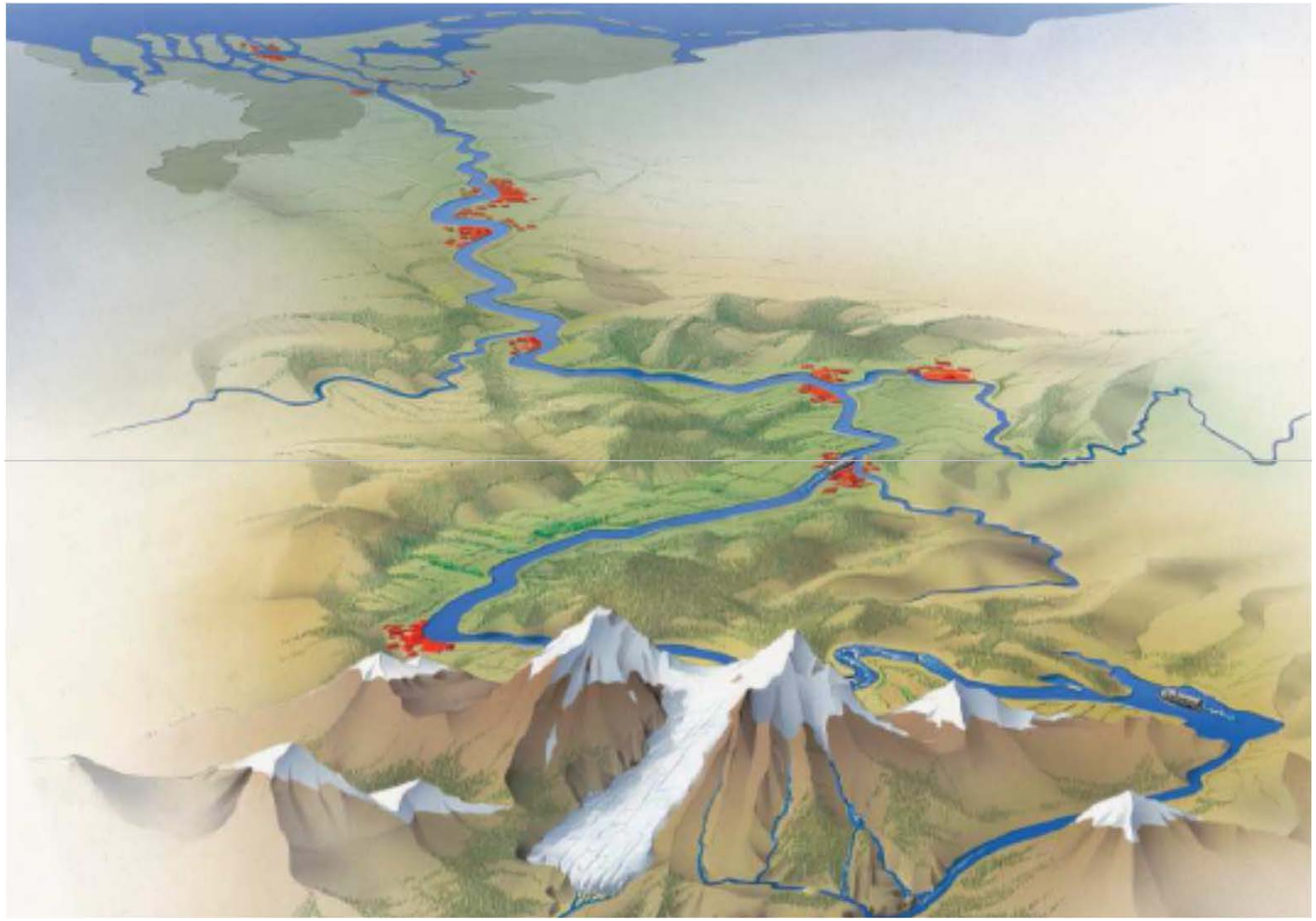
Deposition

Geology 1

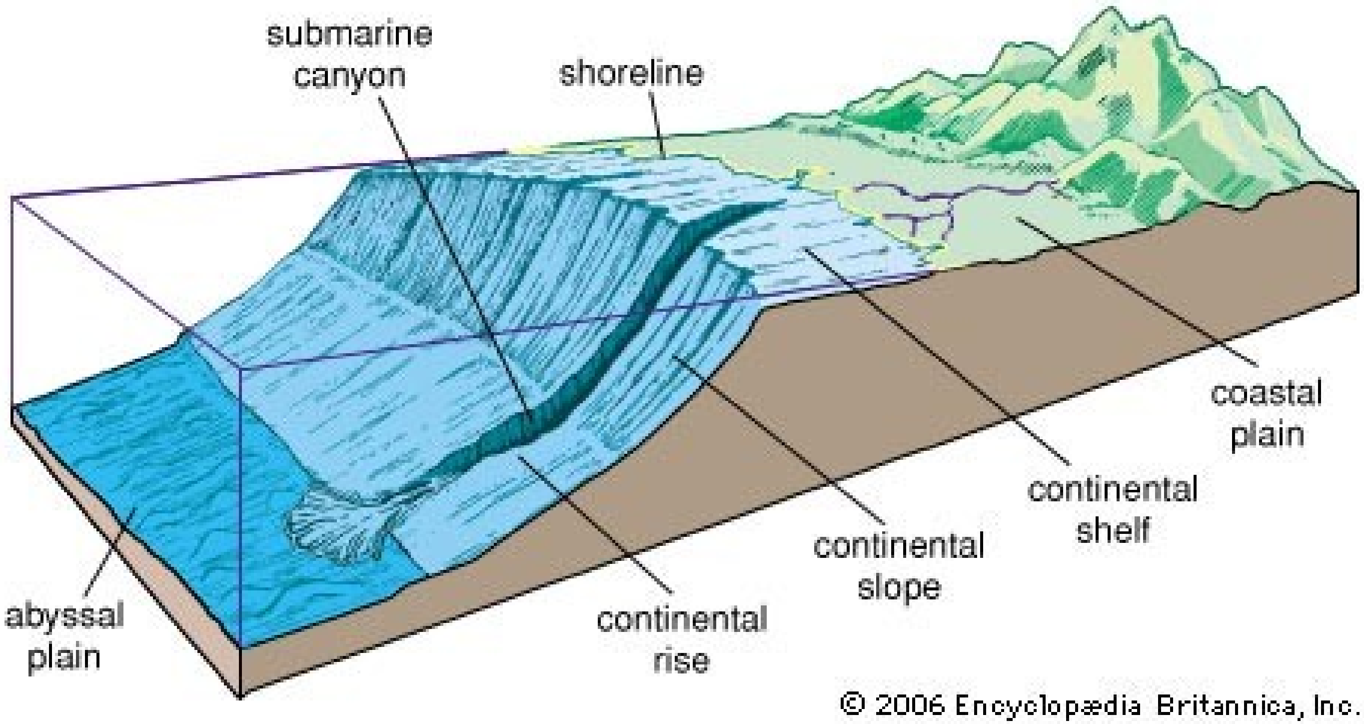
G. Bertotti

We have reached the sea!



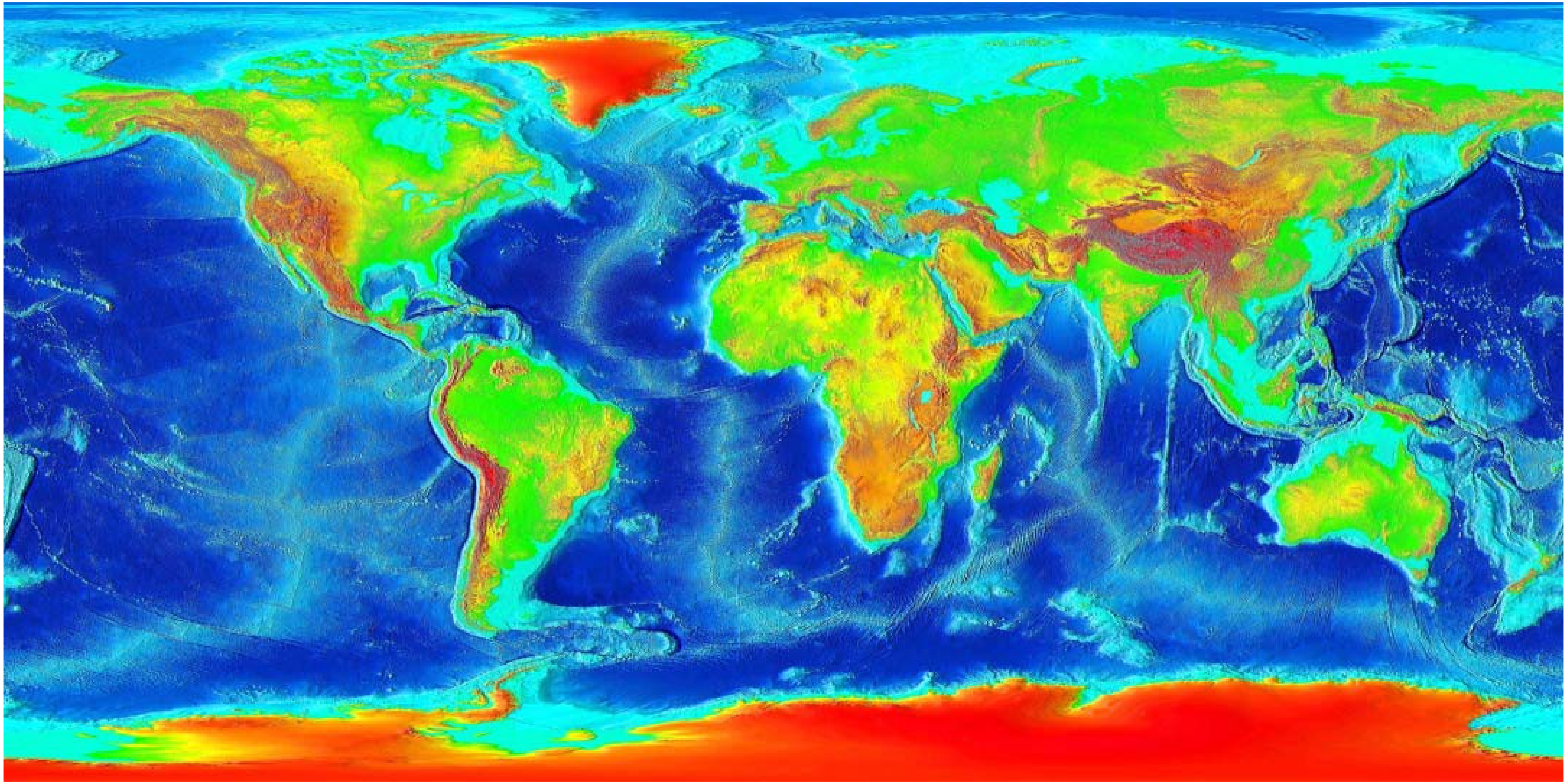
Three very different domains

- **The coast**
- **the continental shelf**
- **the slope and the abyssal plains**



Sediments transported by rivers to the sea are reworked along the coast, parked in the continental shelf and, maybe, eventually transported to the abyssal plain

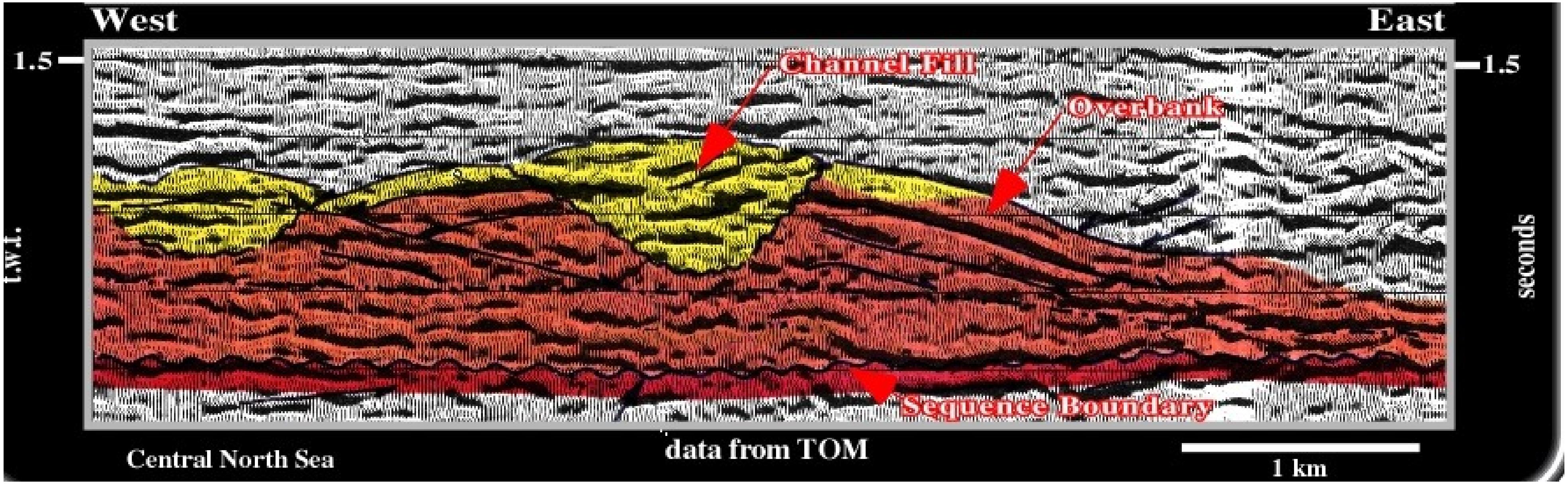
Continental shelves and deep-sea domains in the world



- large scale currents
- tides
- waves and coastal currents
- estuaries and deltas

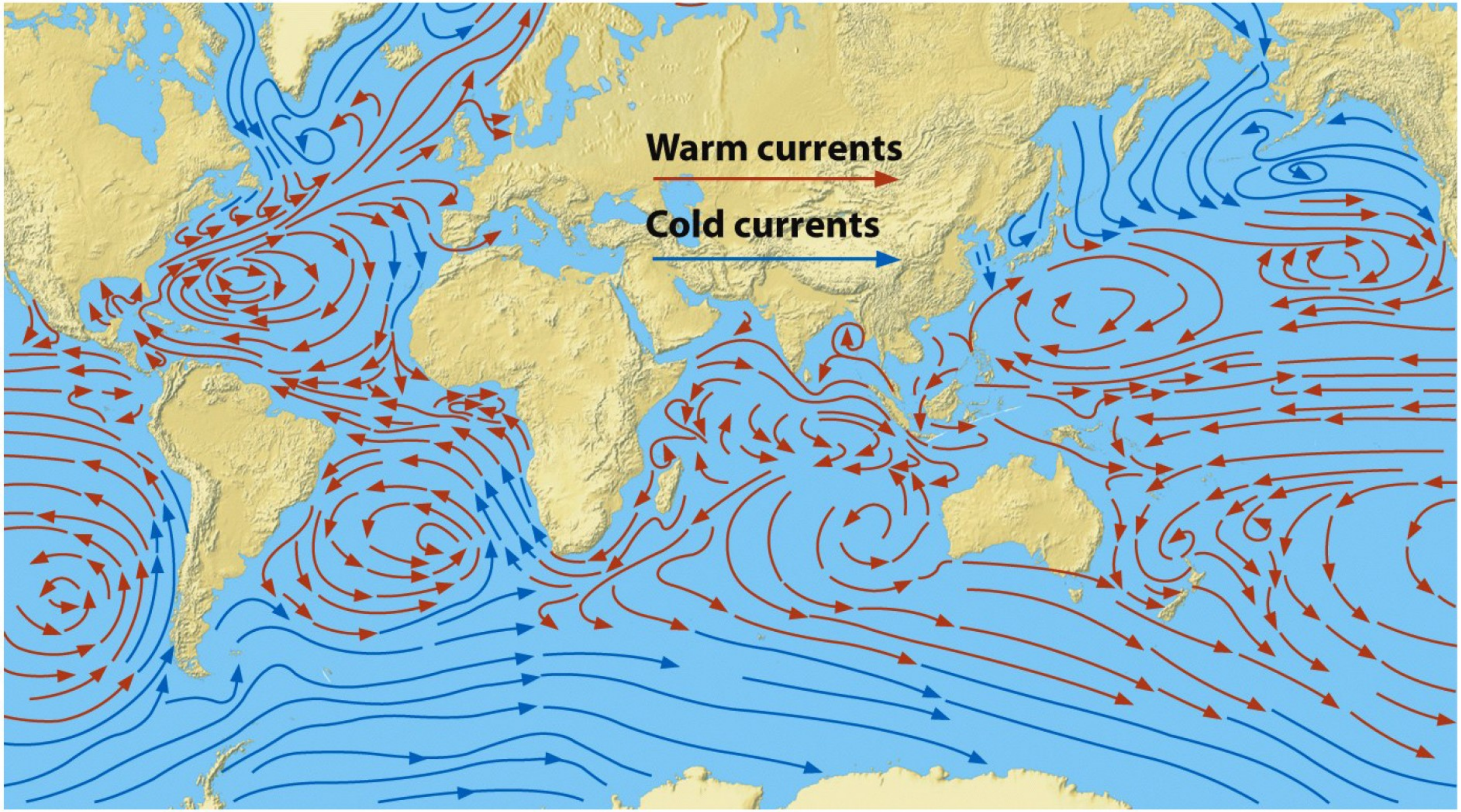
Why do we need to know all this?

1. Water, hydrocarbons and many other resources are in sedimentary rocks
2. Large part of the world population lives on sediments
3. Knowledge of the processes controlling sedimentation allows predictions on volumes and distribution of sands, quality of reservoirs, stability of underground infrastructure etc
4. geologists are paid to make predictions



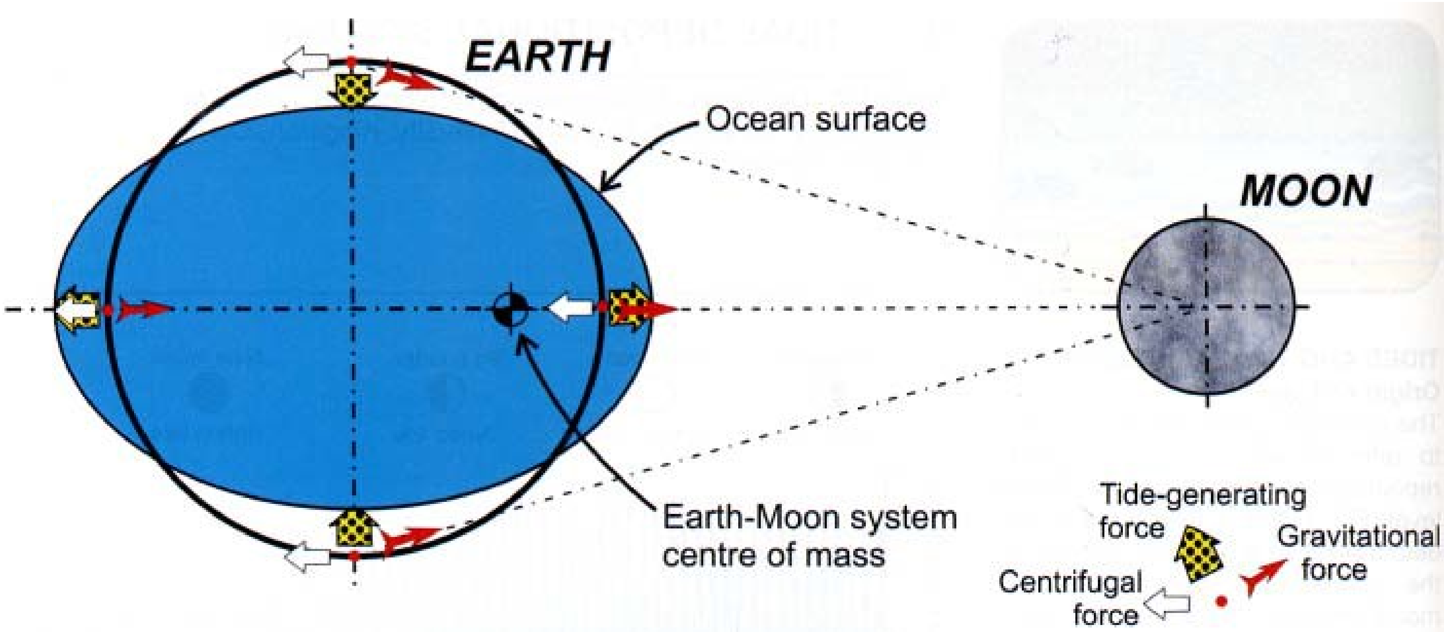
Now we look at deposition environments, in future classes you will learn how to derive them from the rock record

