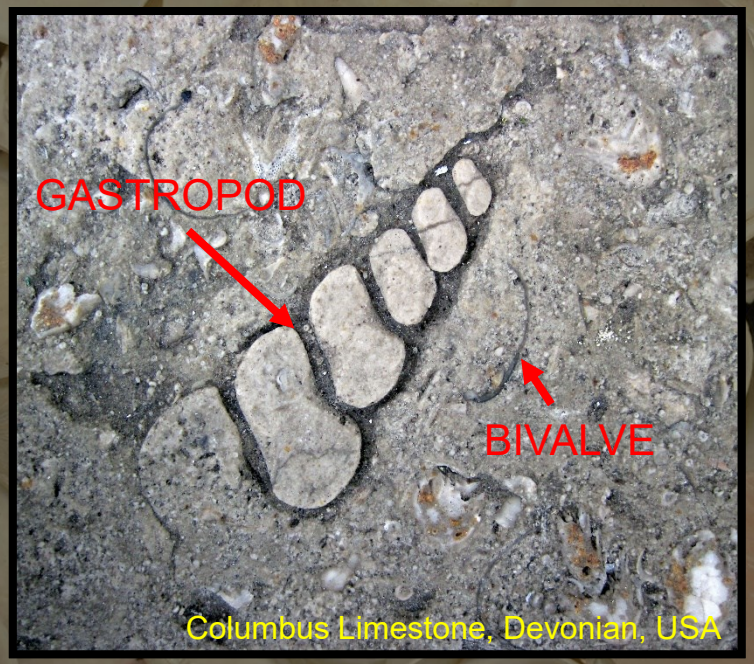
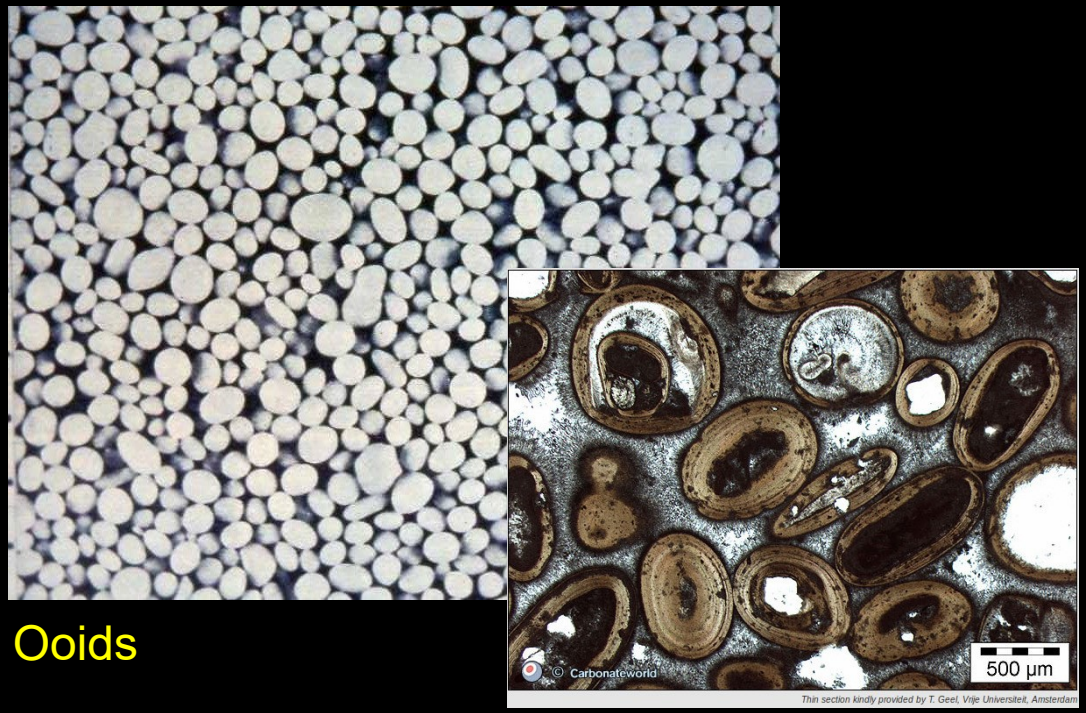


Shallow water precipitation today – ooids

Another notable evidence of carbonate precipitation in shallow waters today is the formation of ooids (and other coated grains).



Ooids

Oolitic limestone (oolite)

In oceans ooids form in high-energy environmnets where che constant movement is resposnible for the acquisition of a more or less rounded shape. Ooids can have different ultrastructures (you will see them later)

Some definitions

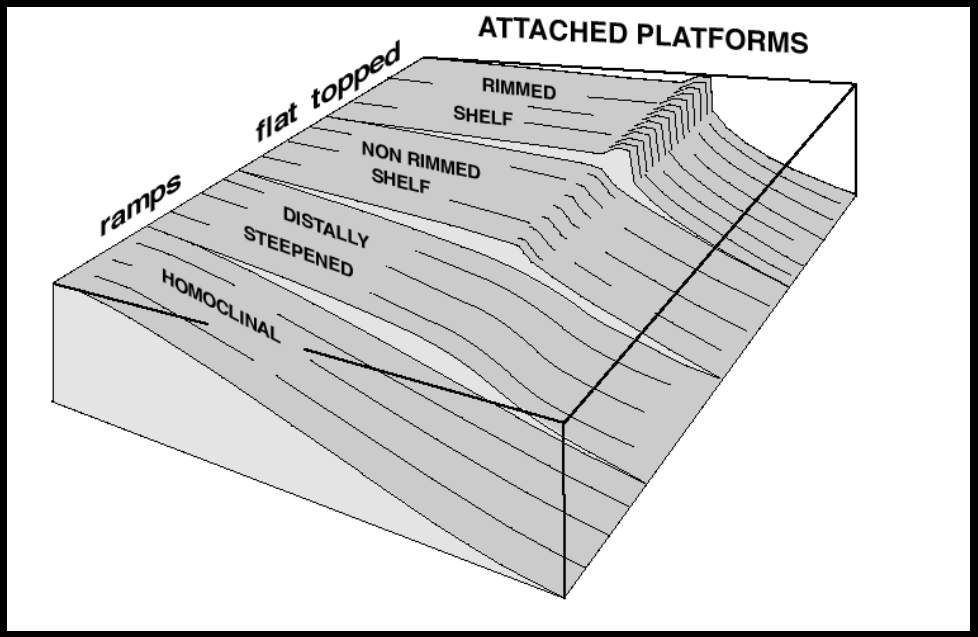
Carbonate platform:

- a geological structure made of **parautochtonous carbonate sediments** and/or carbonate rocks, having morphological relief.