The global current pattern



Tides

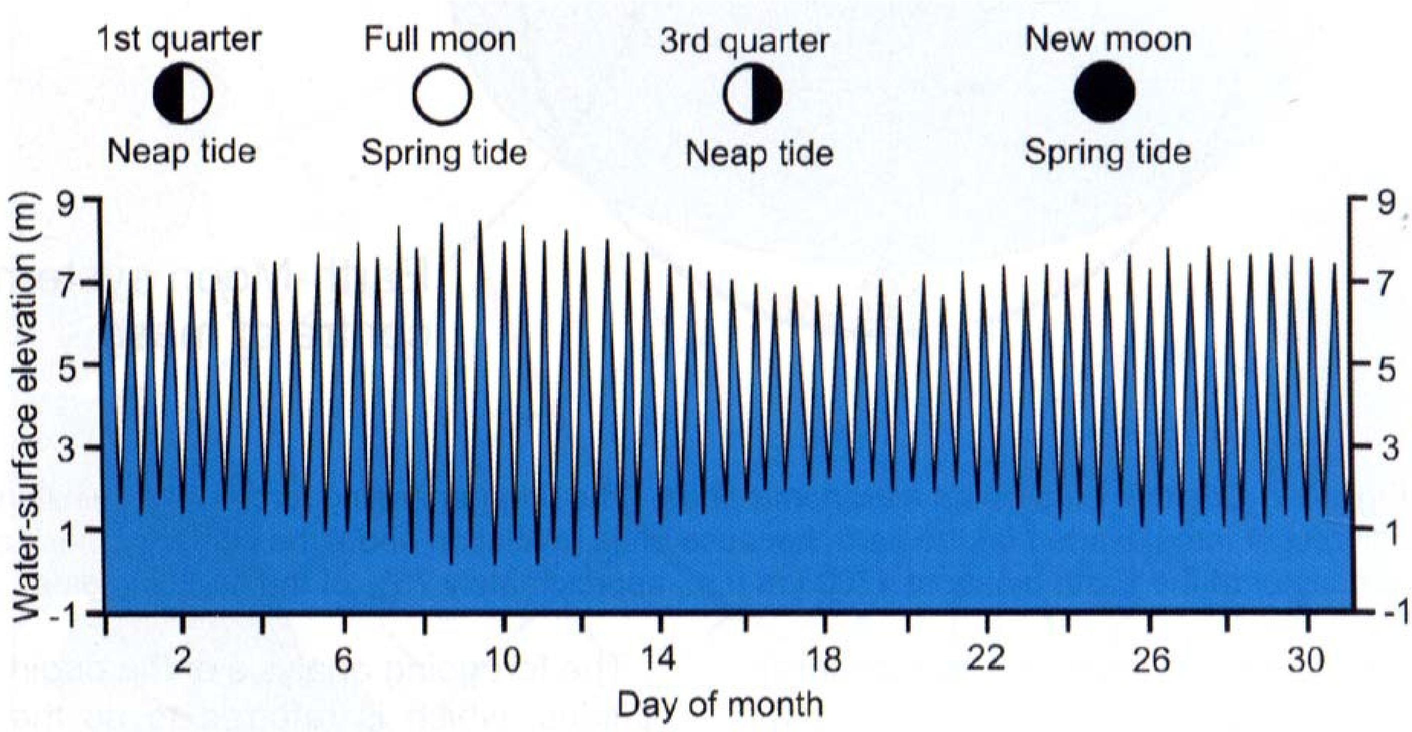
Caused by a) the attraction the moon exerts on the Earth, b) the centrifugal force of the coupled Earth-moon system



During flood times, the water level increases and the shorelines moves landward. During ebb times, .. the opposite. Happens twice a day

As the Earth+moon system rotates around the sun, higher order cyclicities are observed

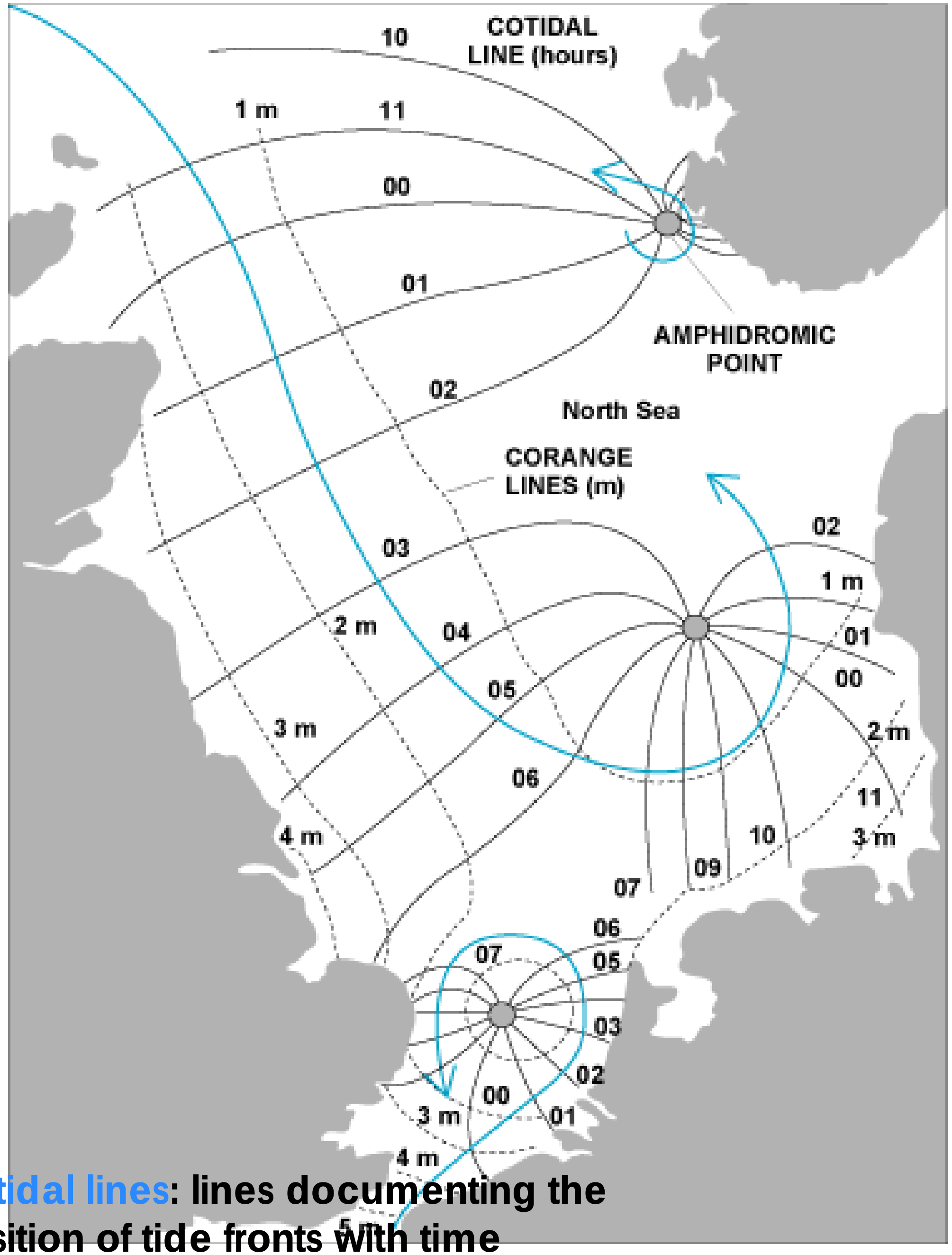
Resulting in a very regular pattern of oscillations with different periods



6 – deposition

Once tides arrive on the continental shelf, they interact with landmasses changing direction and speed

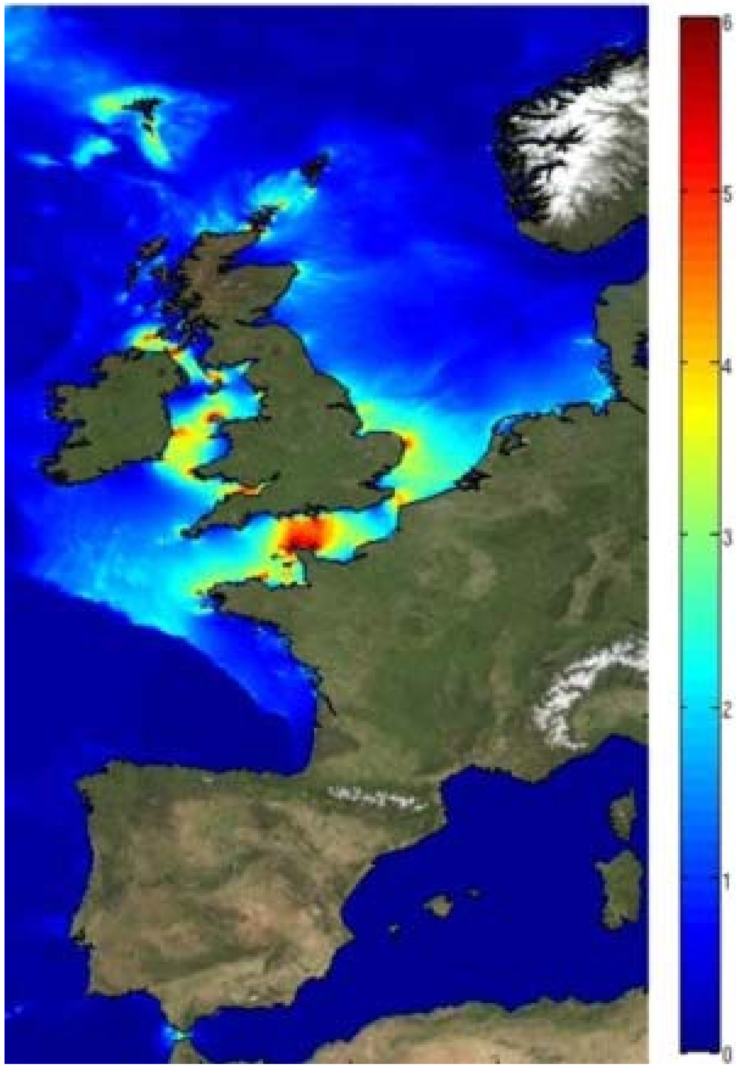
Where the section across the tides have to move, the speed and height increase substantially

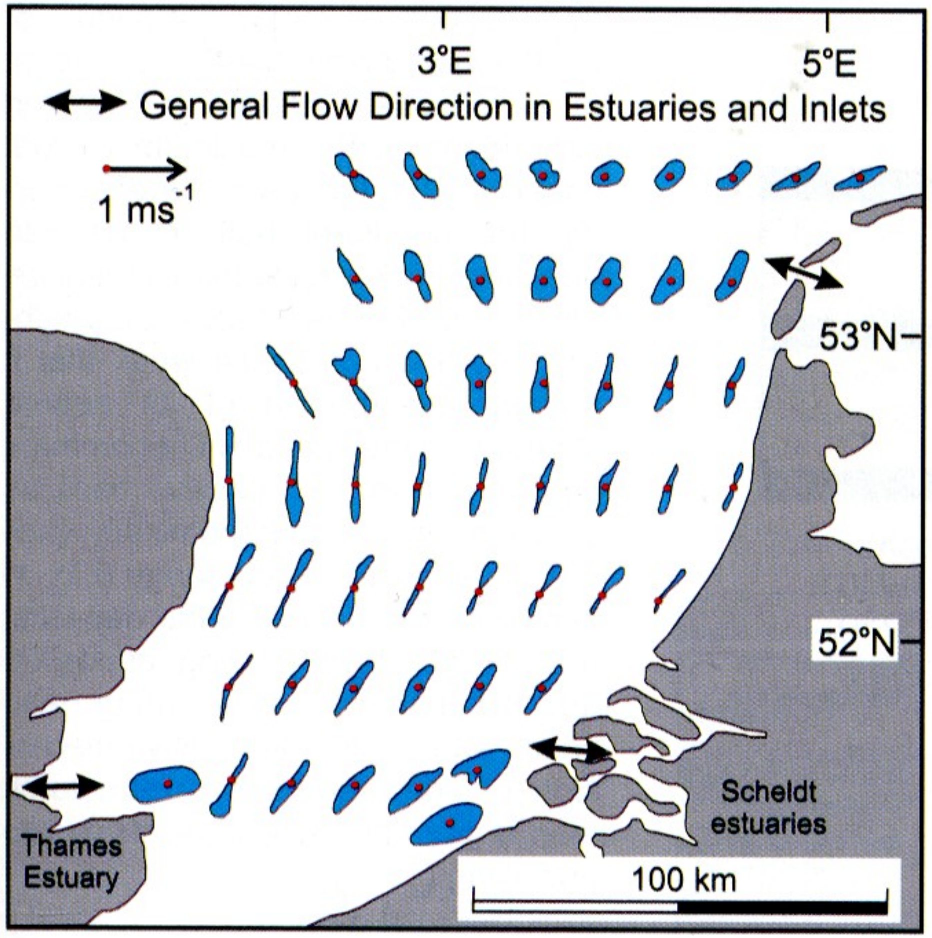


Cotidal lines: lines documenting the position of tide fronts with time

When a lot of water has to pass through a narrow channel, high velocities (>1m/sec) are expected. This with a pattern changing twice a day

max flow velocities (knots)



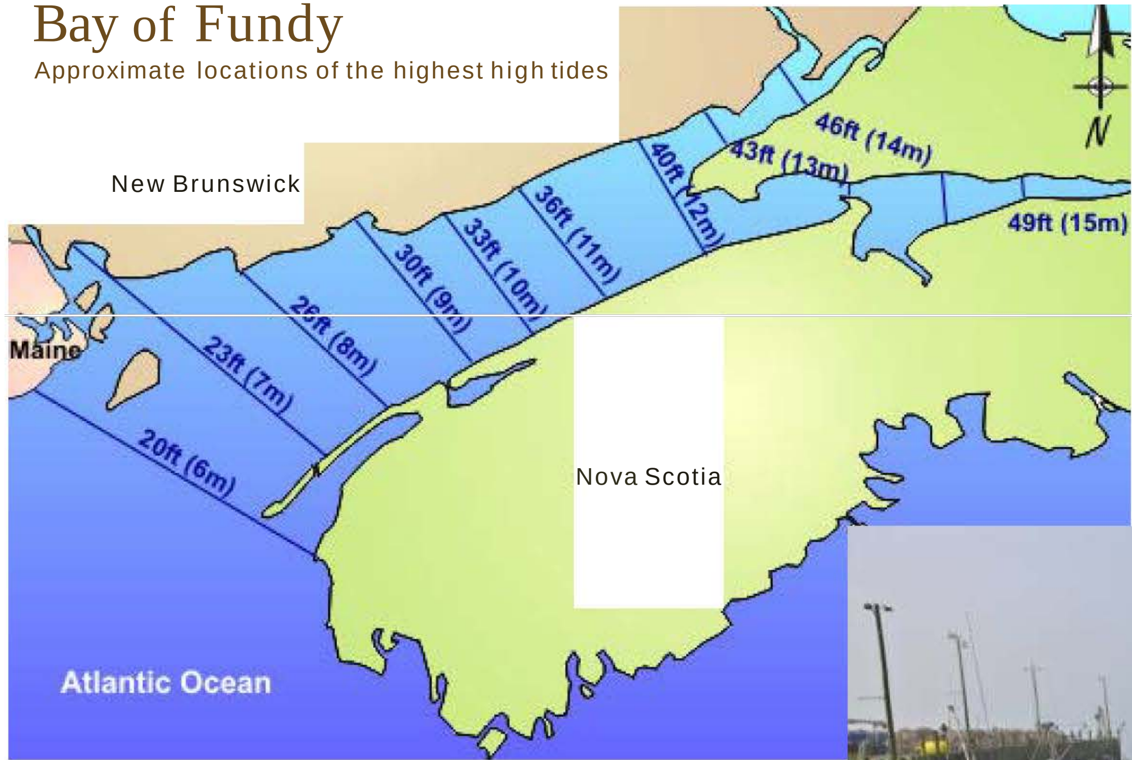


Tidal current ellipses for currents 1 m below sea level

Highest values are found in narrow straights close to large ocean bodies

Bay of Fundy

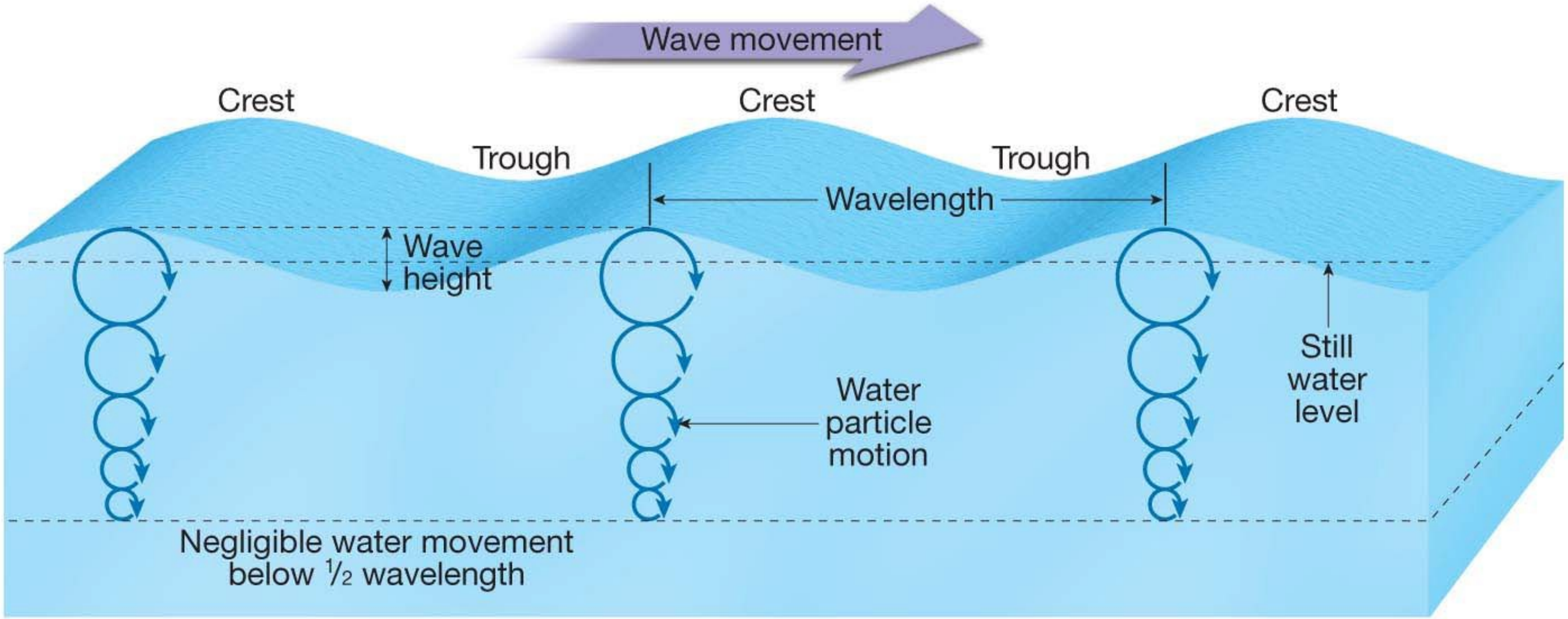
Approximate locations of the highest high tides



Water moves in waves

Characterized by height, wavelength, period for successive waves and velocity (v=λ/T)

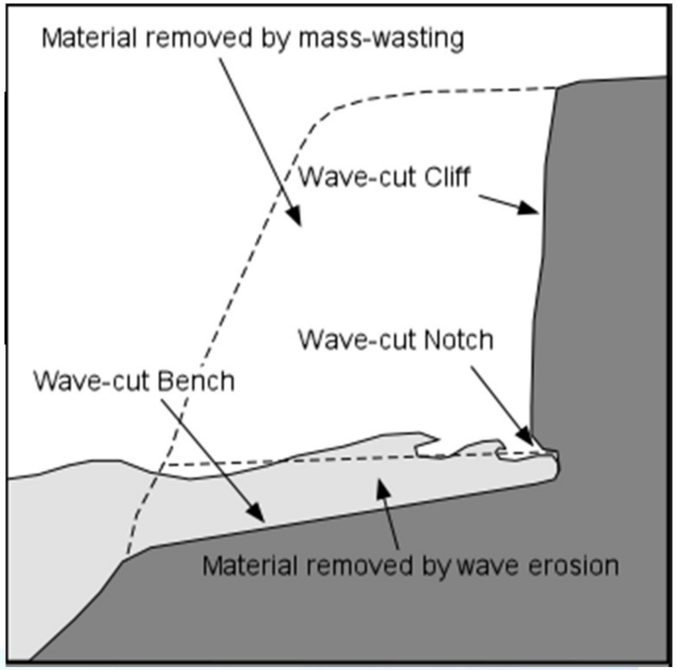
Typical wavelengths: 6-400m
Periods: 2 – 20 sec



Eventually they will reach the coast

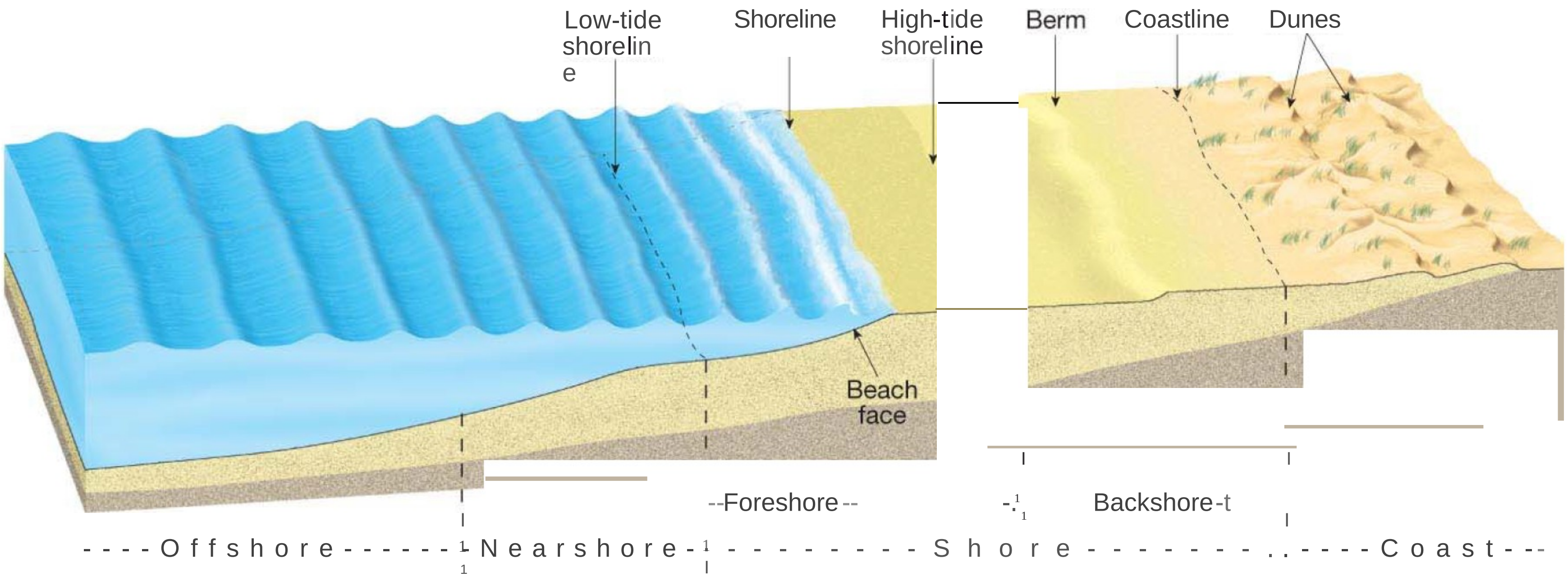
In steep coasts (where this is formed by bed rock) erosion dominates

During tectonic uplift, a competition arises with tectonics winning

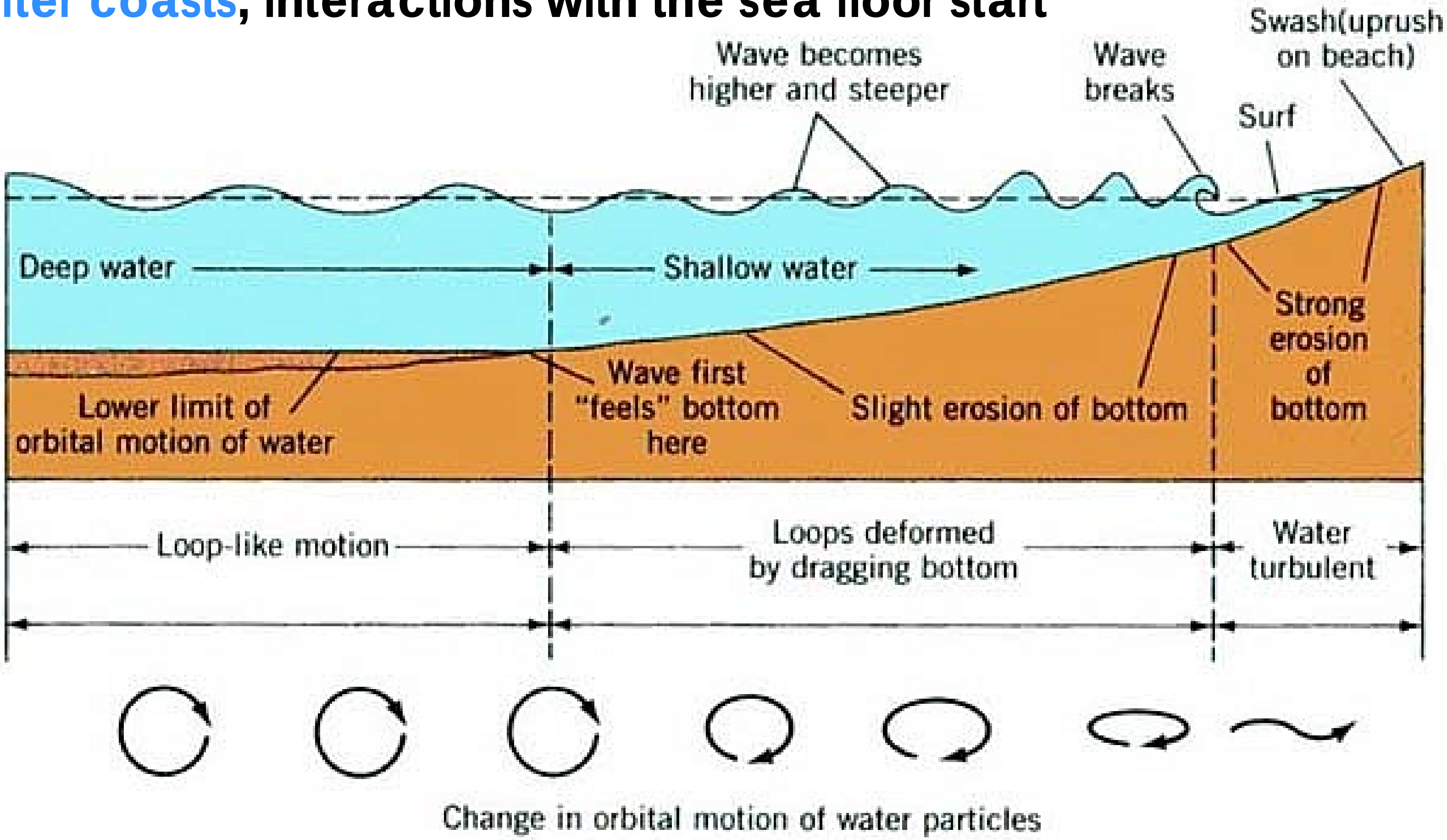


Beautiful flight of terraces are exposed in some areas

In gentle, sandy coasts

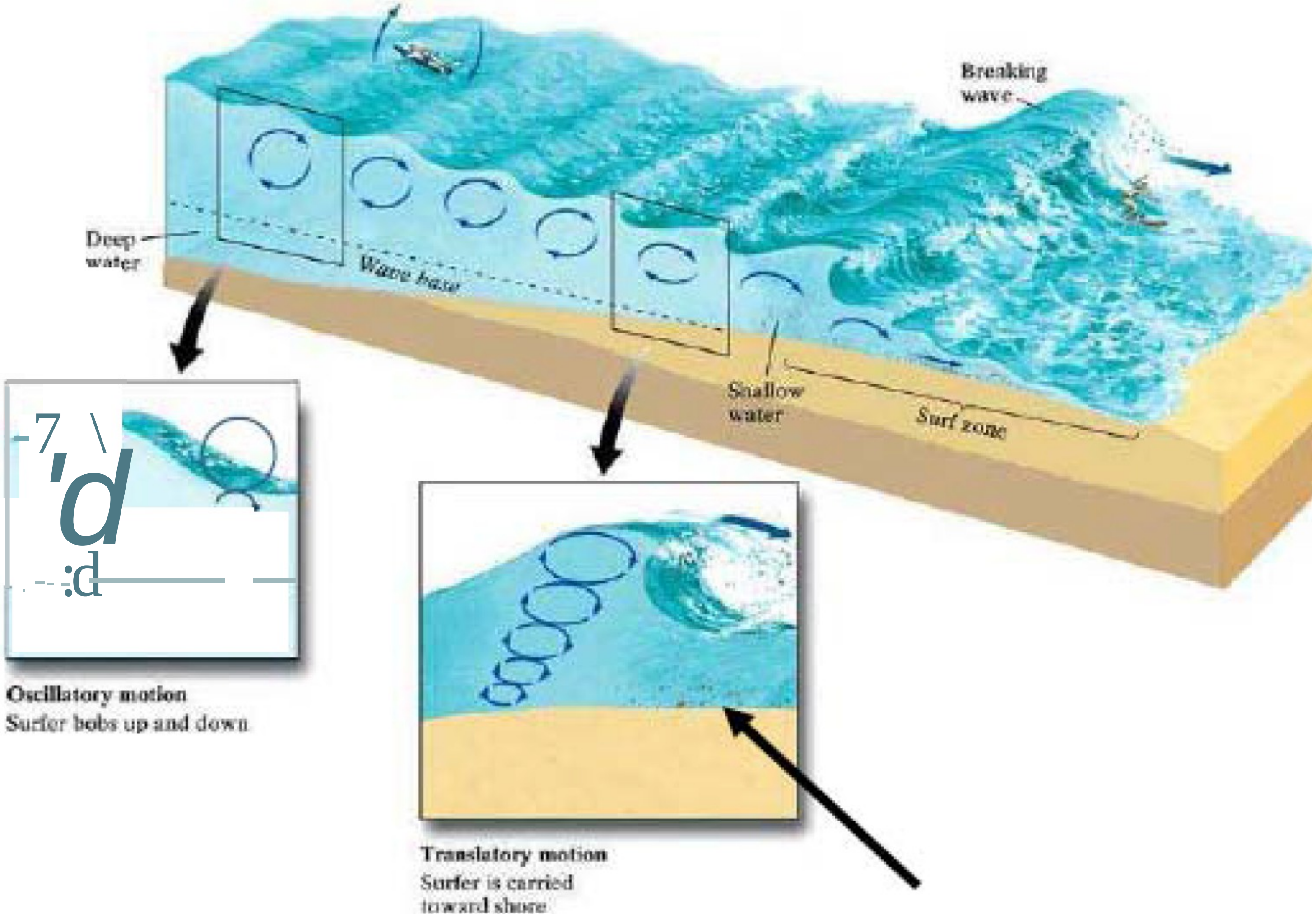


In softer coasts, interactions with the sea floor start

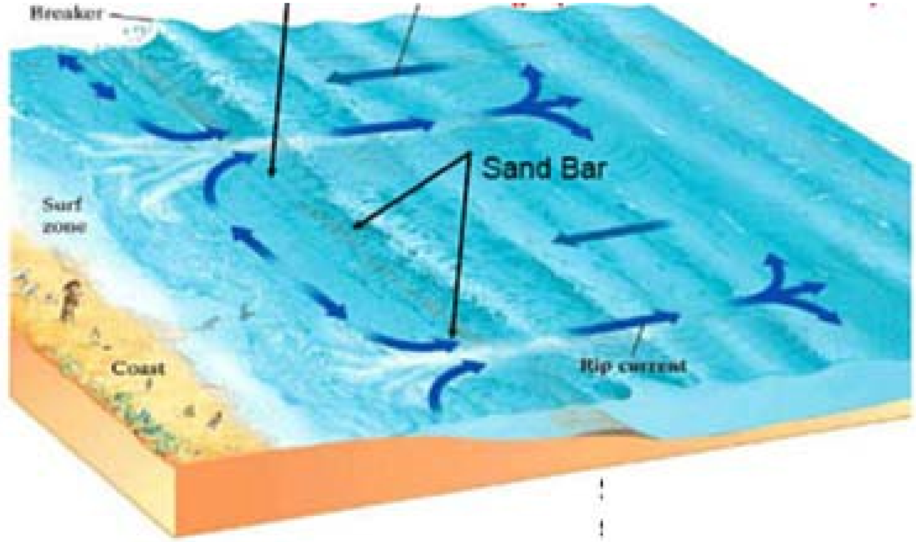


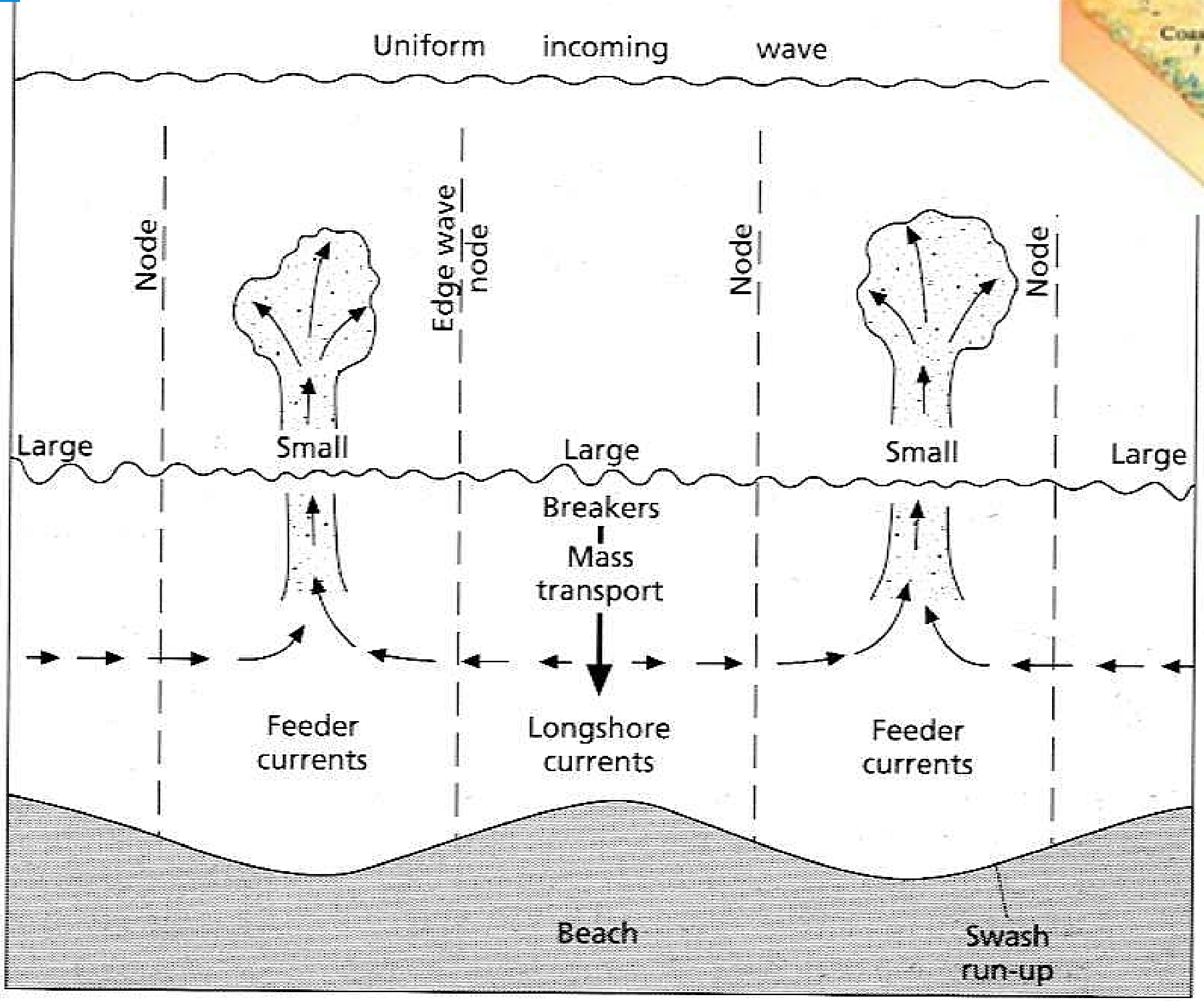
Major interactions with sea floor sediments occur when depth <1/2 λ

waves break and then collapse on the surf section of the shore
a layer with strong turbulent flow is activated bring into movement and suspension a large amount of sediments


Breaking wave
Deep water
Wave base
Shallow water
Surf zone
Oscillatory motion
Surfer bobs up and down
Translatory motion
Surfer is carried toward shore

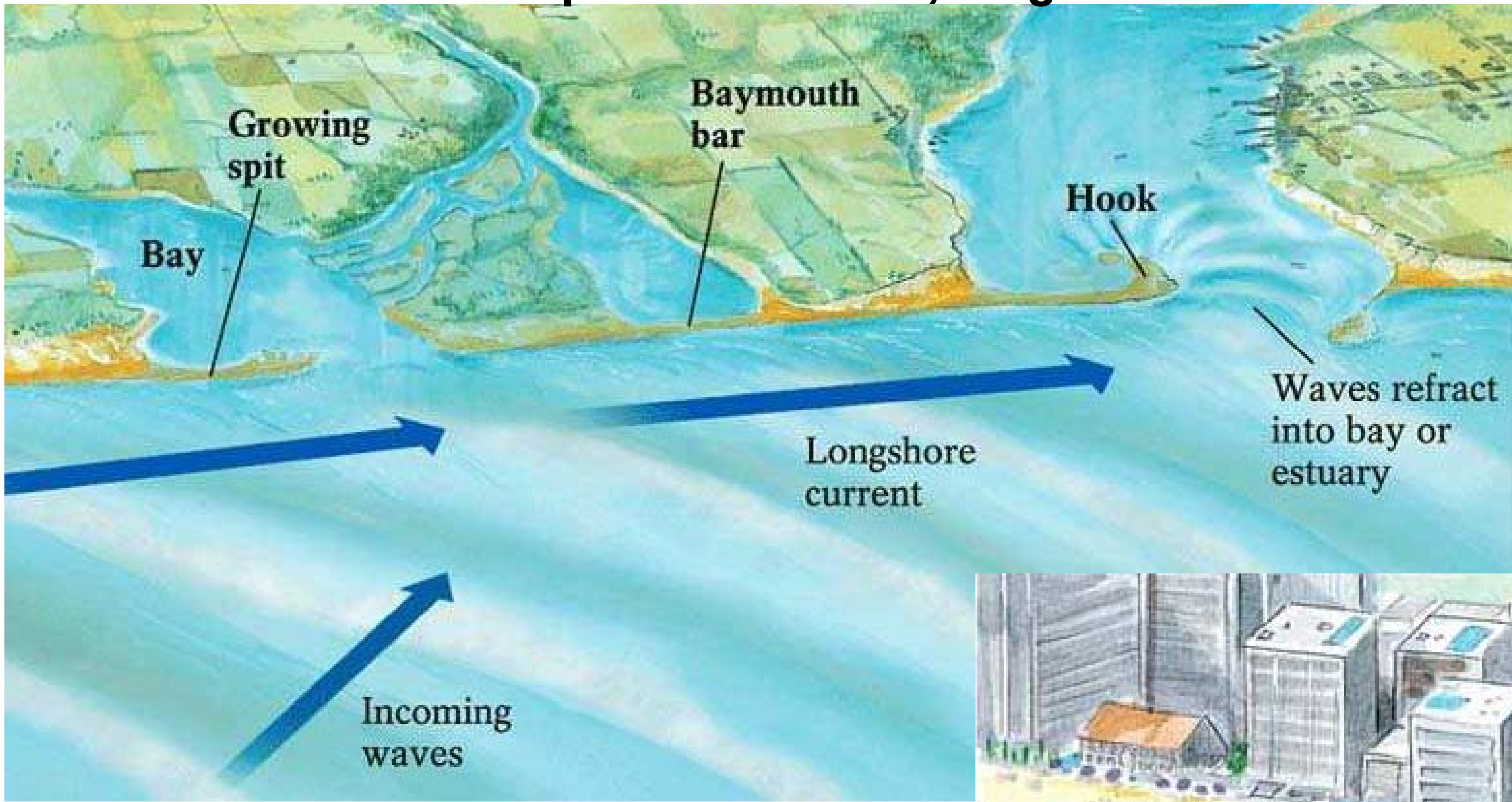
In map view

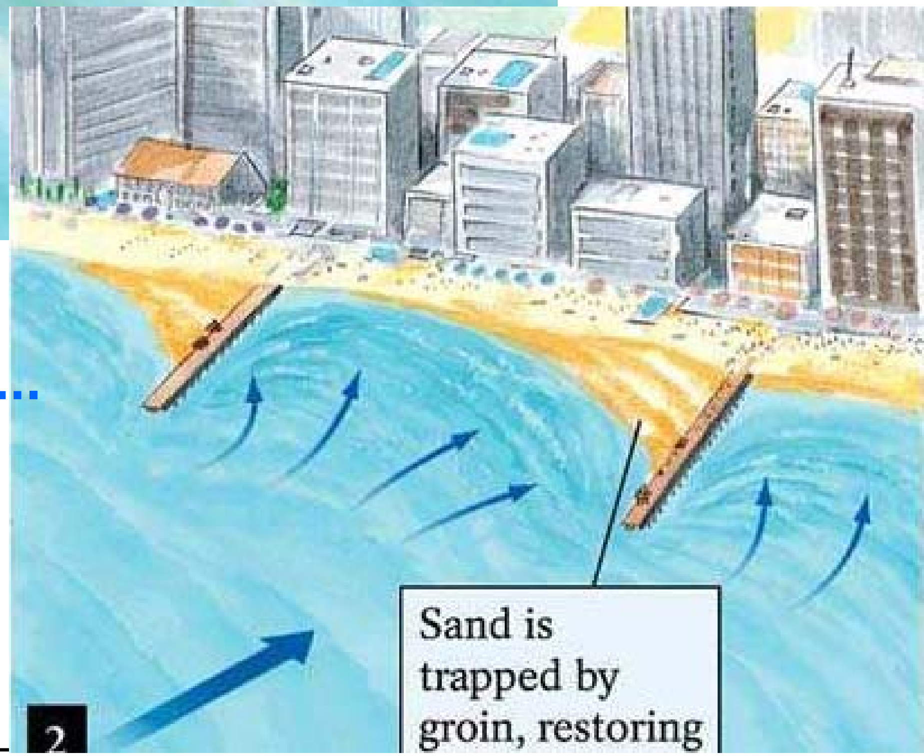




The ± linear front of the incoming waves splits reaching the shore and water+sediment going returning to the sea is channelized flowing at high velocities (>1-2m/sec) underneath the incoming water.