Reef:

- a carbonate deposit made of **in situ sessile organisms** *(Riding, 2002)*

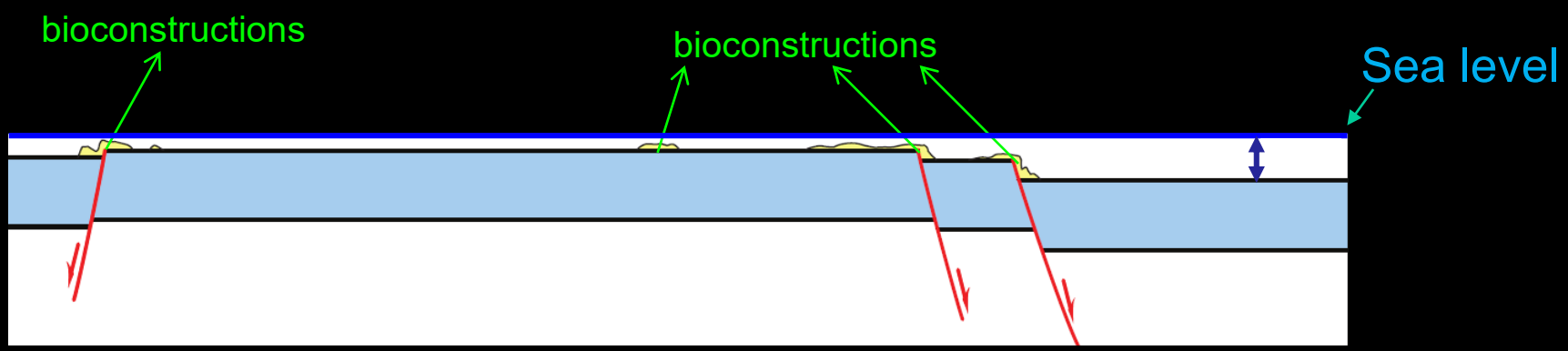
- a biogenic structure limited in space, produced by sessile organisms, that is **rigid and with morphological relief** (*Kiessling, 2002)*



Pomar, 2001

Some modern examples of carbonate platform

Formation of a carbonate platform (simplified model)



CARBONATE PRECIPITATION STARTS ON A SUBSTRATE

from Preto et al., 2011, modified

accumulation of carbonate sediment requires the creation of accomodation below sealevel.

Formation of a carbonate platform (simplified model)

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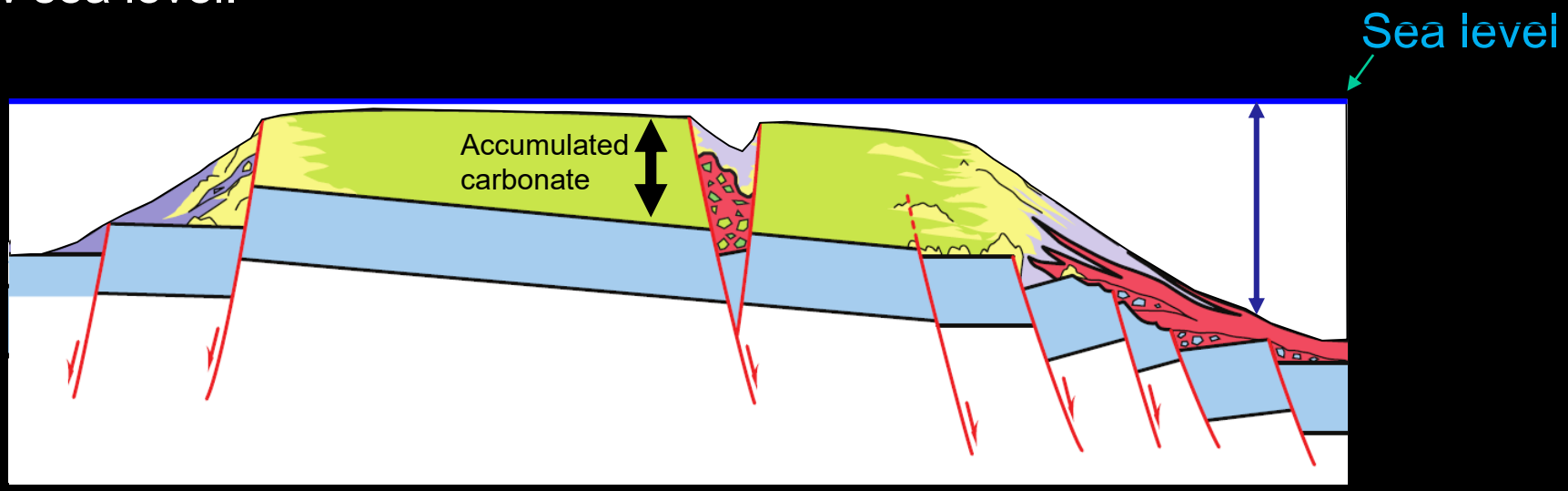

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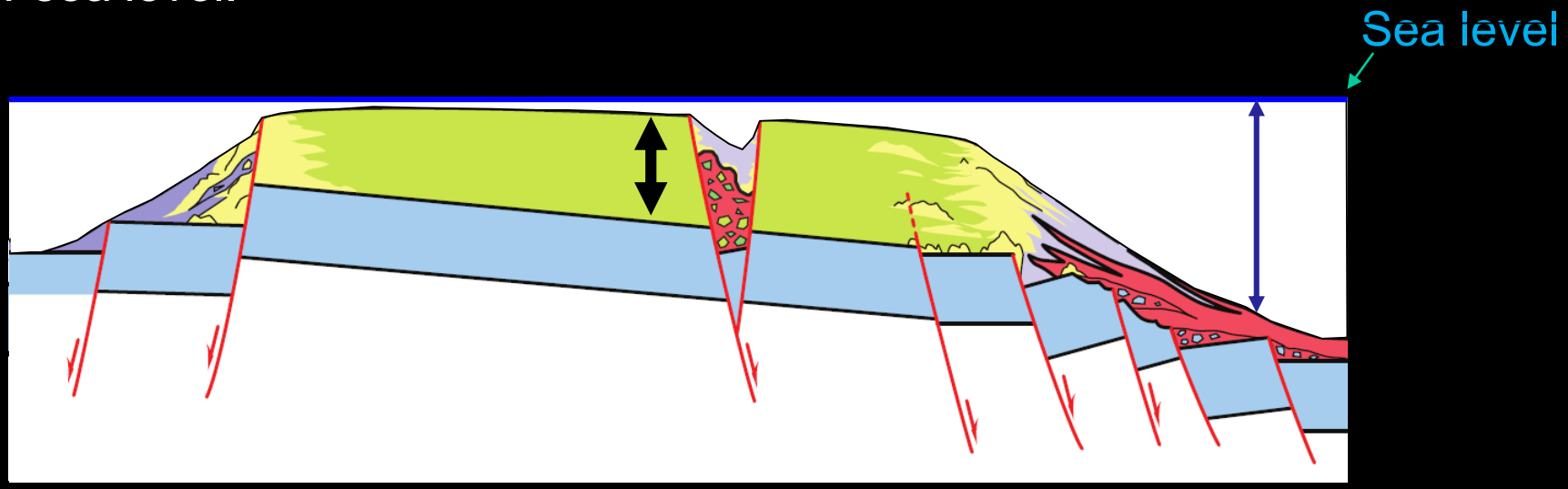

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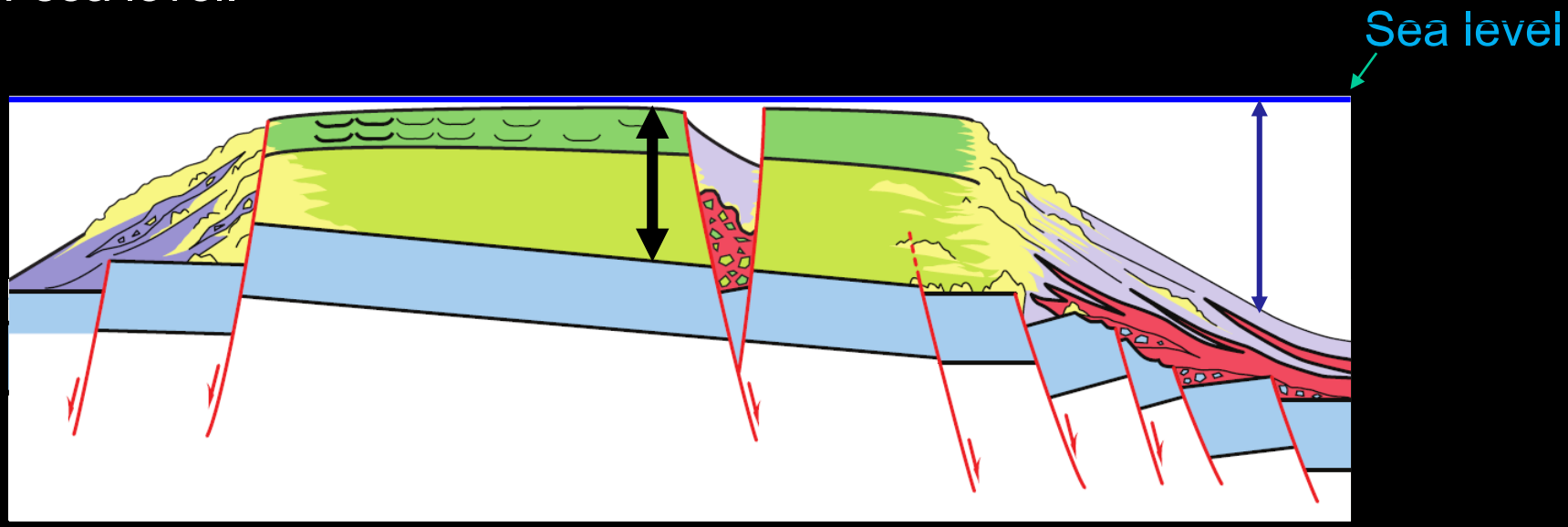

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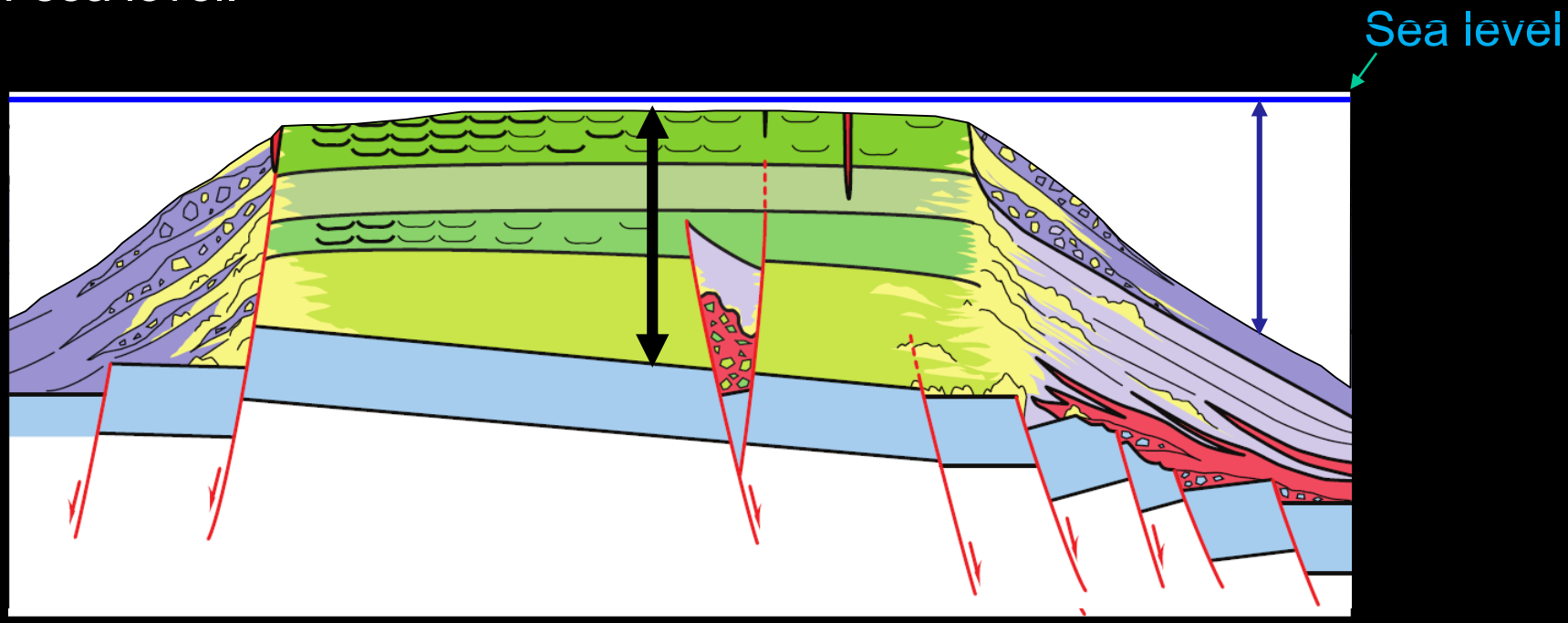