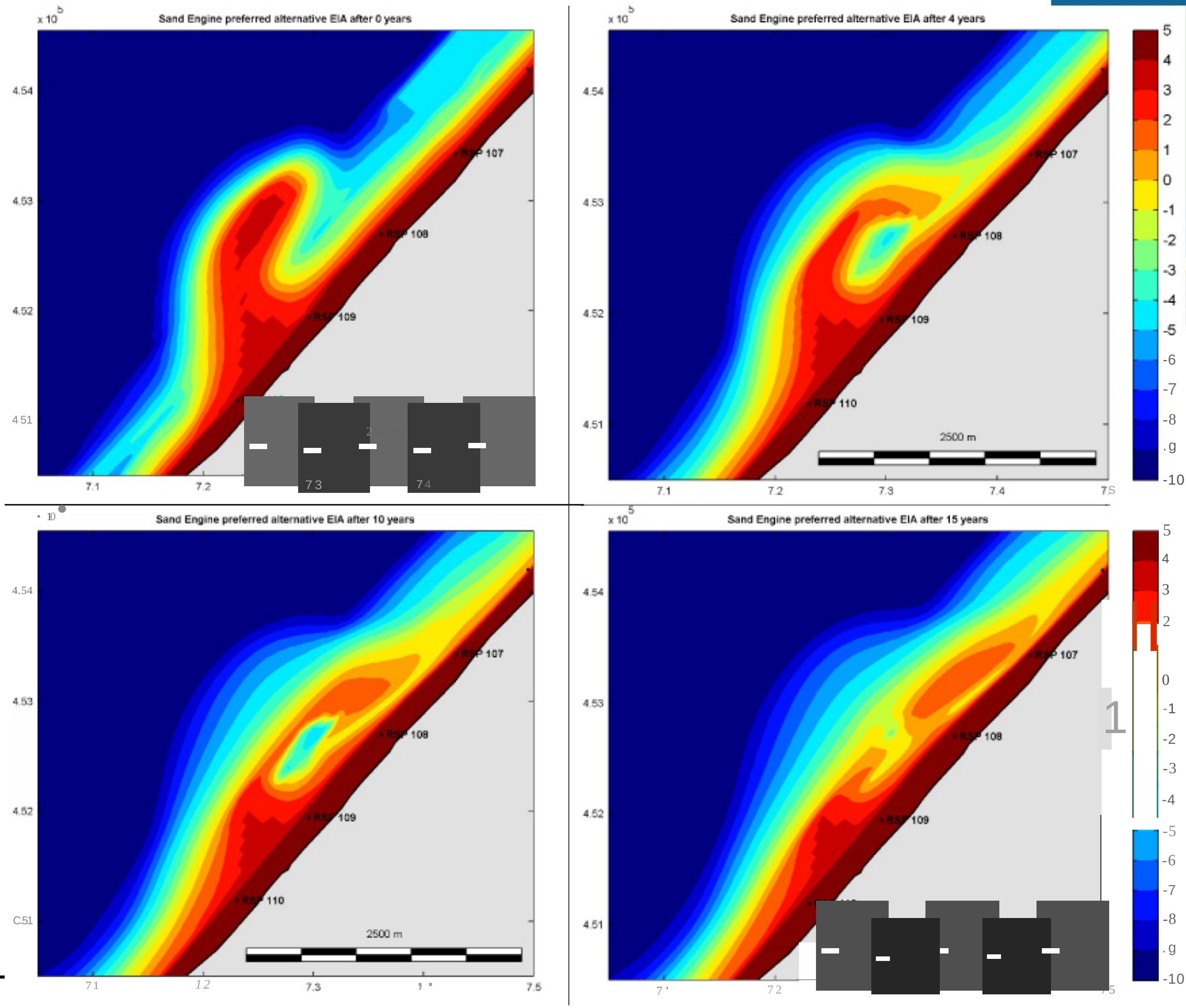
When currents are oblique to the coast, long shore currents arise

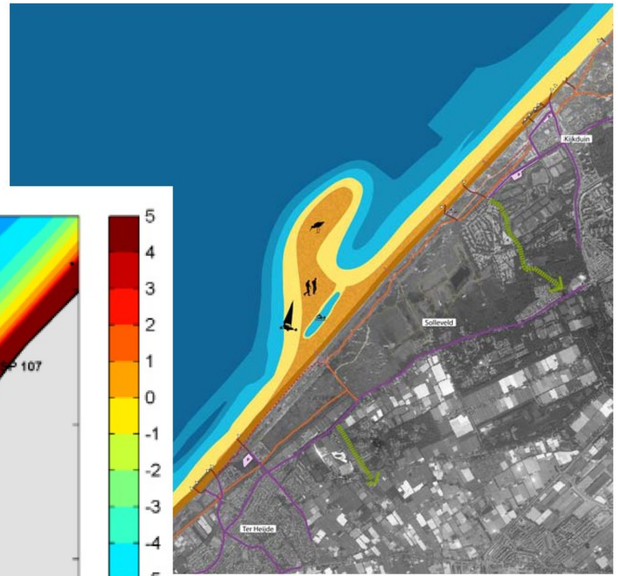




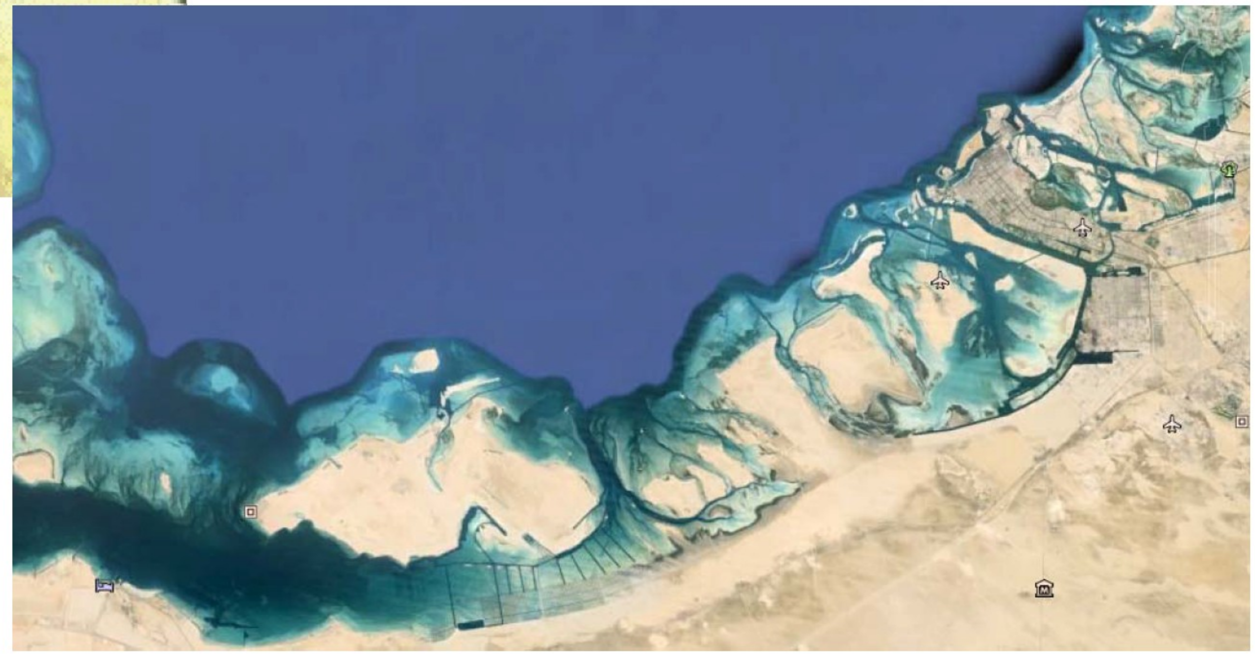
Redistributing sand in spits, bars, hooks ….
And when interacting with groins

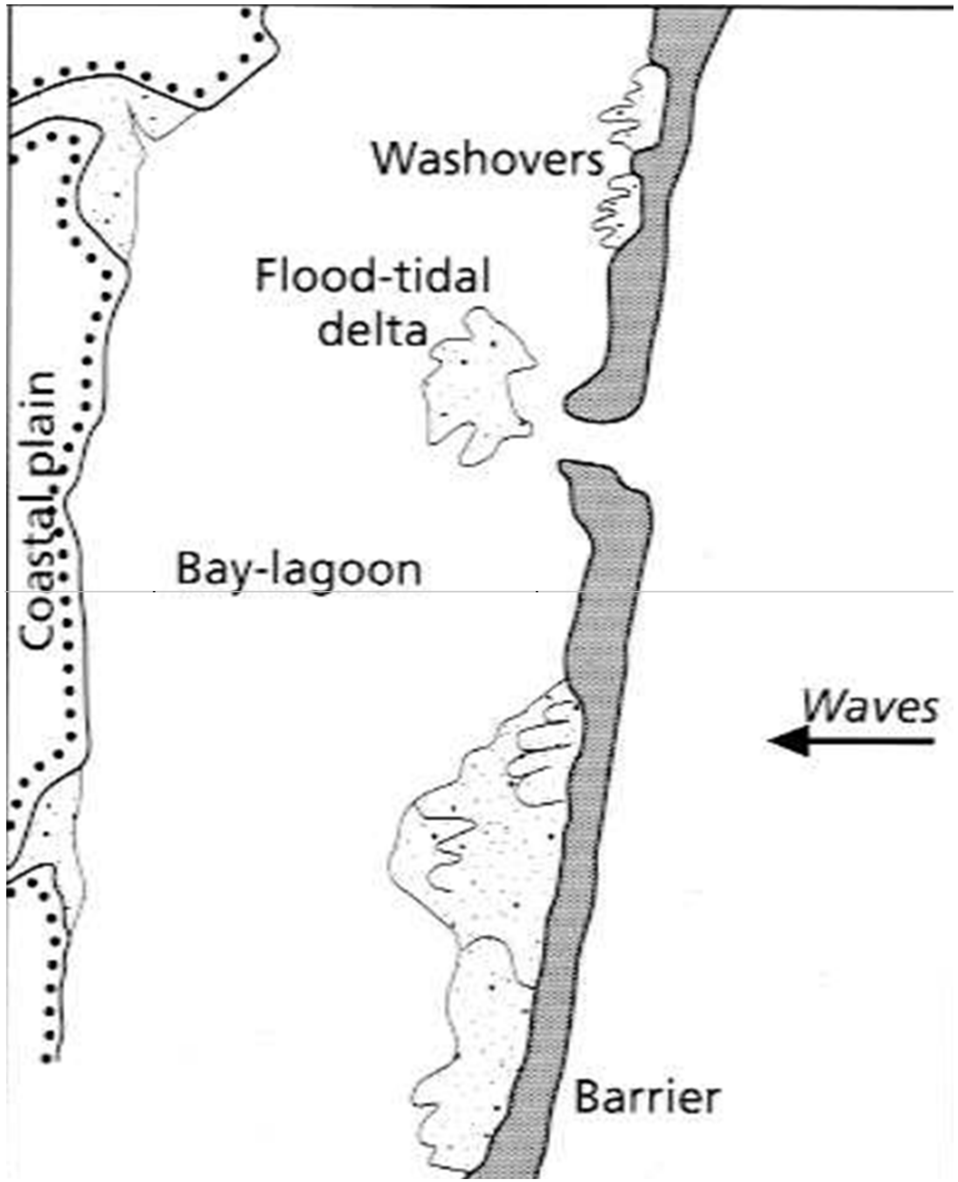
The Zandmotor:A great (TUD) experiment





Wave- and tide-dominated coasts

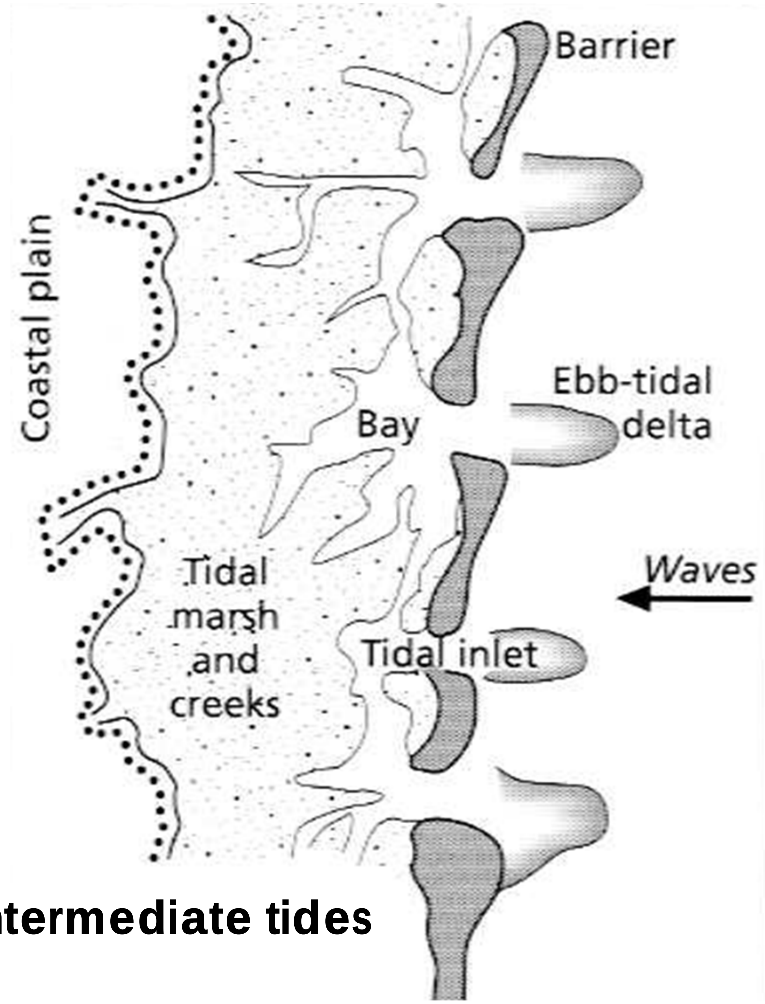




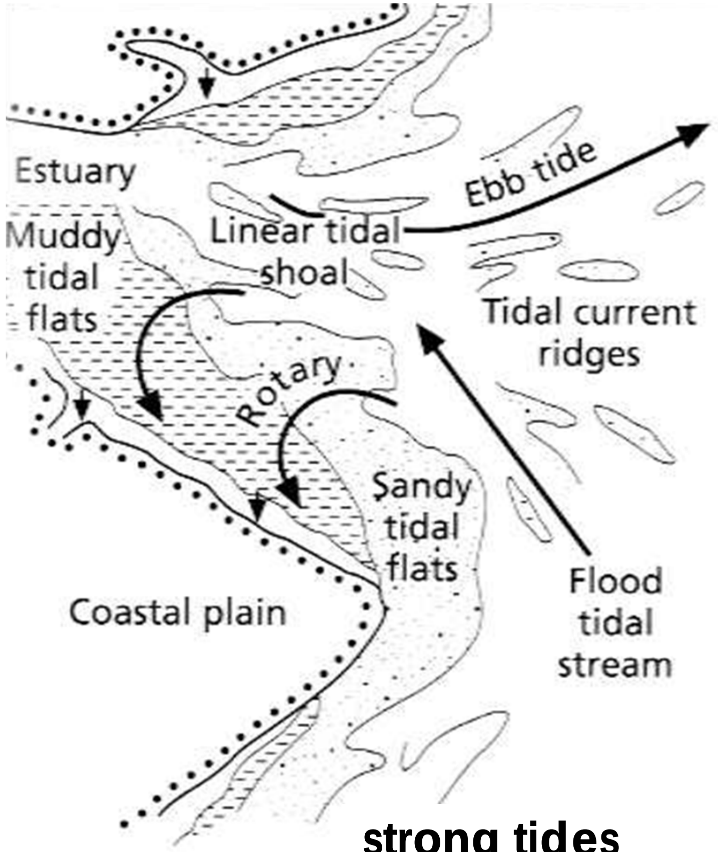
Wave- and storm-dominated coasts characterized by linear elements parallel to the coast

- **along-shore currents produce elongated barriers parallel to the coast**
- **small flood-tidal deltas (landward)**
- **the lagoons are generally quiet and elongated**
- **storms are the important agents suddenly bringing coarser sediments in the lagoon**

Increasing importance of tides



intermediate tides

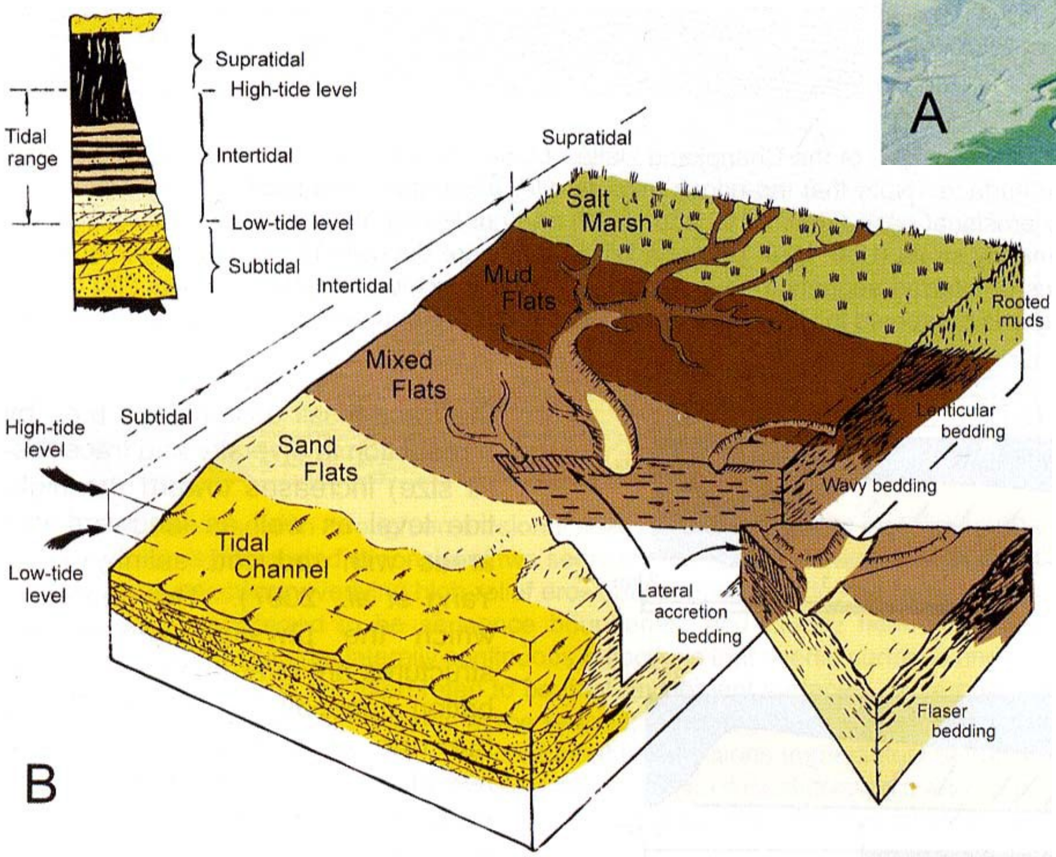


strong tides

Water movement becomes predominantly perpendicular to the coast destroying coast-parallel features and developing transversal ones

Water rises gently over the entire coast carrying fine-grained sediments, leaving them in the tidal flat and returning along channels

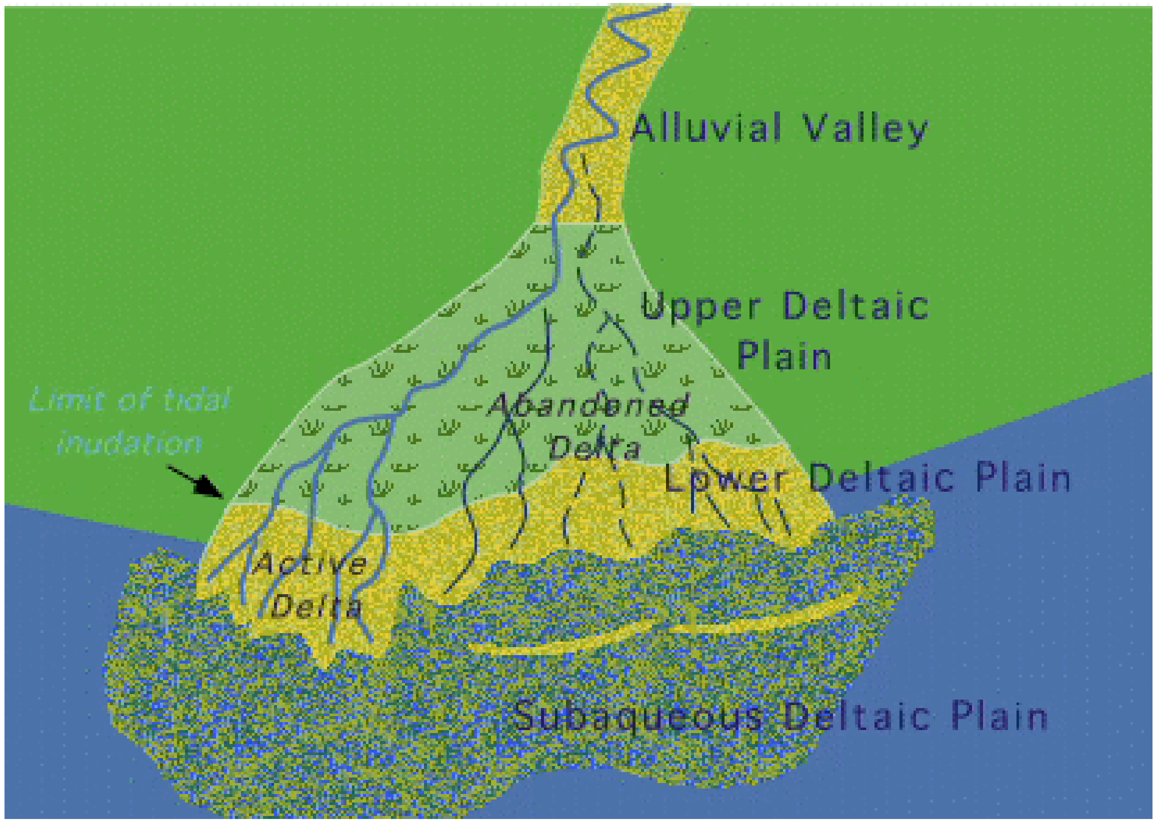
Tidal flats in the Bay of Fundy



Very different types of sediments are deposited in the different environments! (we will see later)