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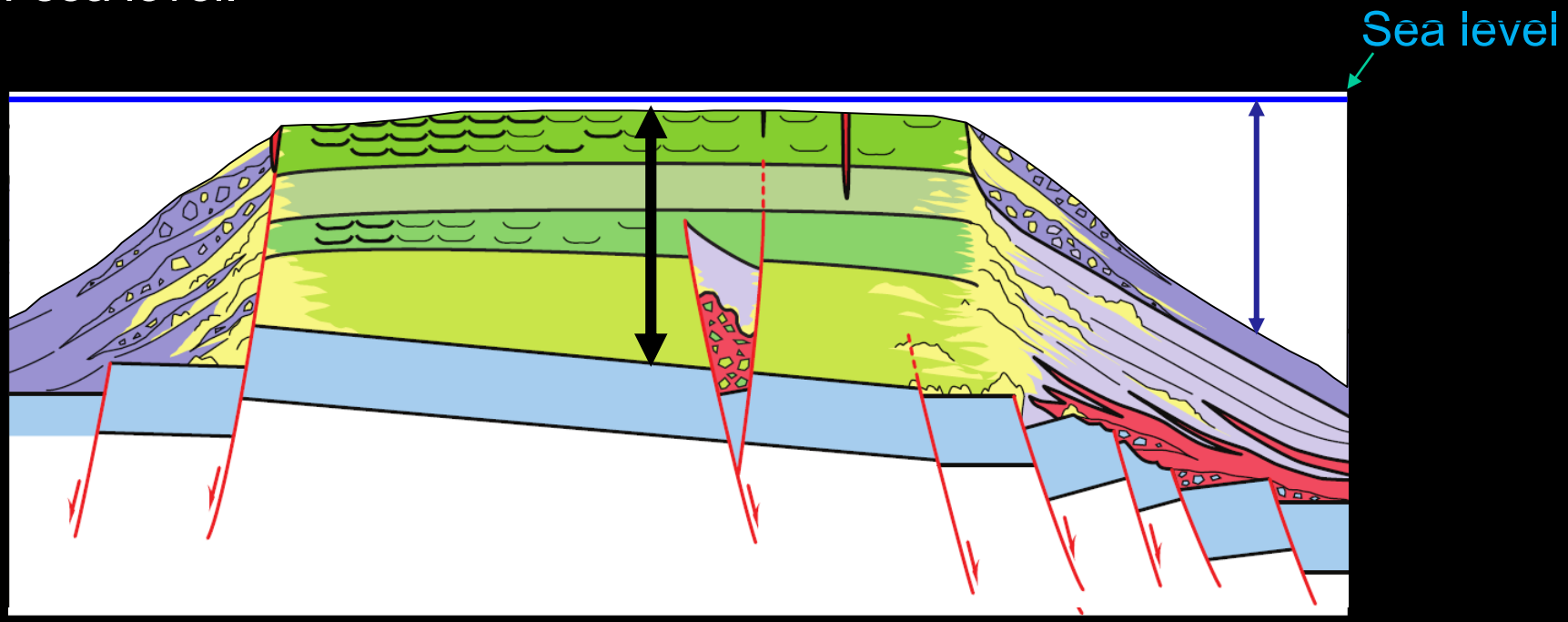
Formation of a carbonate platform (simplified model)

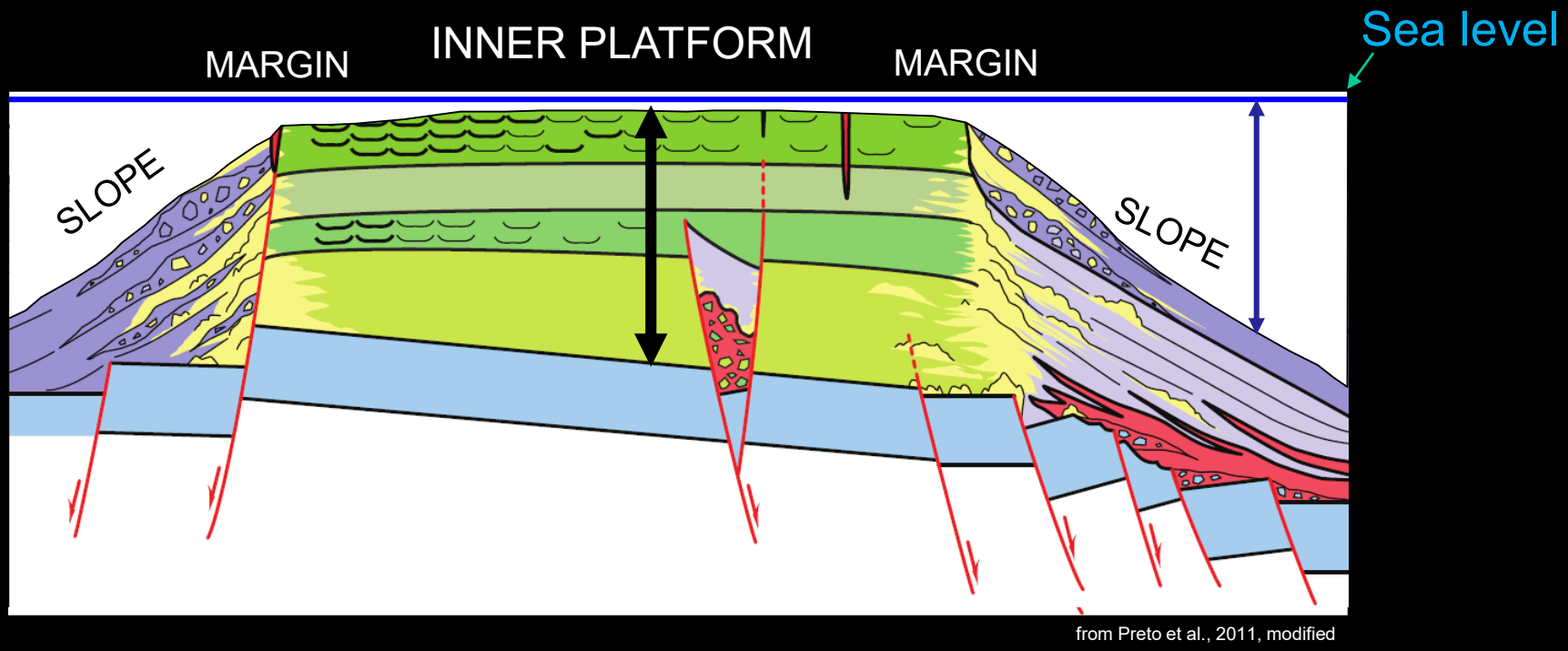
accumulation of carbonate sediment requires the creation of accomodation below sea level.



from Preto et al., 2011, modified

Accomodation is created by the **interplay** of subsidence and sealevel change

Formation of a carbonate platform (simplified model)