Deltas

systems of great importance in delivering sediments



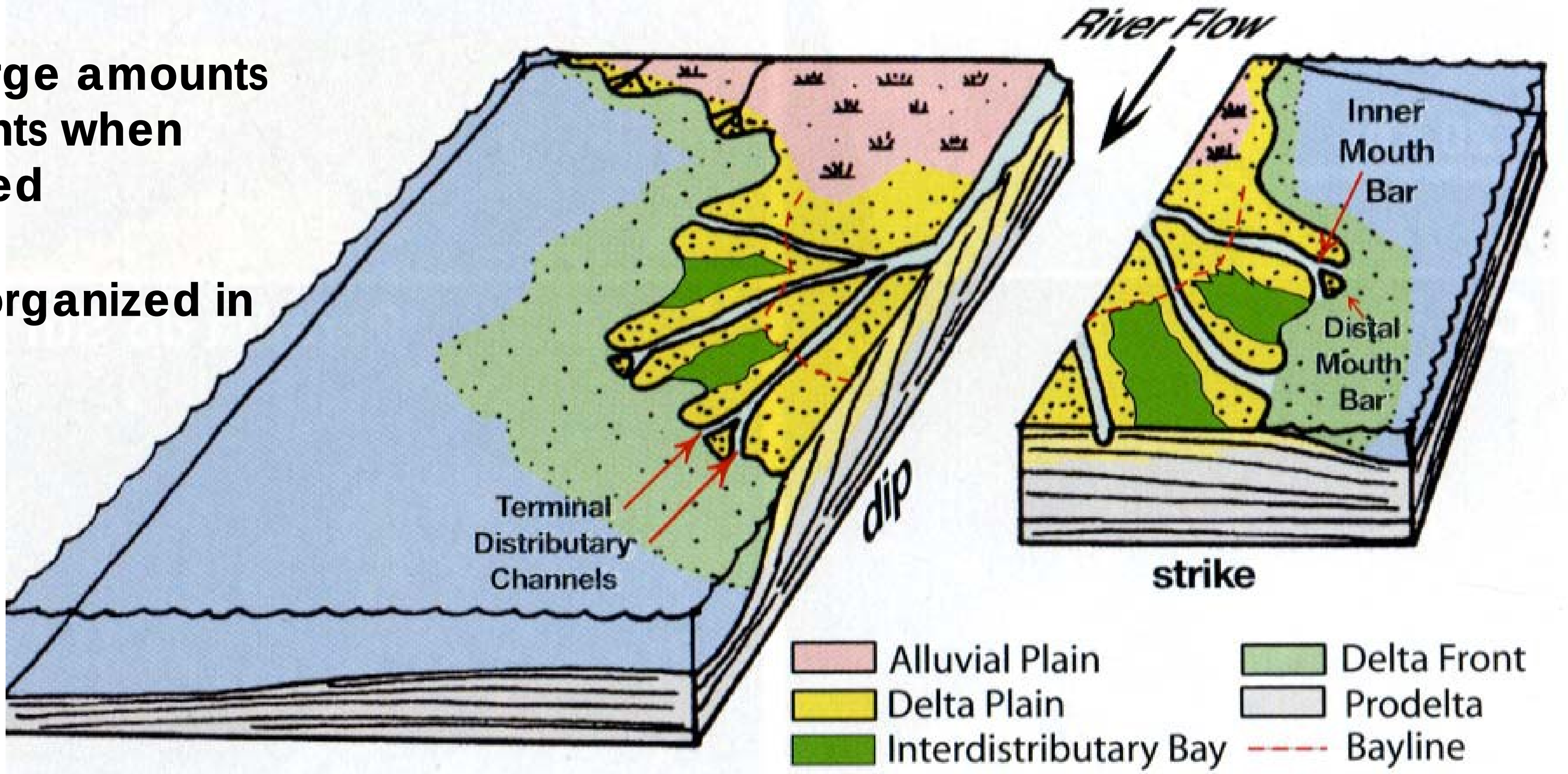
Triangular areas of alluvial deposits where a river divides before entering a larger body of water

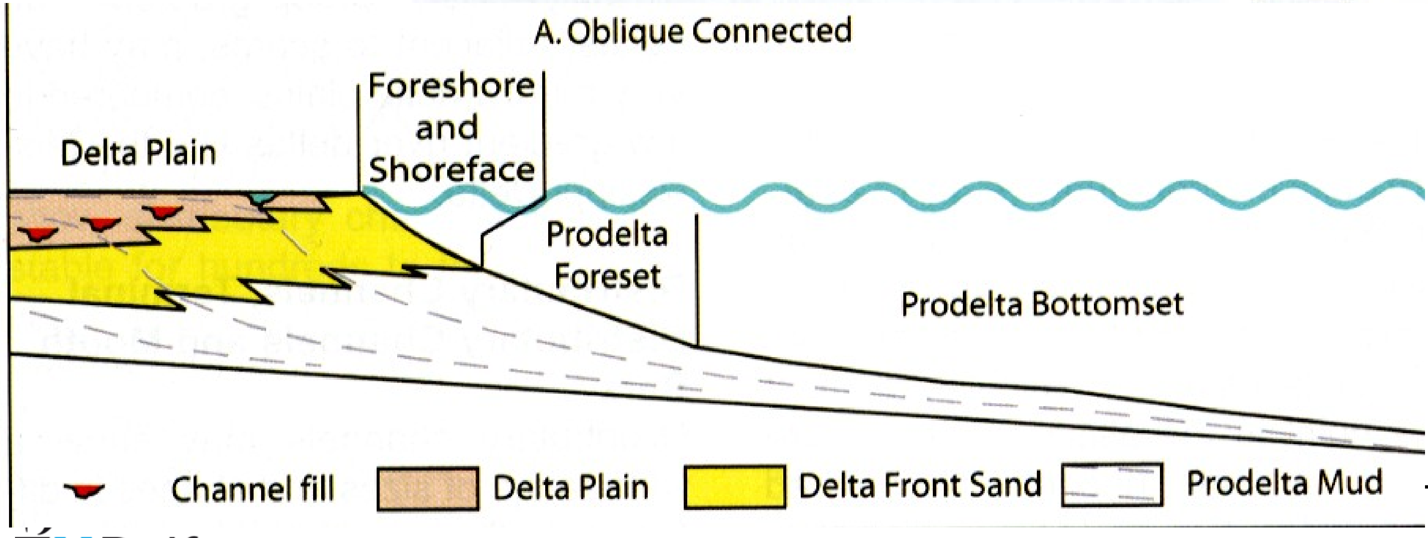
Typically have a delta plain, a front (both subaerial) and an offshore part

Main features of river-dominated deltas

Deposit large amounts of sediments when water speed decreases

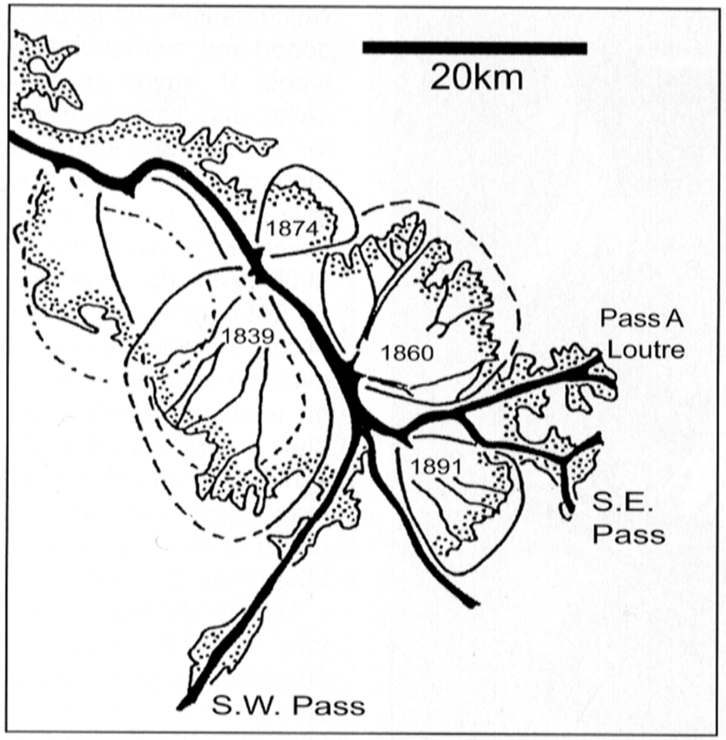
Typically organized in lobes



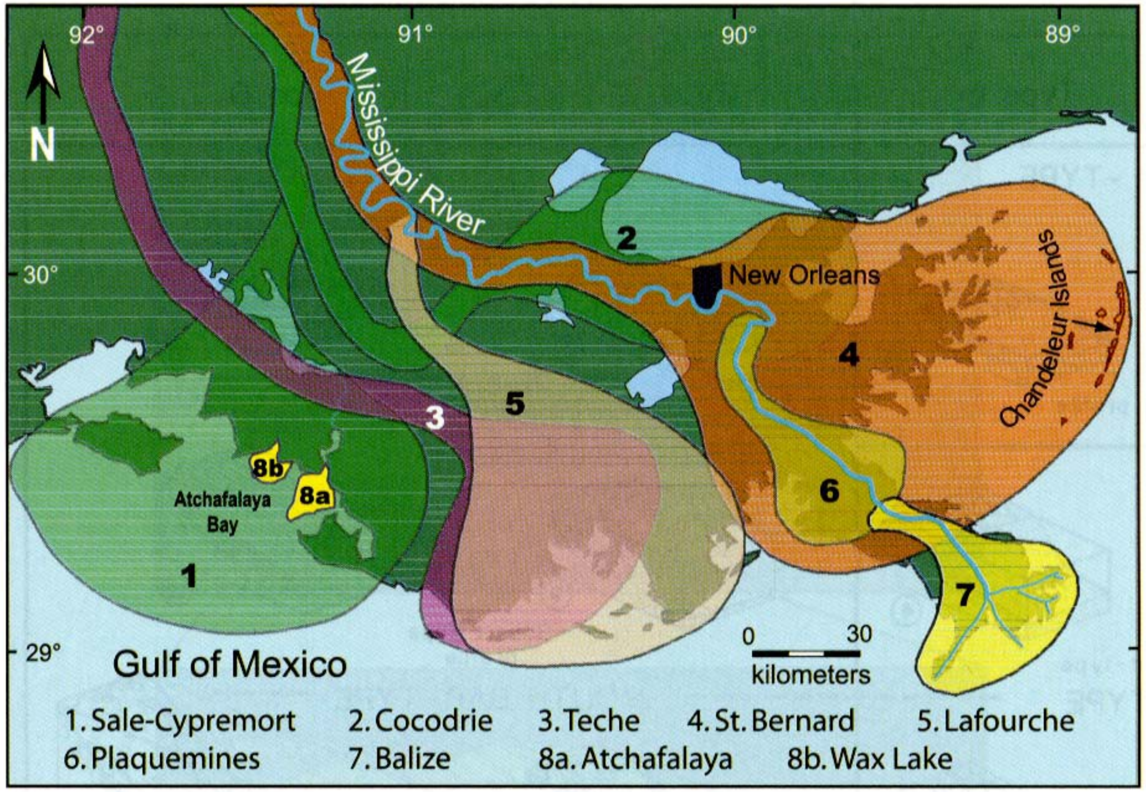


Strongly tend to prograde

Quite unstable features (at different scales)



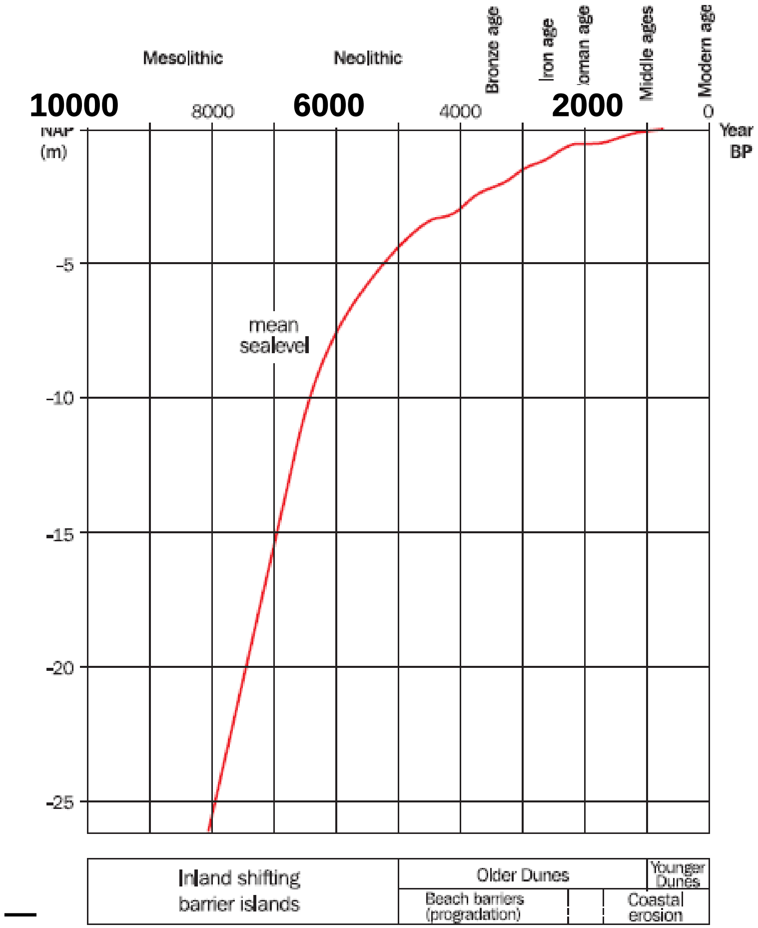
Sub-deltas in the Missisipi delta

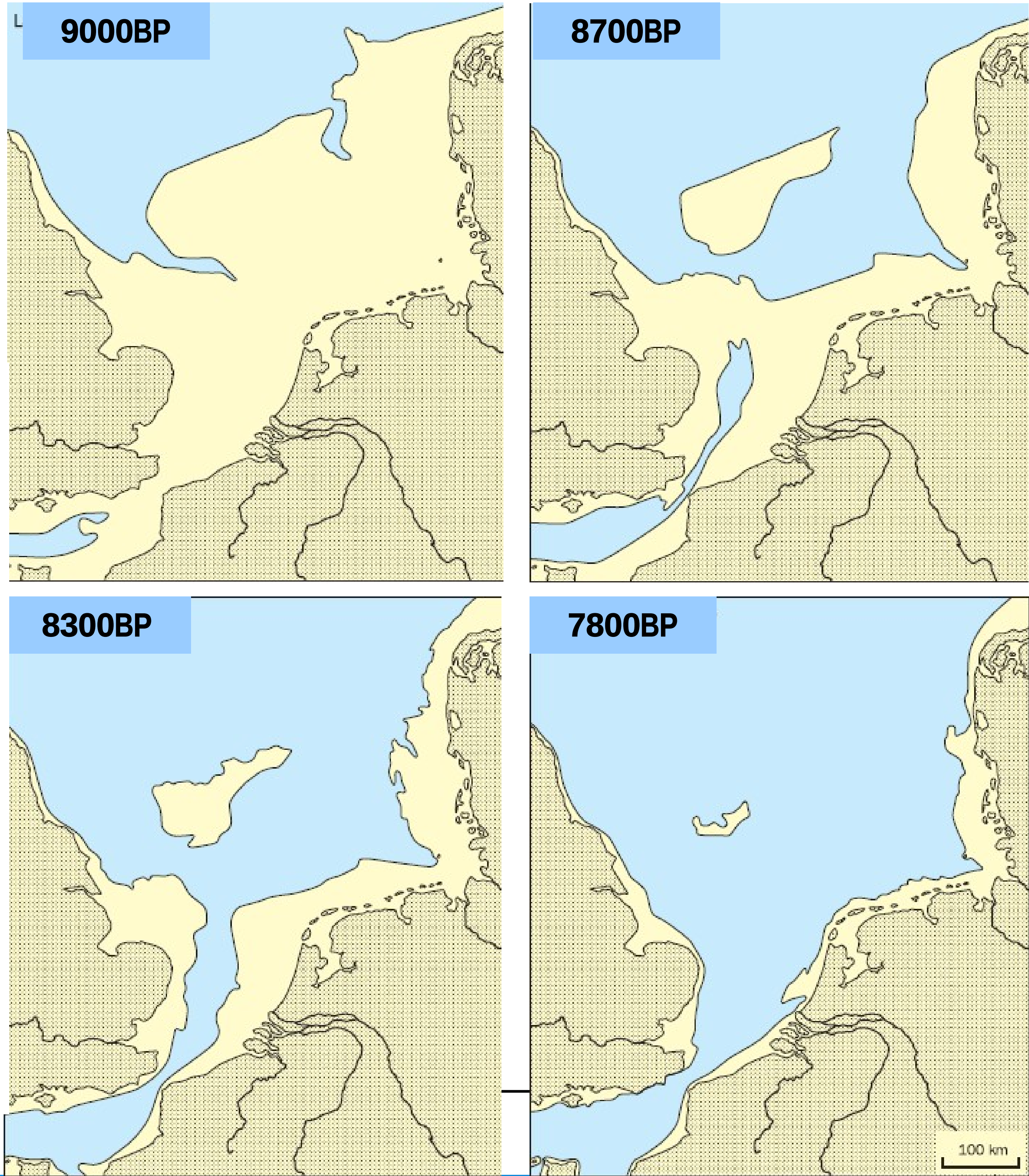


Missisipi delta lobes during the last ***9000 years,.***
Changes occurr ca.every 1000yr

Relevant?

Holocene evolution of the North Sea region



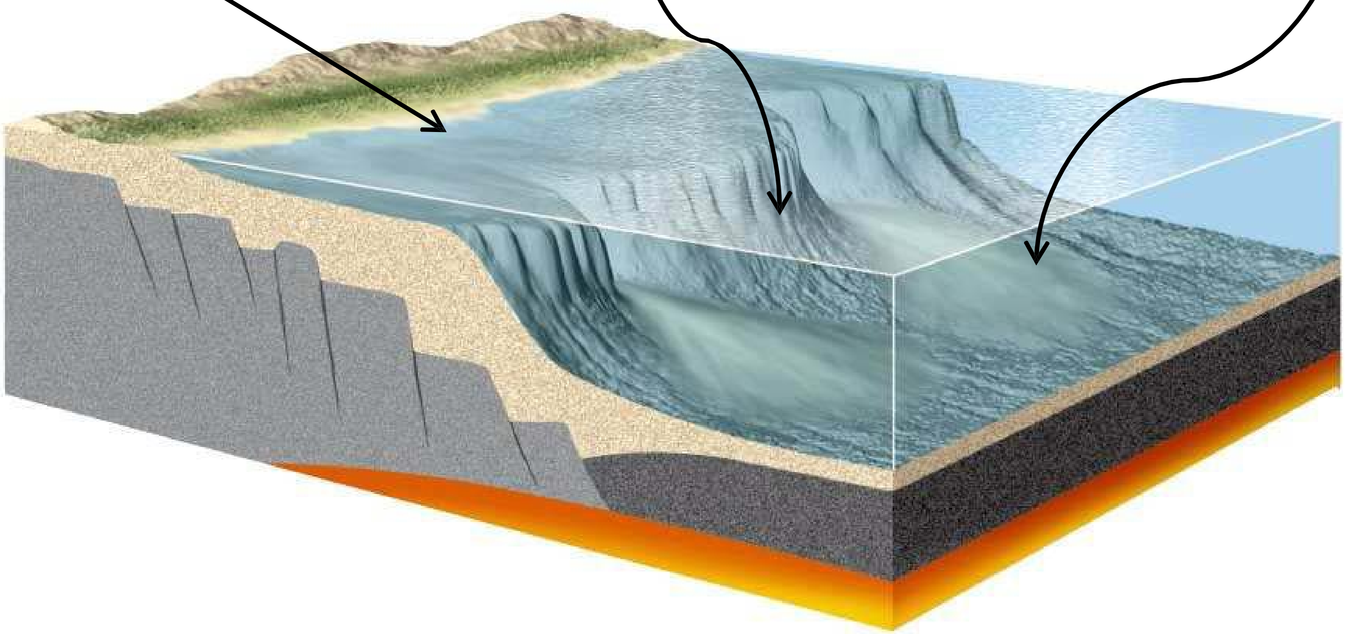


towards the deep ocean

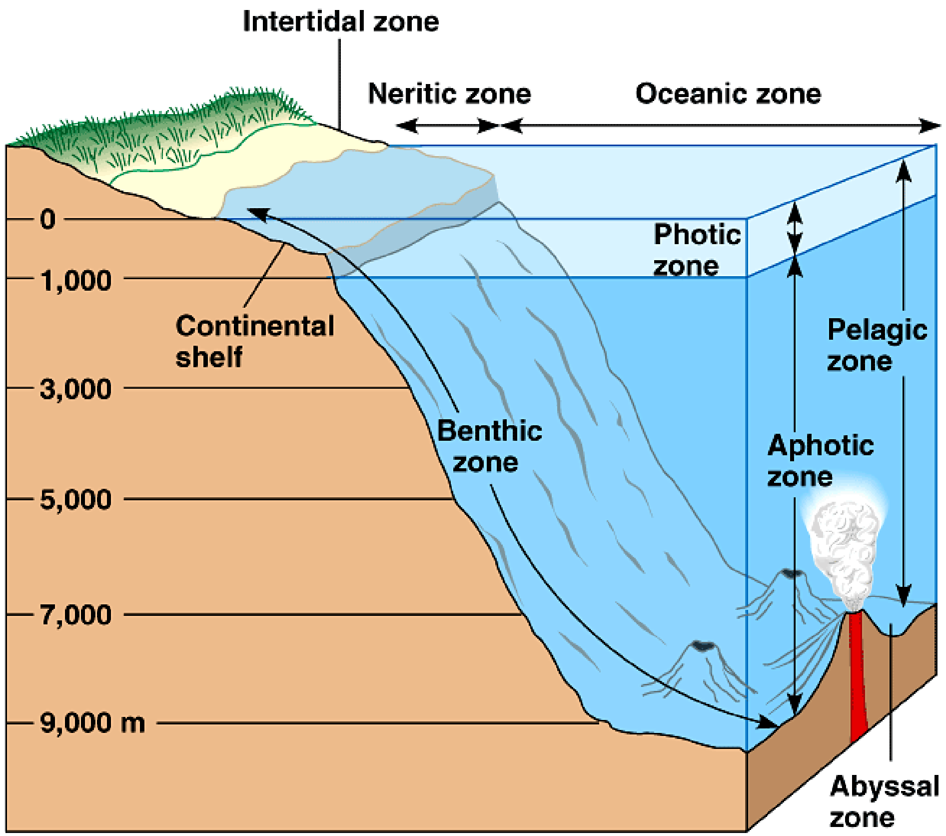
the continental shelf. Domain of currents, storms, glaciations ...

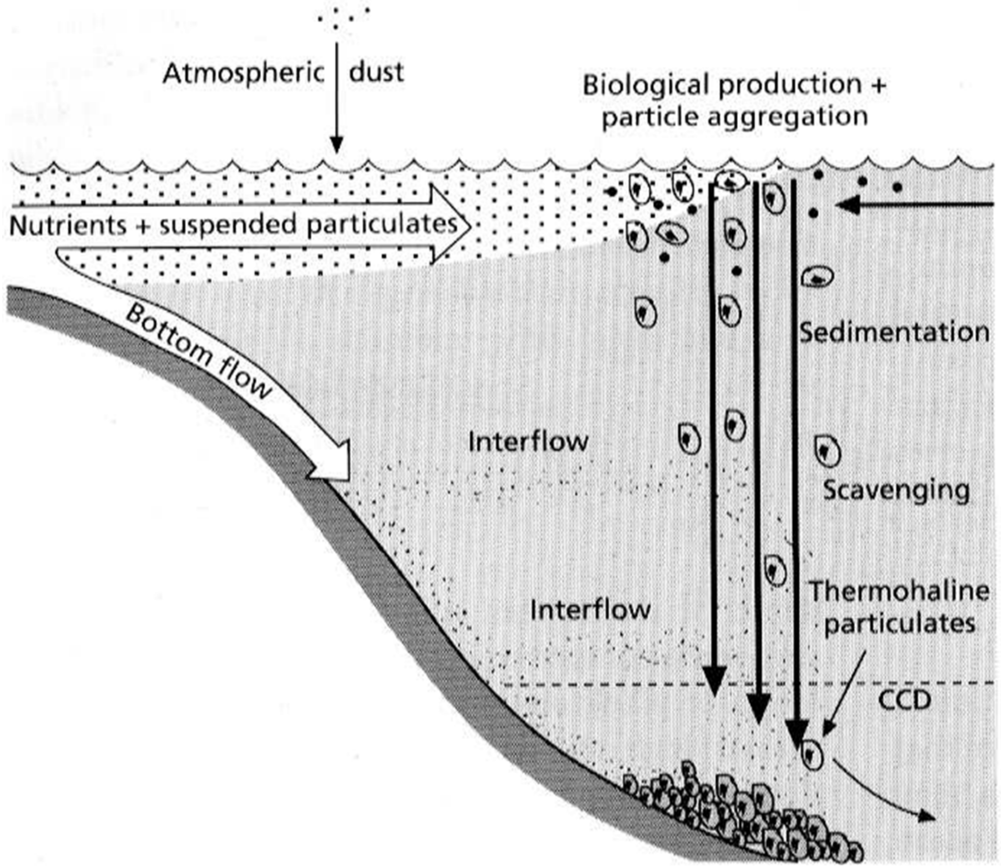
the continental slope, a steep domain separating two different worlds

the abyssal plain: gentle currents, no waves, little light ...



The two sedimentary system





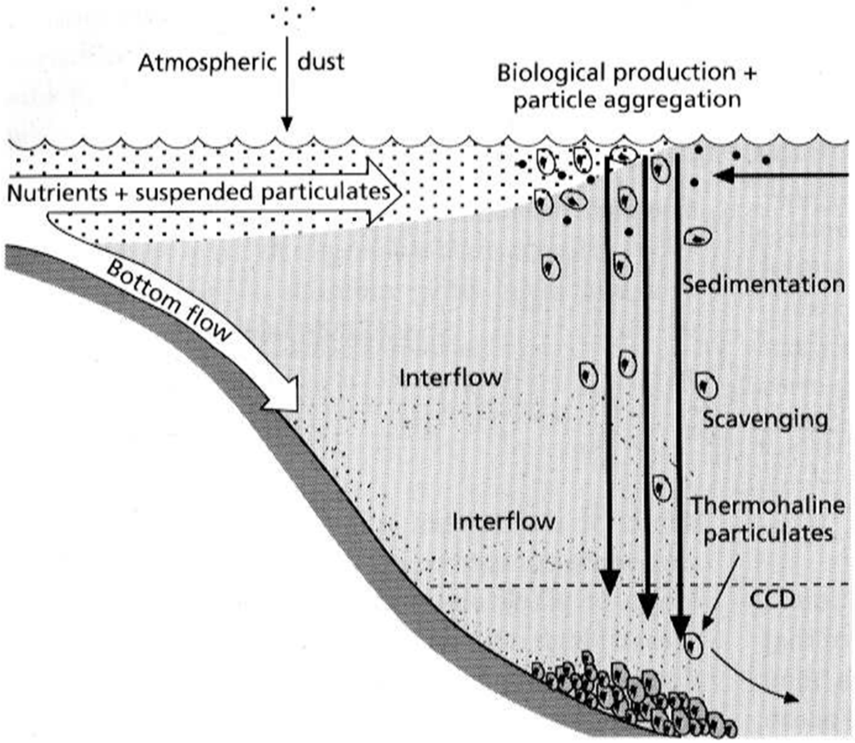
Sediments formed in the upper part of the water column and "raining" down to the ocean floor (background sedimentation – pelagic sediments)

Sediments initially parked on the continental shelf being destabilized and reaching then the basin floor (episodic sedimentation)

The “raining system”

Continent-derived sediments

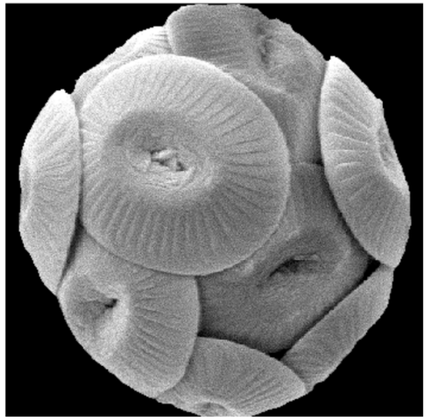
Winds bring (very fine) sediments above oceans which settle and very slowly but continuously reach the ocean floor without major changes



Sediments from the water column

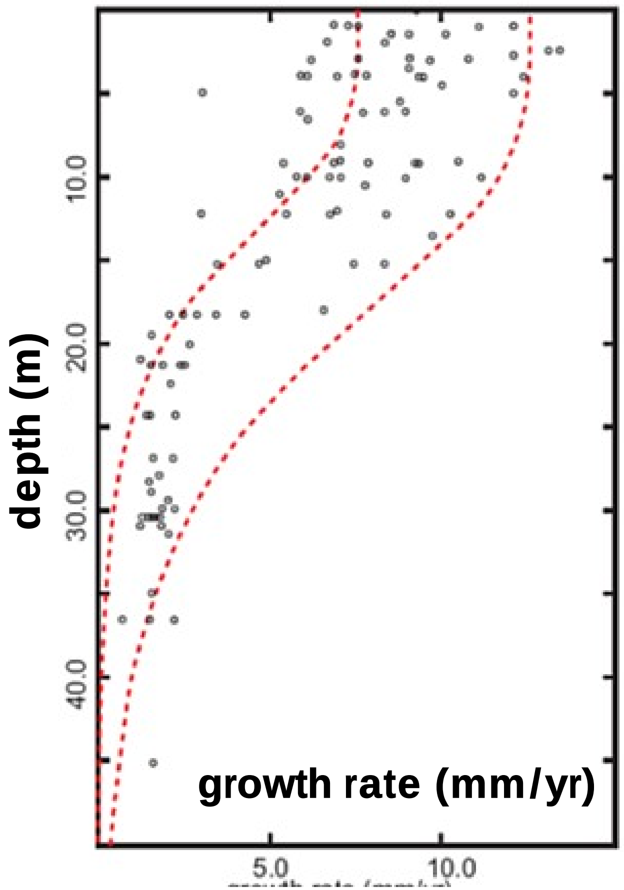
Organisms living in the (upper part) of the water column, die and try to reach the seafloor to be transformed in sediments

Who is living in the water column



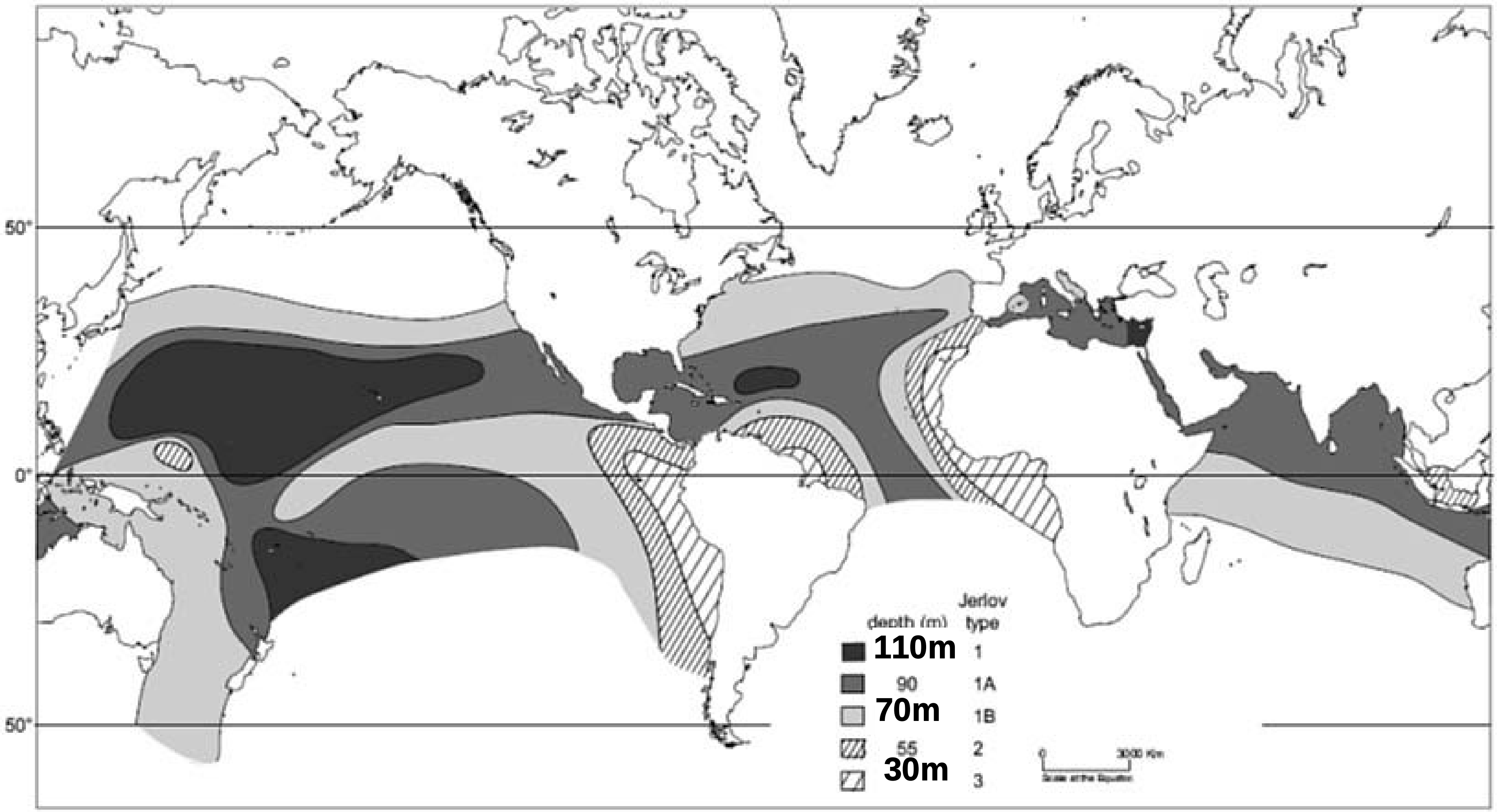
- Fishes ....
- Foraminifera...
- Crucial are the coccoliths (plants) and the foraminifera which form the base of the food chain

Plants and small animals thrive with light, food and warm temperatures



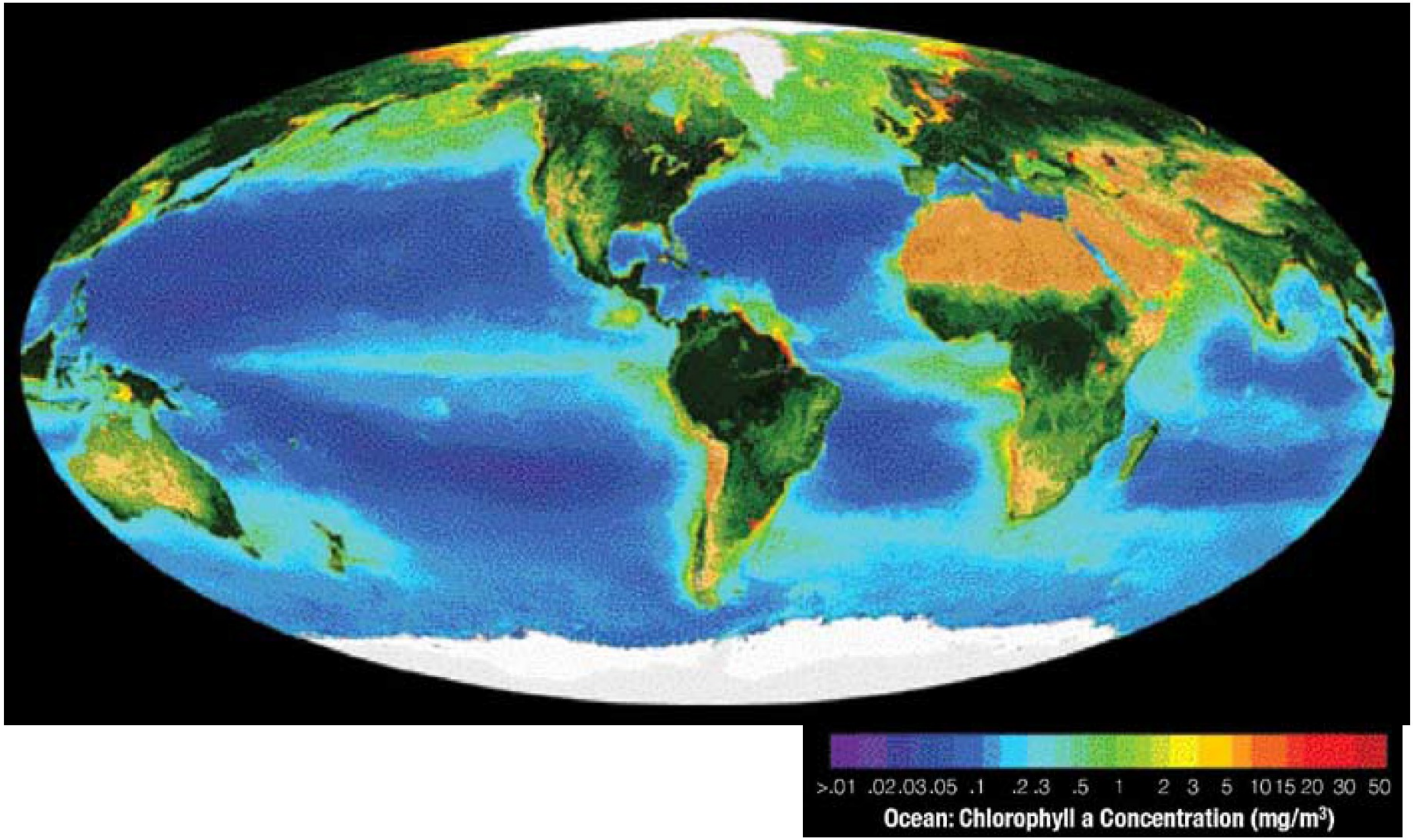
In the vertical dimension, production concentrated in the uppermost 10s of meters

These are mostly abundant in the upper layer of the seas (the photic zone)



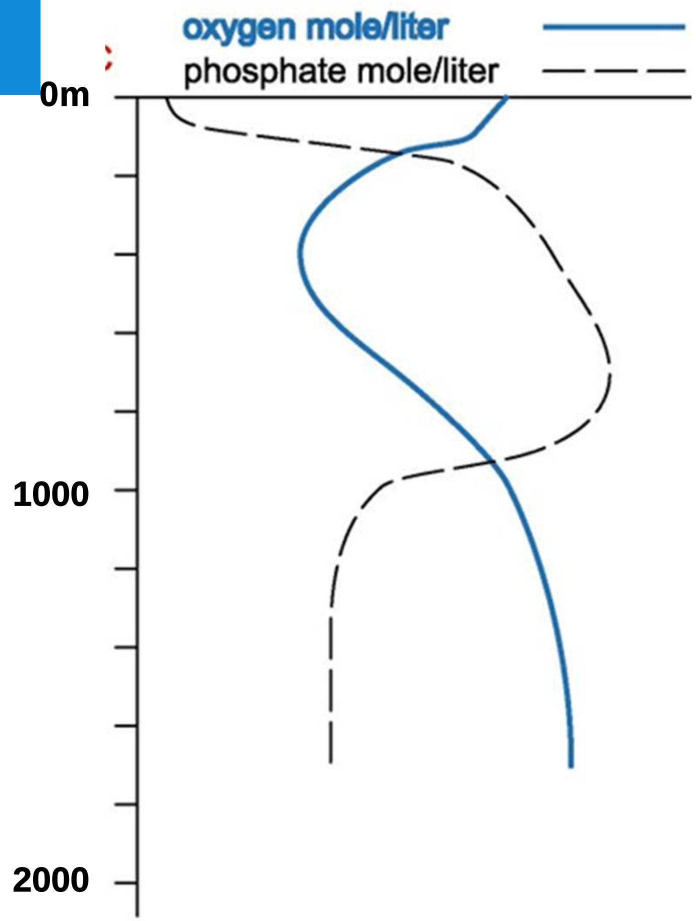
Thicknesses of the photic zone (zone of light and oxygen)

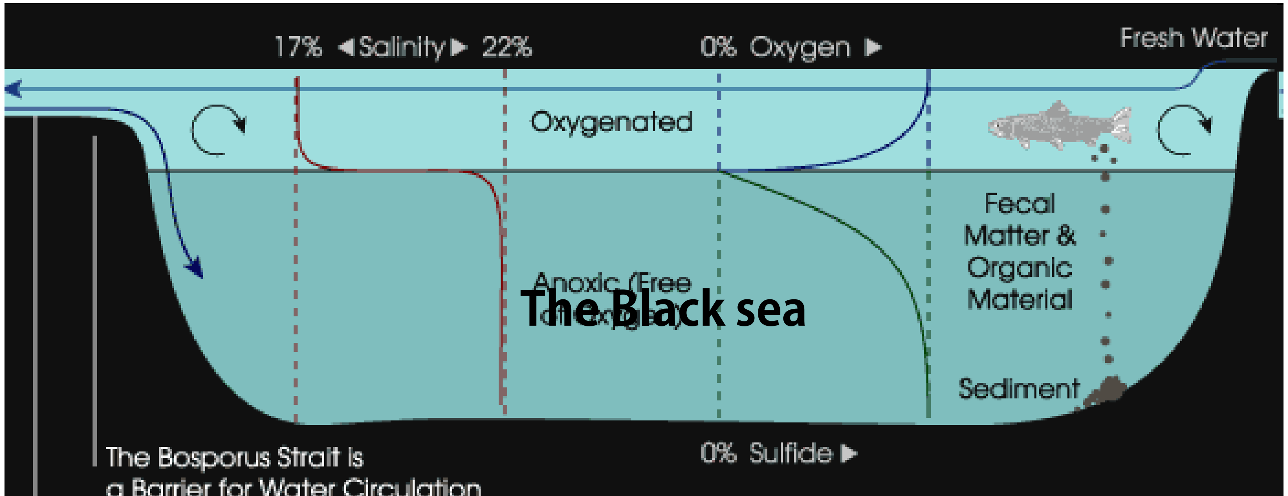
The distribution of plankton biomass in the ocean



After death

Once the organisms die, they will gradually sink.
Organic parts will be consumed by oxidation, thereby consuming oxygen and creating an anoxic zone