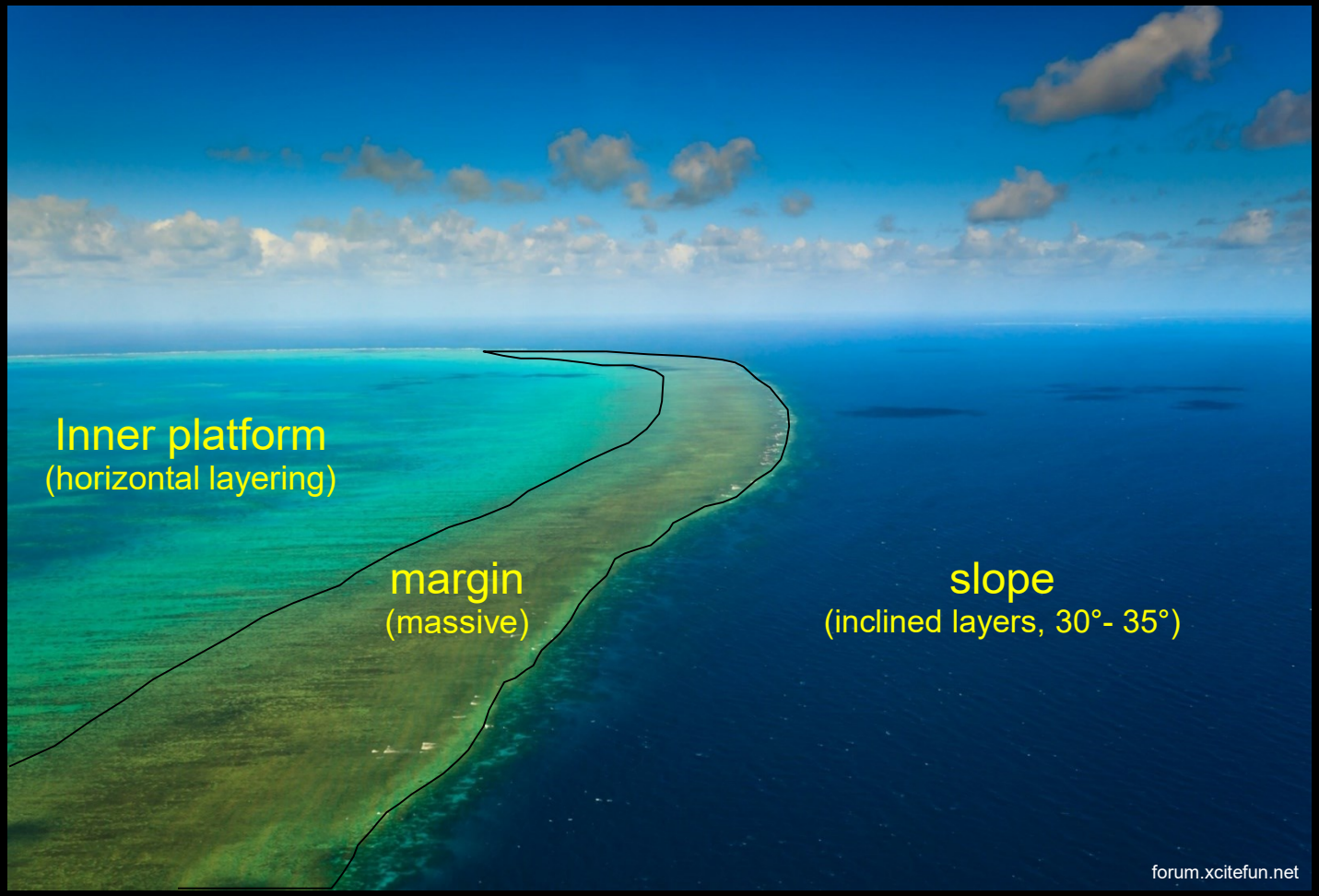


from Preto et al., 2011, modified

Accomodation is created by the **interplay** of subsidence and sealevel change

Note that in this cartoon the lagoon area stays always approximately at the same depth. In order to do so, the carbonate production must match the rate of the creation of accomodation. If this does not happen the platform is going to sink and ultimately drown.