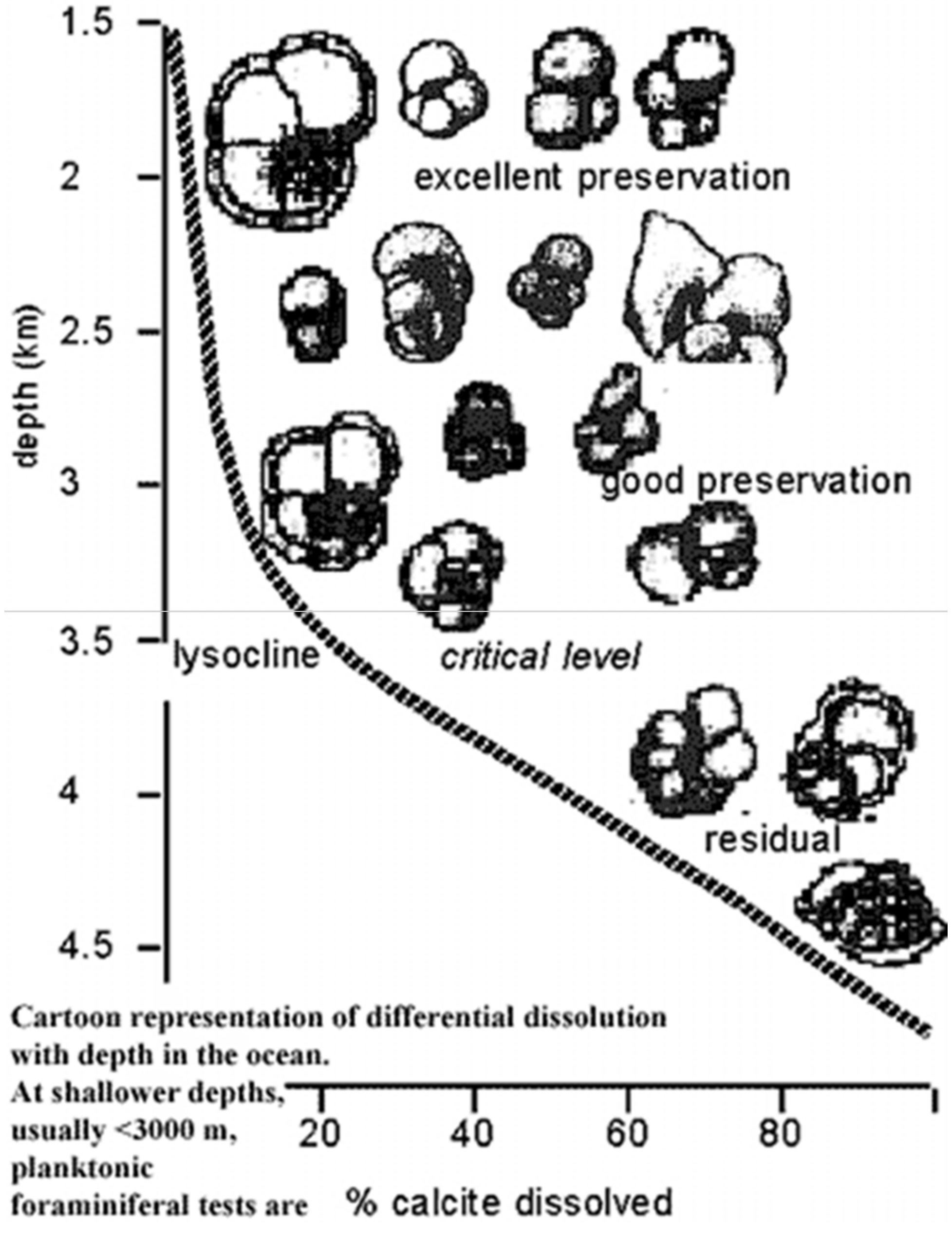


oxygen distribution in the Black Sea

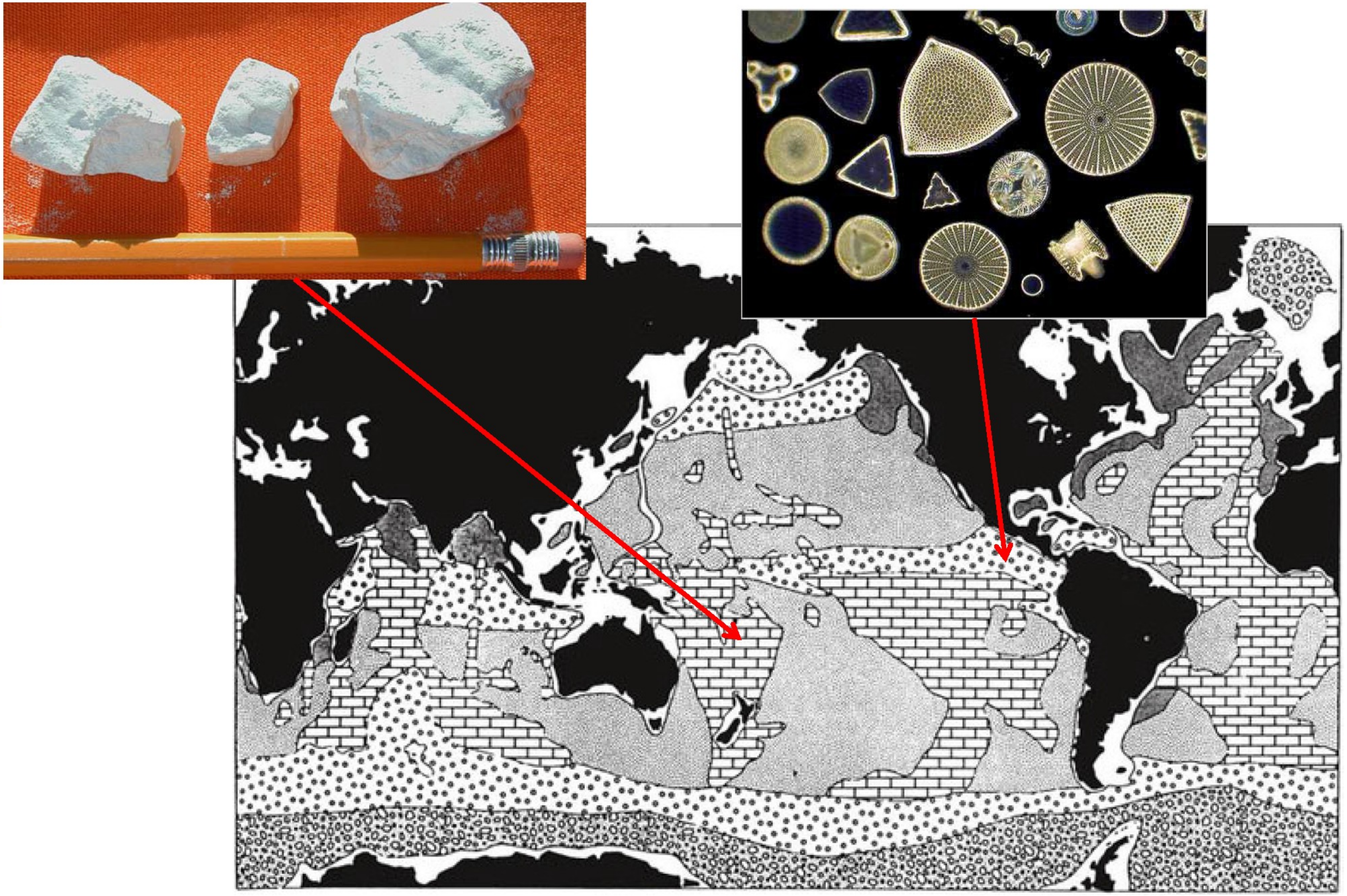
Sediments then deposited in the anoxic zones have a high organic content (excellent source rocks)

The sinking **carbonate particles** enter increasingly colder waters and start being dissolved because $CaCO_3$ solubility increases with decreasing T.

Ocean floors deeper than the CCD will have no carbonate sediments and will have only clays which accumulate at very low rates (10^{-3}mm/yr)



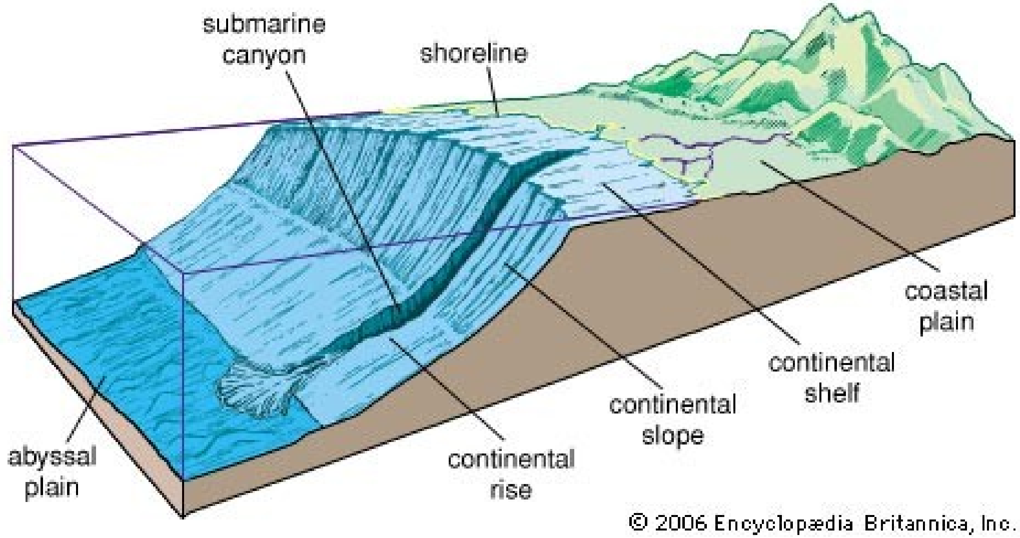
Cartoon representation of differential dissolution with depth in the ocean. At shallower depths, usually <3000 m, planktonic foraminiferal tests are


Calcareous sedfments
Deep-sea clay
Glacial sedfments
Siliceous sediments
Terrigenous sediments
Continental-margin sediments

Once in a while, the quite world of the deep sea is perturbed by catastrophic events

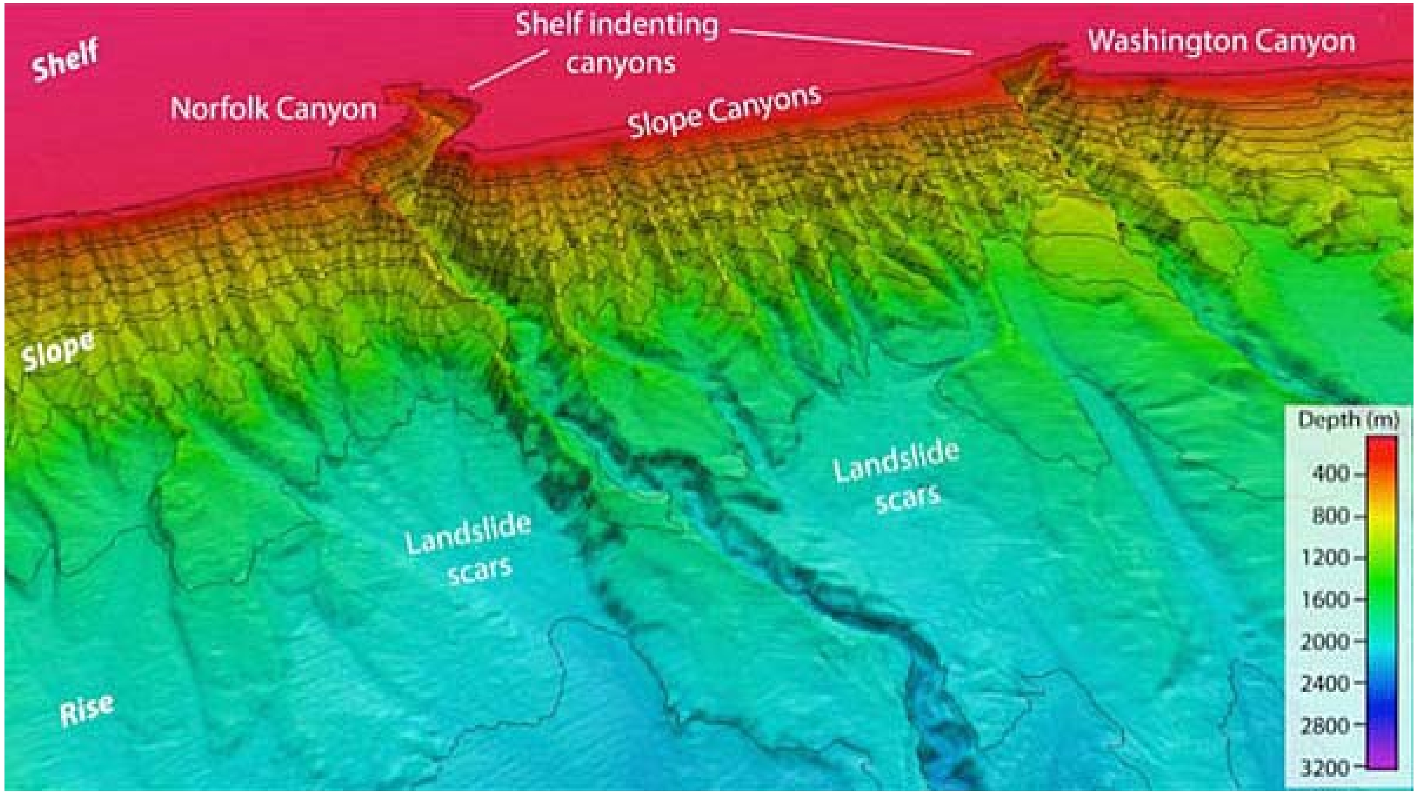
From the continental shelf to the deep sea:

The continental slope

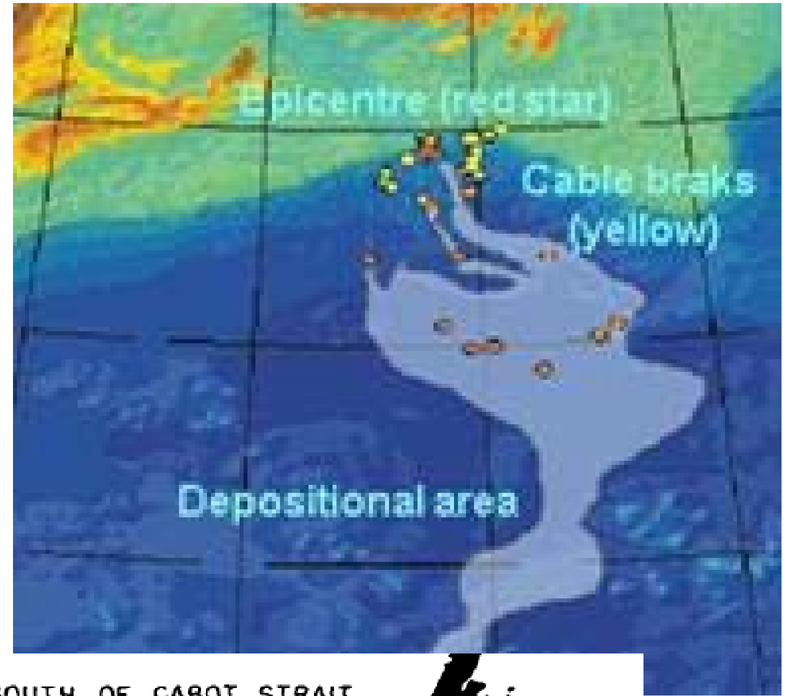


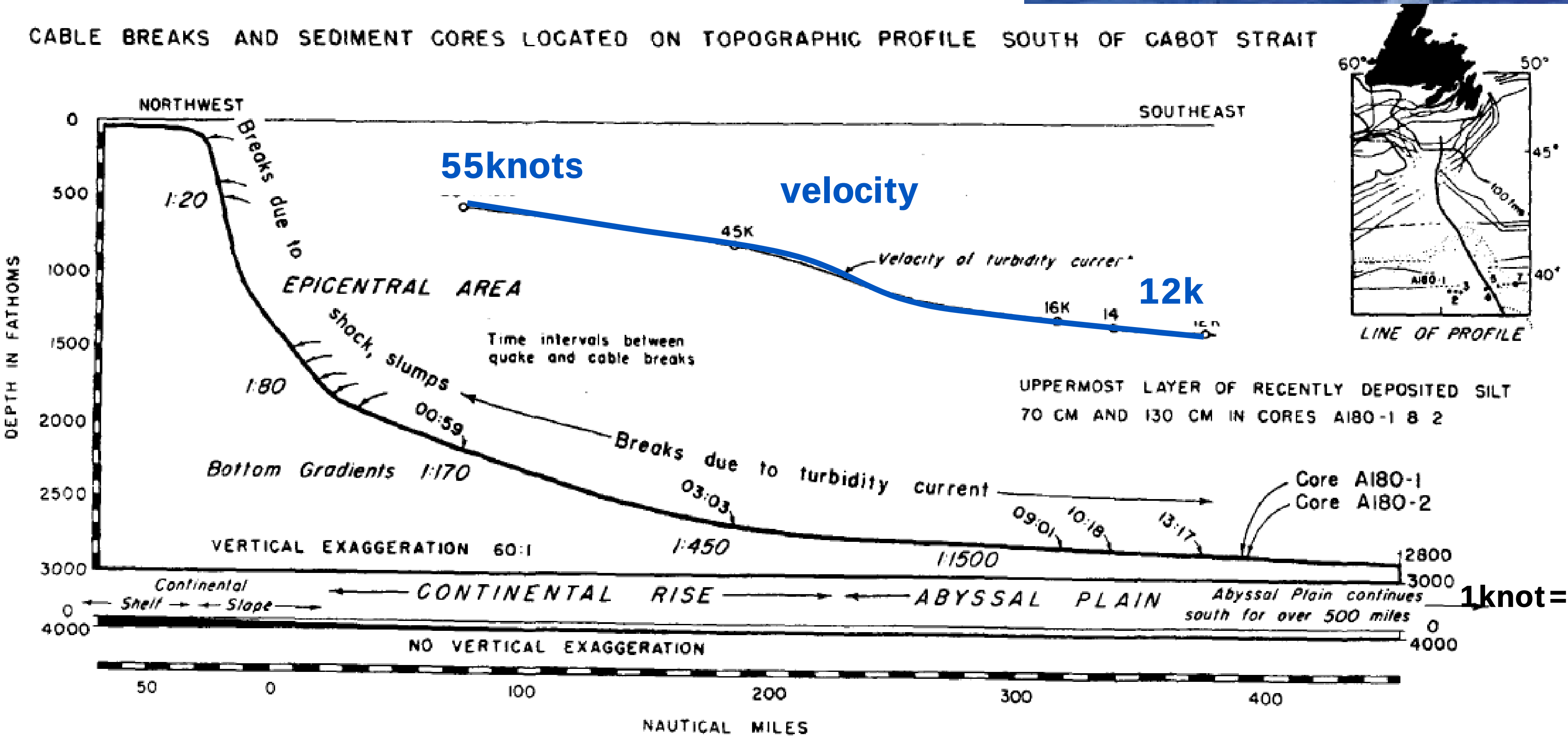
Sediment from the shelf runs down the slope following submarine canyons

These submarine currents are a mixture of water and sediments, have densities higher than water and are called turbidites

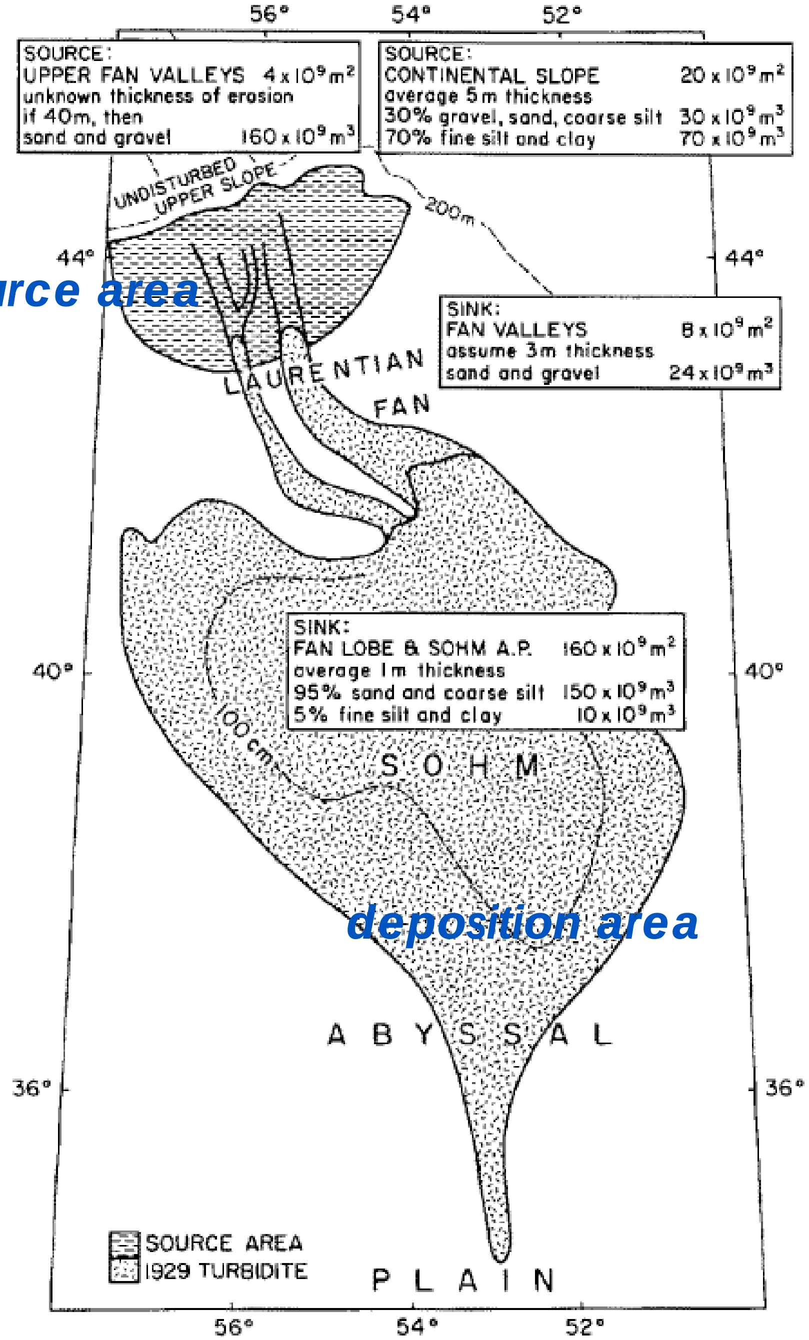


The first well-documented episode of turbidite sedimentation: the 1929 Grand Bank earthquake