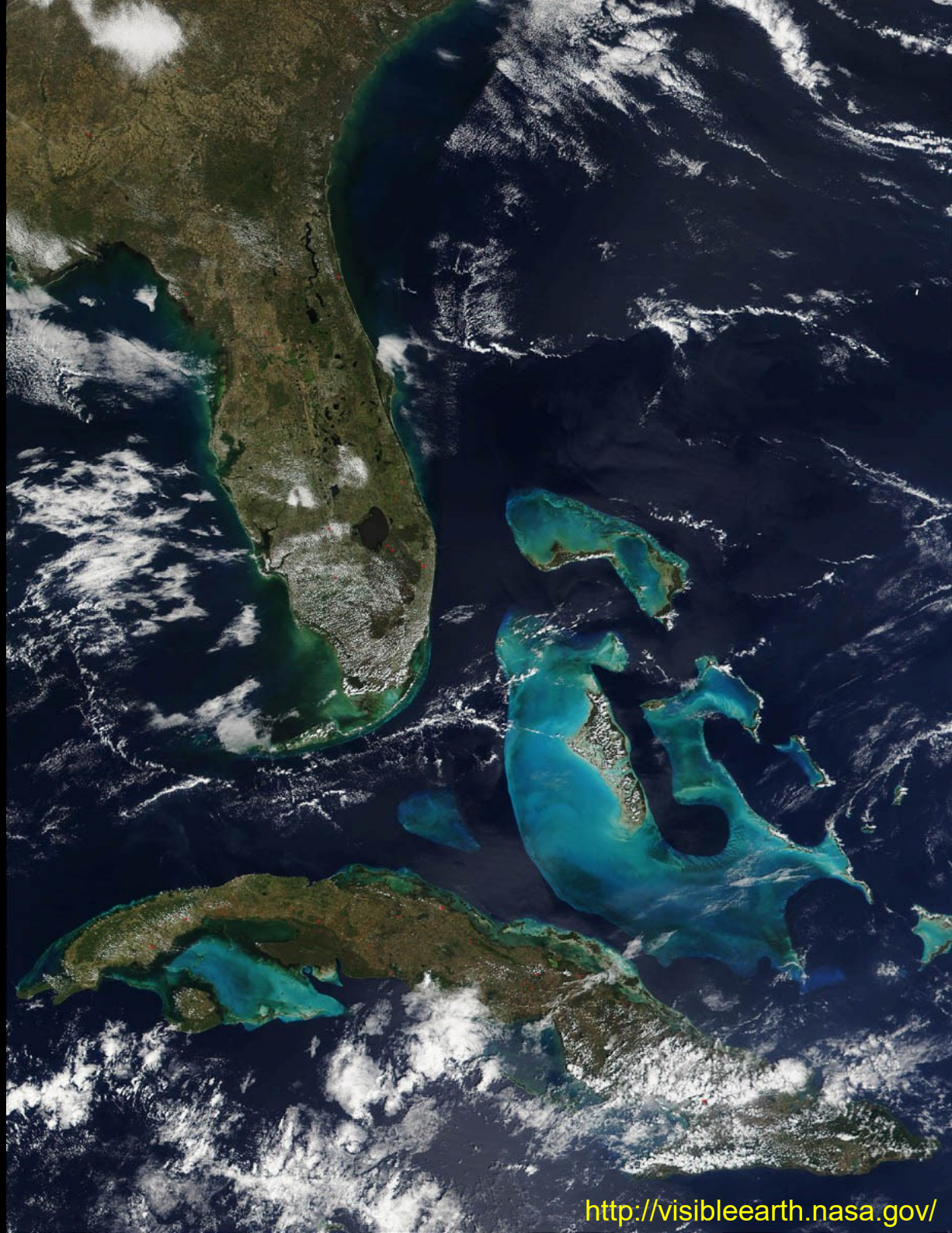

forum.xcitefun.net


Inner platform
(horizontal layering)
margin
(massive)
slope
(inclined layers, 30°- 35°)
forum.xcitefun.net

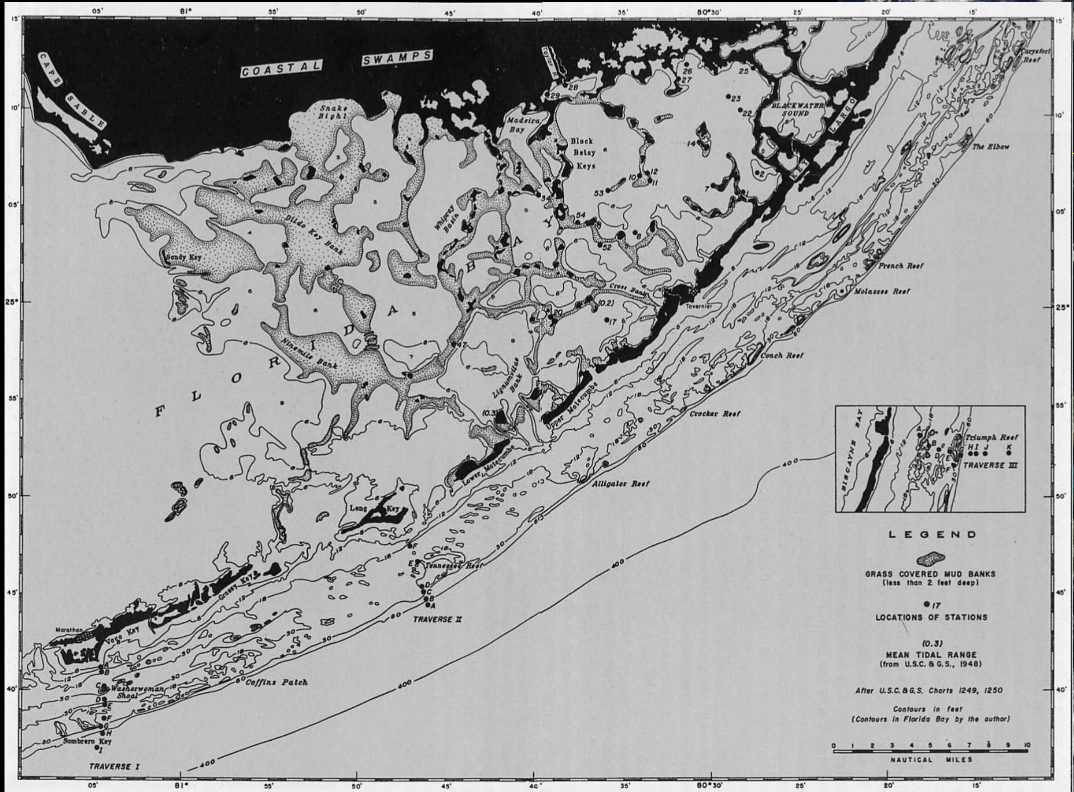
THE carbonate platform

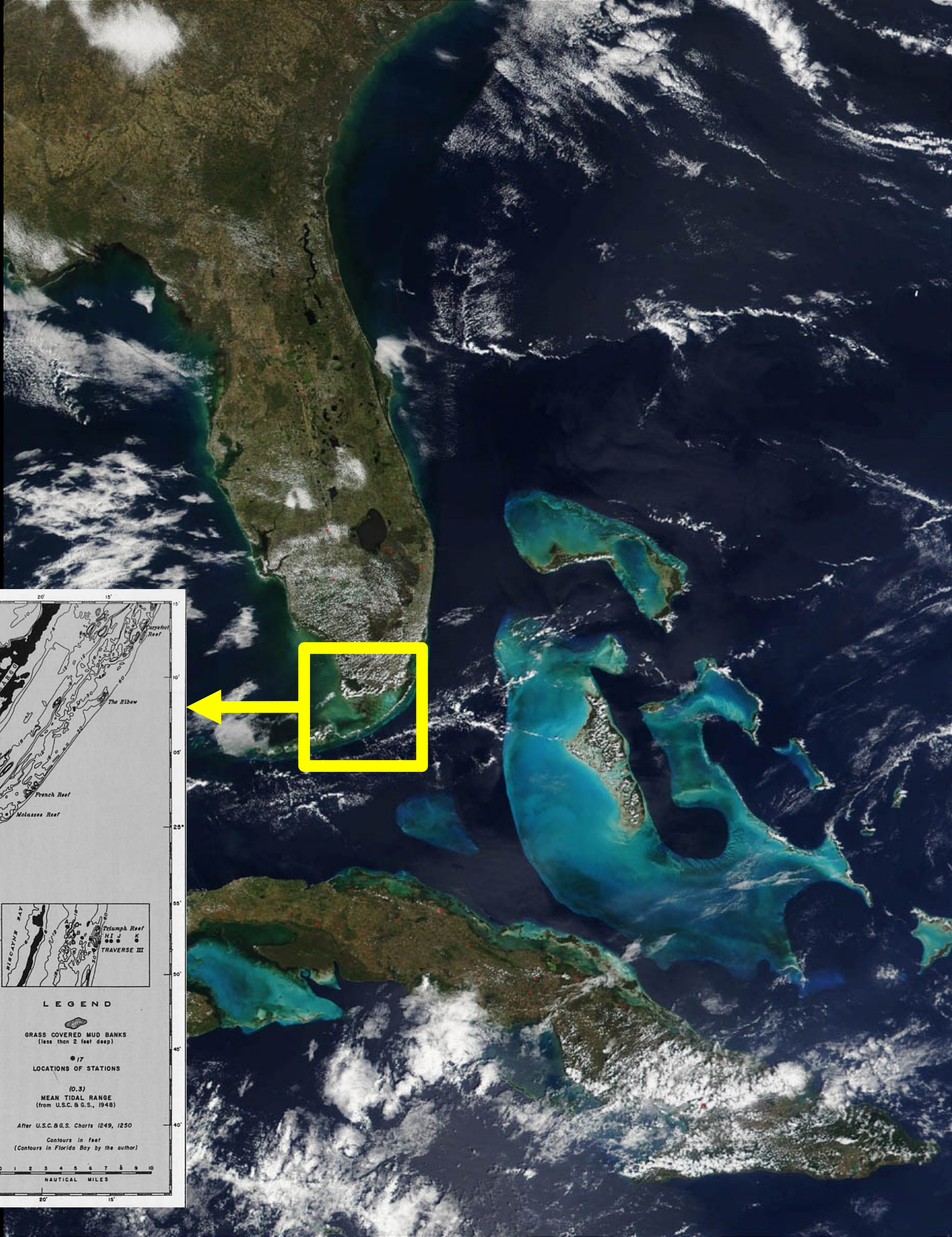
Most concepts about carbonate platform sedimentation derive from pioneering studies on the Bahamas and Florida Bay. Other classical localities:

- Belize reefs
- Great Barrier Reef
- Maldives
- Tahiti
- Persian Gulf
- Red Sea



Florida Bay


COASTAL SWAMPS
CAPE SABLE
FLORIDA BAY
BLACKWATER SOUND
The Elbow
French Reef
Molasses Reef
Conch Reef
Crocker Reef
Alligator Reef
Tennessee Reef
Coffins Patch
Sombrero Key
Washerwoman Shoal
Marathon
Long Key
TRAVERSE I
TRAVERSE II
Triumph Reef
TRAVERSE III
BISCAYNE BAY
LEGEND
GRASS COVERED MUD BANKS
(less than 2 feet deep)
17
LOCATIONS OF STATIONS
(0.3)
MEAN TIDAL RANGE
(from U.S.C. & G.S., 1948)
After U.S.C.&G.S. Charts 1249, 1250
Contours in feet
(Contours in Florida Bay by the author)
NAUTICAL MILES



Some more definitions

Isolated carbonate platform:

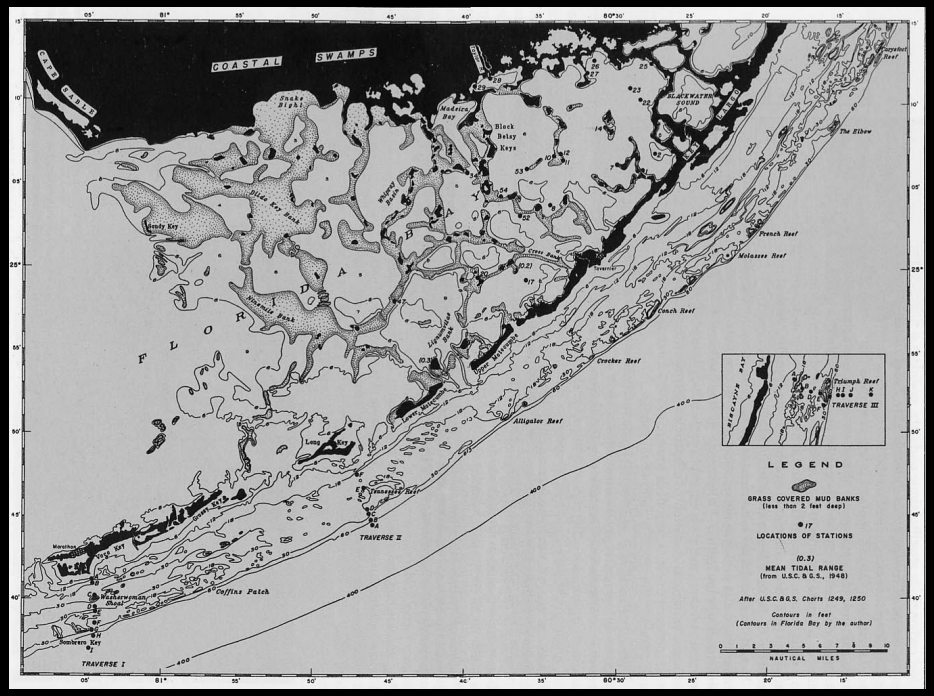
- is not connected to a continent or emerged land.

Examples: Bahamas, Maldives

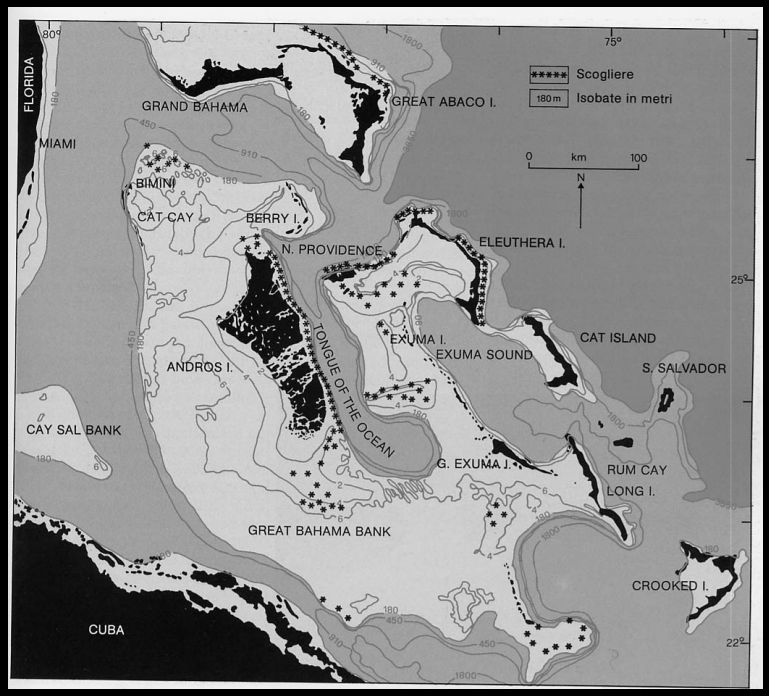
Epicontinental (or **attached**) carbonate platform:

- is connected to a continent or emerged land.

Examples: Florida bay, Great Barrier Reef

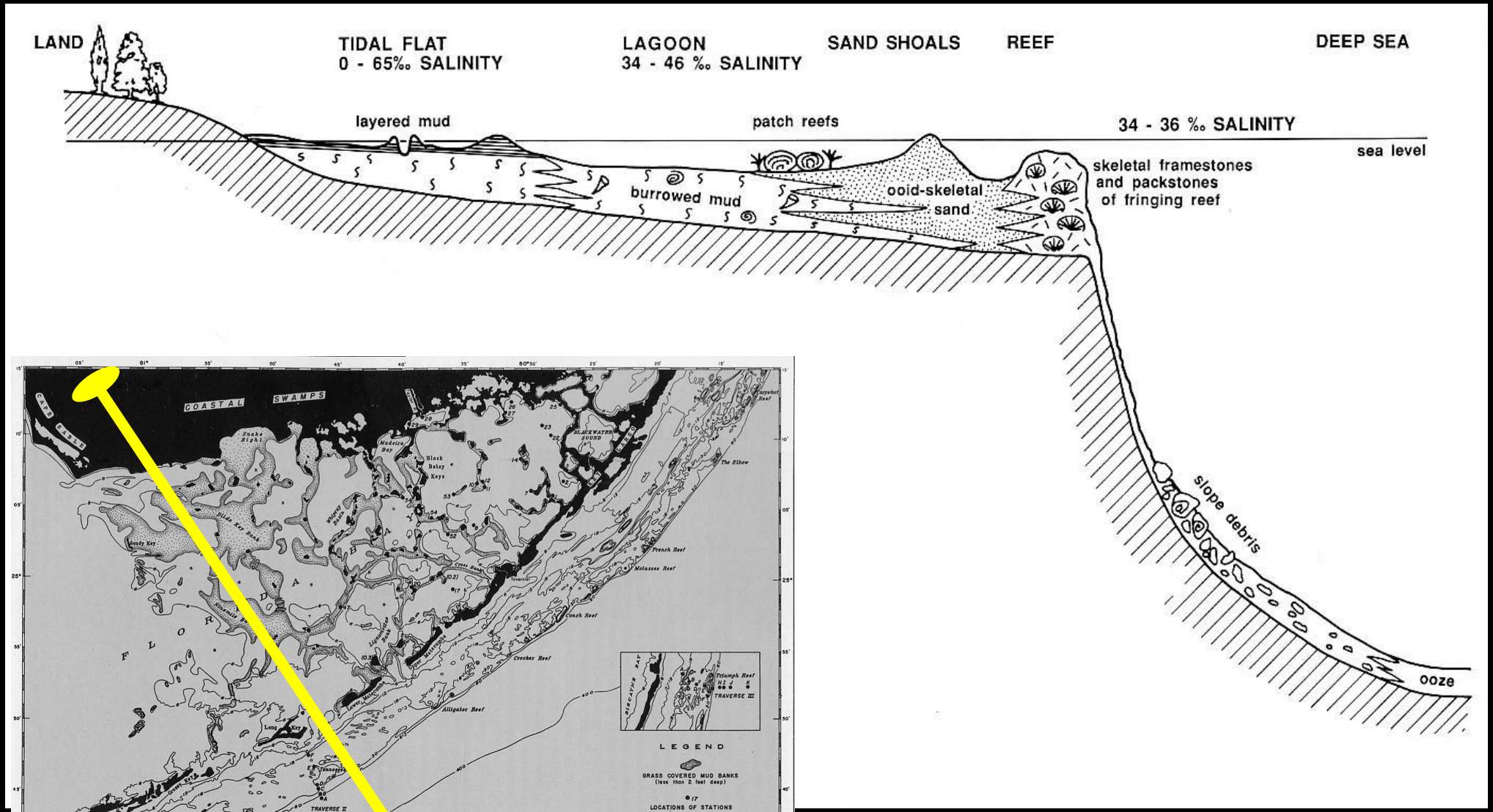


Florida Bay (attached), from Bosellini, 1991



Bahamas (isolated), from Bosellini, 1991

Depositional profile of Florida Bay

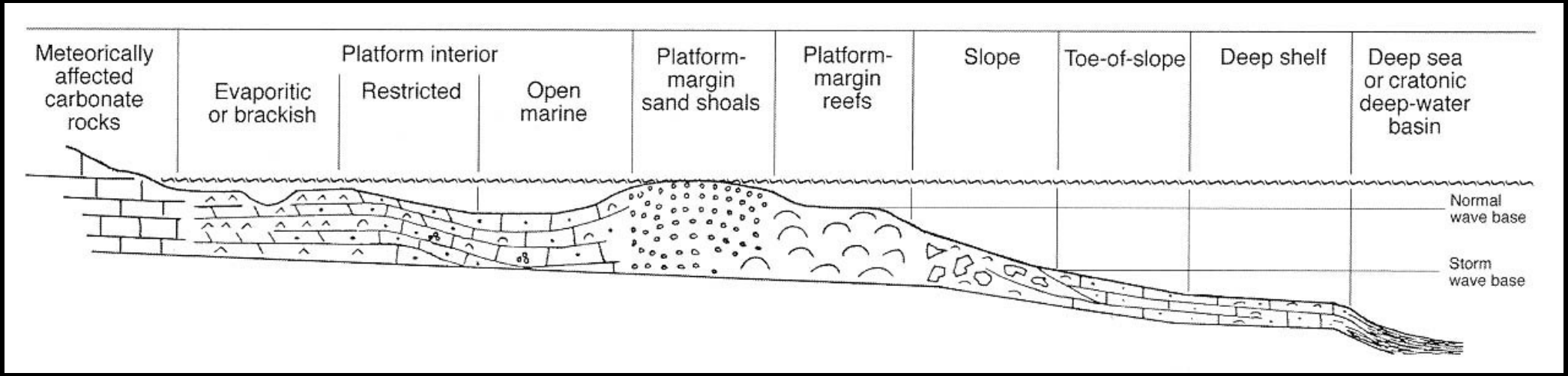


Demicco and Hardie, 1994

The Wilson model

Based mostly on the depositional profile of Florida bay, Wilson (1975) conceived a influential carbonate facies model, that refers to an *attached*, *rimmed*, *high-relief* carbonate platform.

A **facies model** is the description of how different sedimentary environments (and, thus, facies associations) are arranged in space or along a depositional profile, within a depositional system.



Flügel, 2004 (based on Wilson, 1975)

The Wilson model: main facies associations

Lagoon: a low energy environment that exists because it is enclosed by a reef or barrier island

Reef: see definition give in previous slides

Carbonate platform **slope**: a depositional surface-environment with primary inclination and deposition dominated by gravitational processes