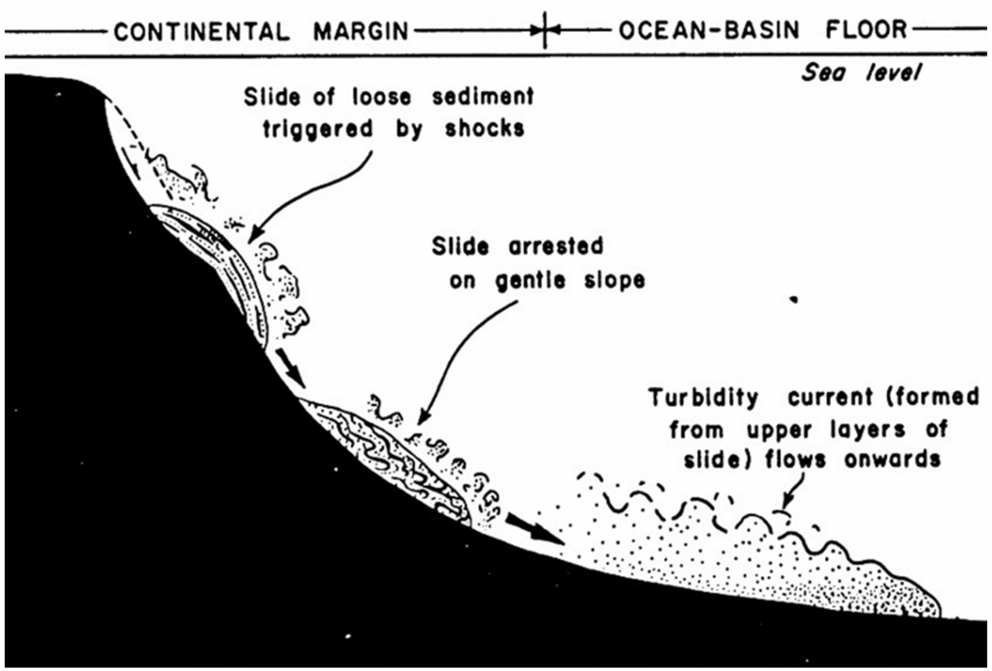




1knot=1.85km/h



It brought >185km³ of sediments from offshore Newfoundland to the abyssal plain travelling at 70km/hr



Huge submarine fans are created

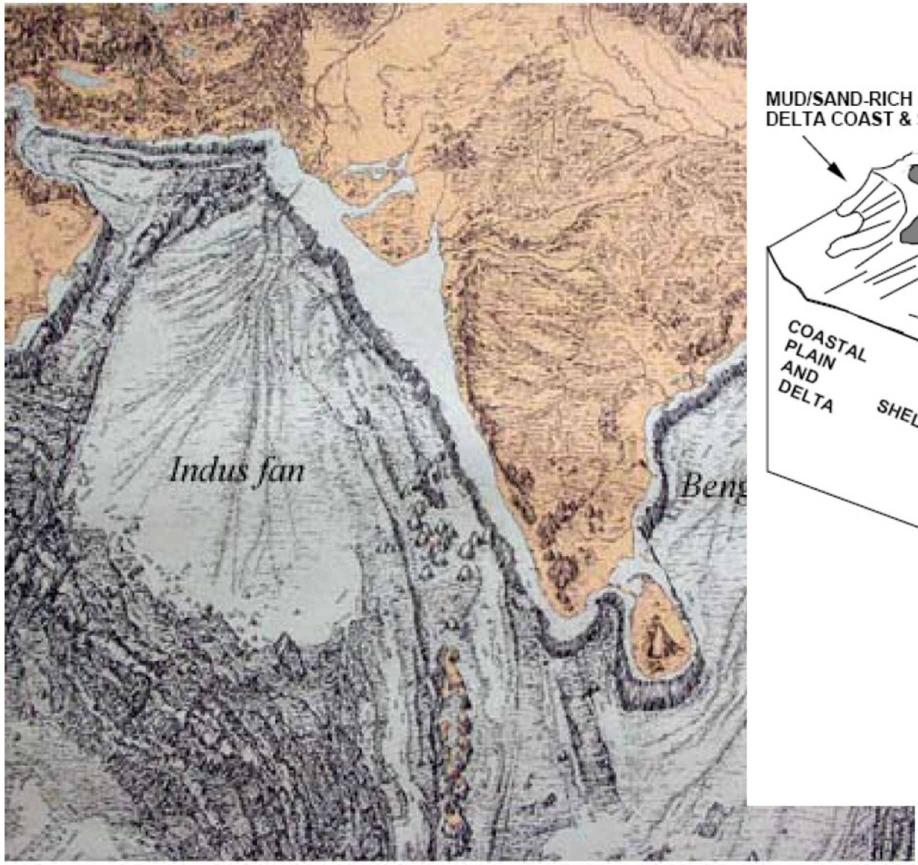
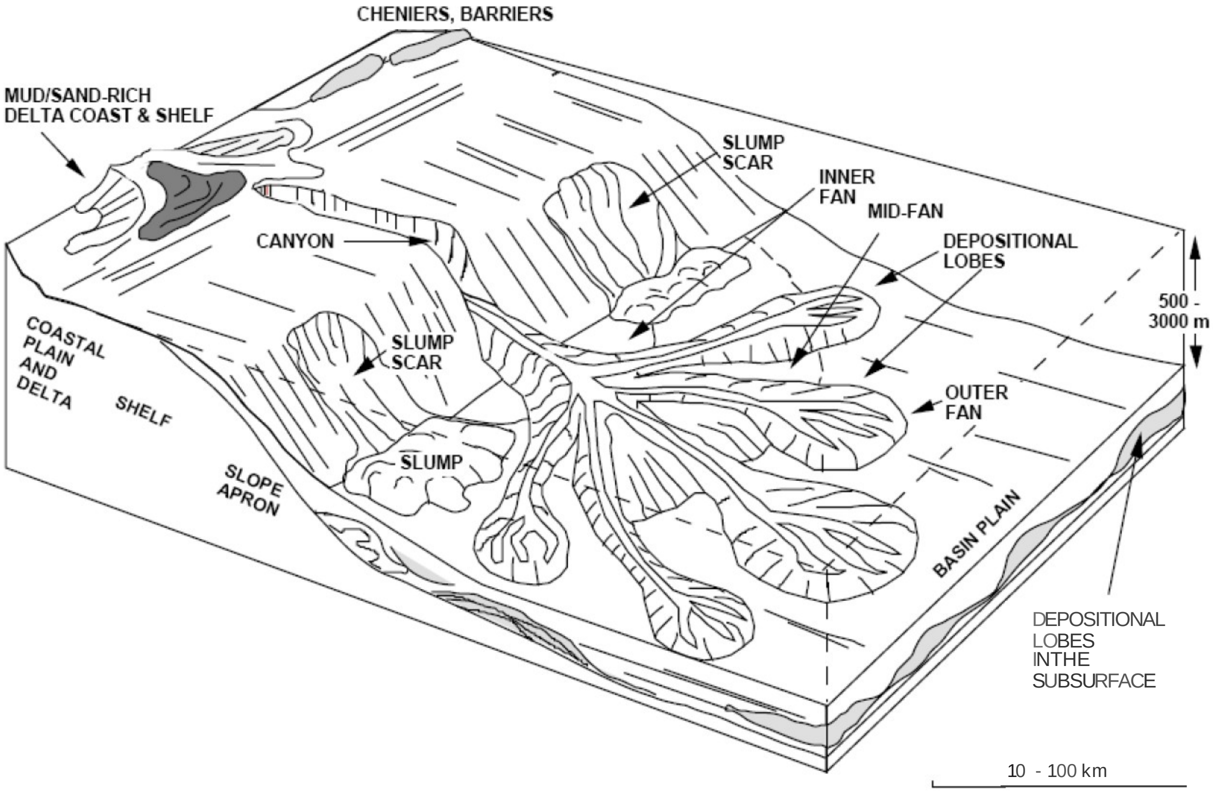
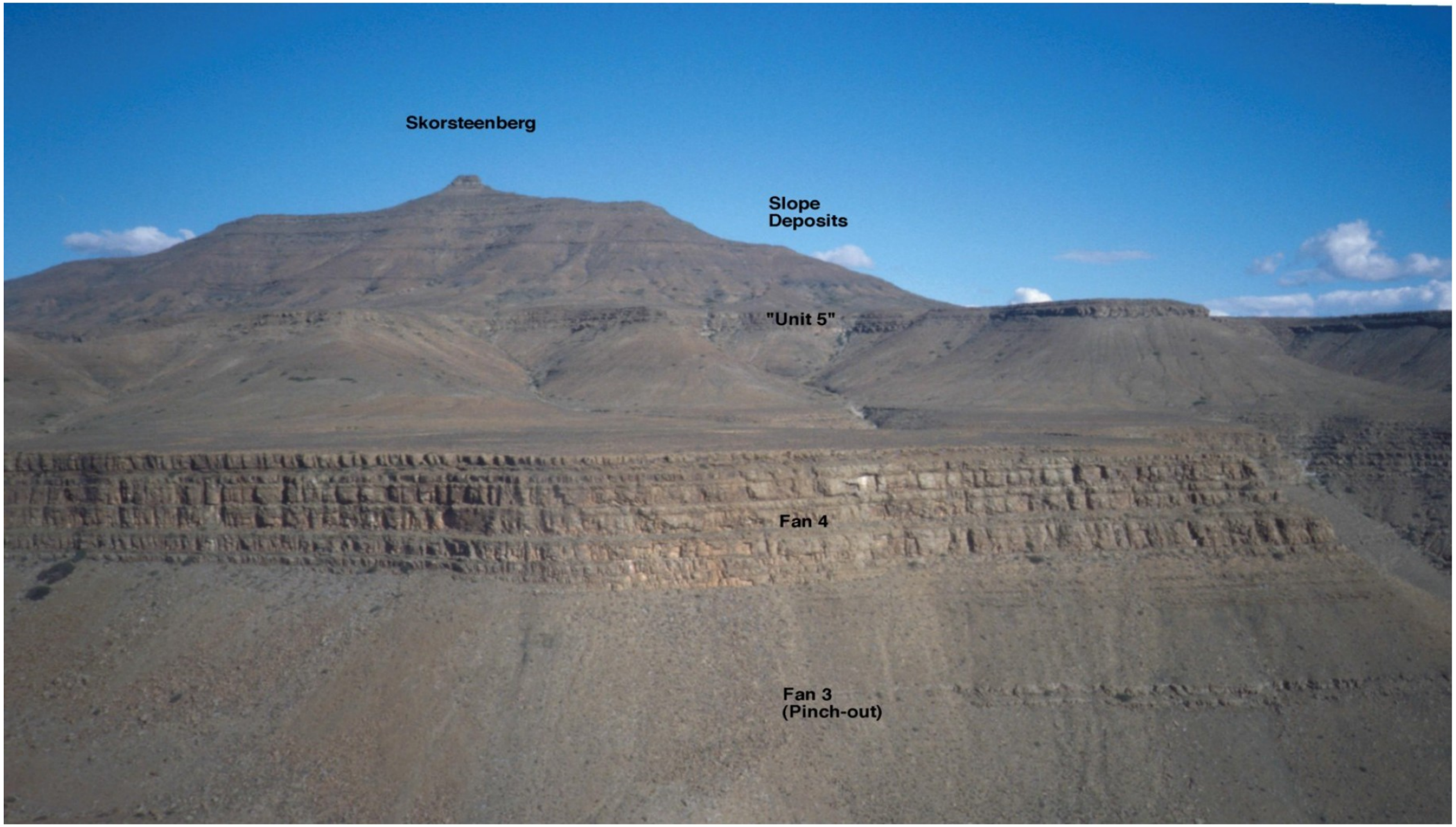


Fig. J0. Bengal fa n and lndusfan




Skorsteenberg
Slope
Deposits
"Unit 5"
Fan 4
Fan 3
(Pinch-out)

Millions of turbidites can be generated in geological time and form huge sedimentary successions

Carbonate sediments

A world very different from that of silicoclastic rocks

In carbonates, the production, distribution and deposition of carbonates is crucially dependent on life

Carbonate sediments are born not made

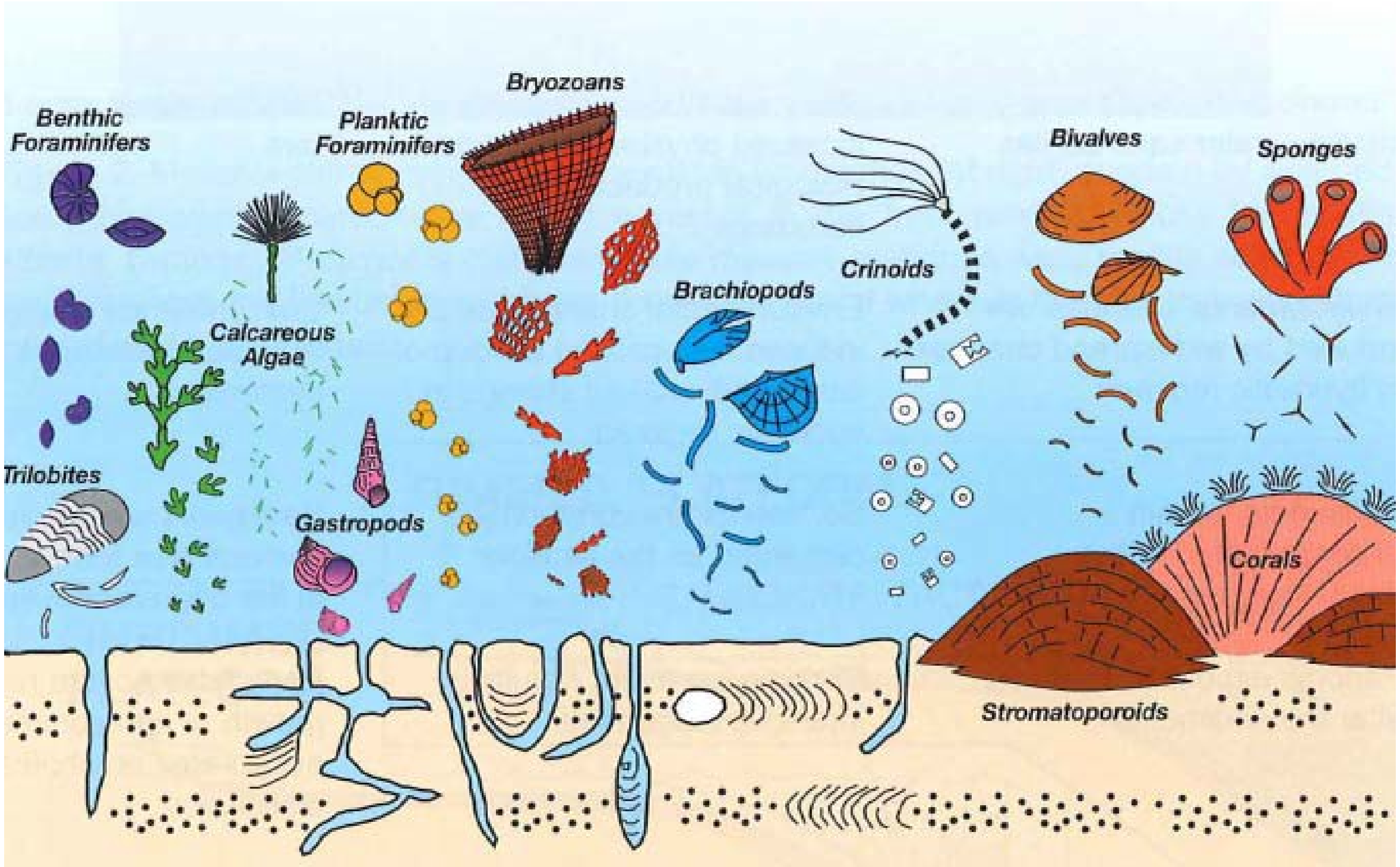
The carbonate factory (chemistry)

Extract Ca from the sea water (typically supersaturated) to produce carbonates with biotic and abiotic processes

$$Ca^{2+} + 2HCO_3^- \leftrightharpoons CO_2 + H_2O + CaCO_3$$

Organisms can produce calcite or dolomite ($CaMg(CO_3)_2$)

the (tropical) carbonate factory



Some consequences:

- **sediment composition fundamental defines the depositional environment**
- **grain-size variations need not to signal changes in hydraulic regime**
- **.....**

factory driven by phototrophic (need light) organisms such as microbes, algae, coral etc

algae

echinoderms

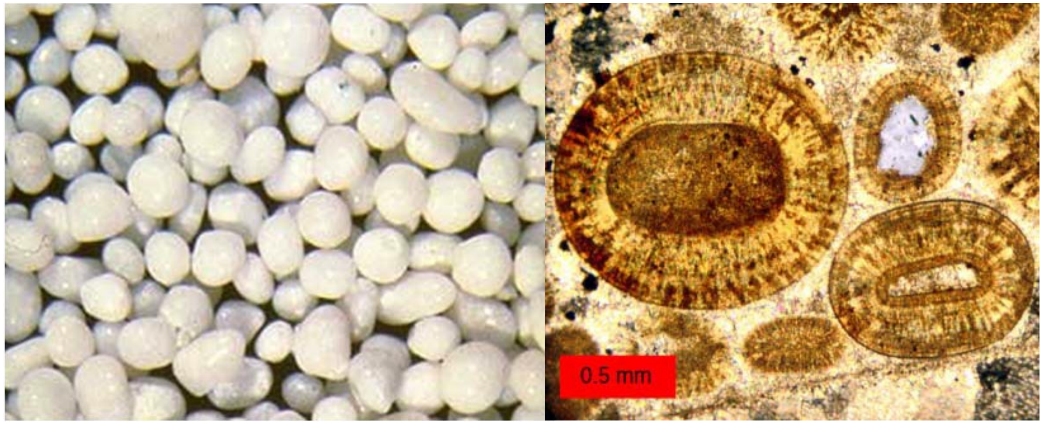
bryozoans

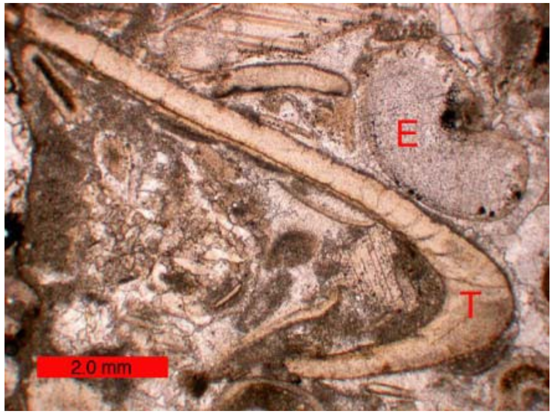
sponges

These organisms live and die in the water column and/or at the sea floor and can produce huge amounts of sediments

They produce four types of particles (soft parts degrade)

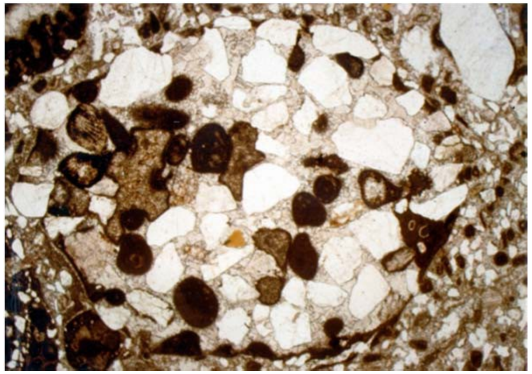
precipitates: grains formed by direct or indirect chemical precipitation (ooids, some muds)





biofragments. Shells, tests, spicules etc of all inverterbrates, microbes, algae etc

Peloids: grains of micro-crystalline carbonates



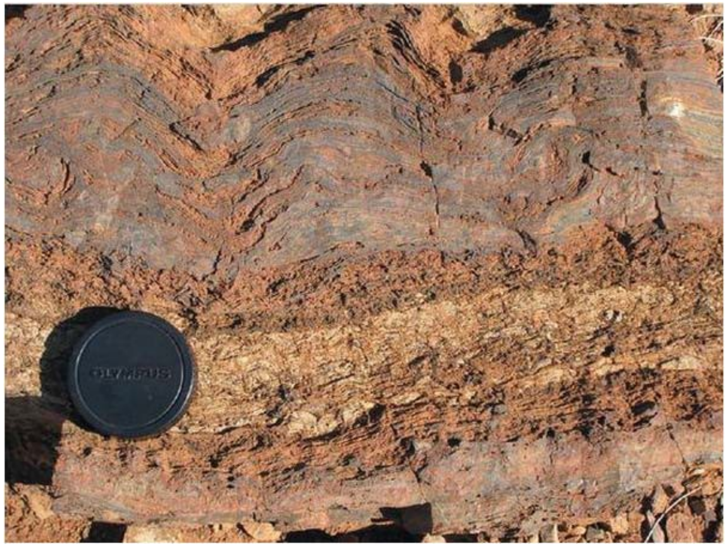
Intraclasts: fragments of consolidated and lithified sediment

Some of the organisms are excellent builders and produce constructions

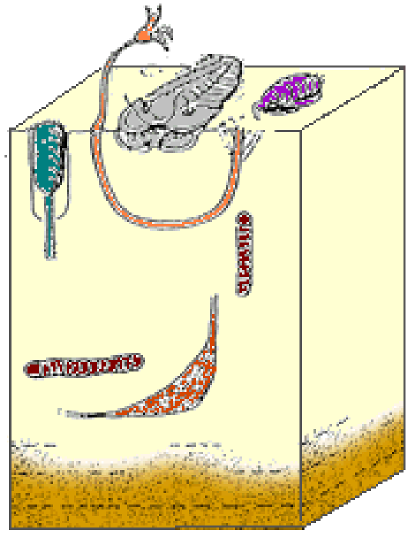
Extremely strong and resistant

Organisms are not only producers

Algae are very efficient in trapping, binding and stabilizing fine grained sediments (algal mats)

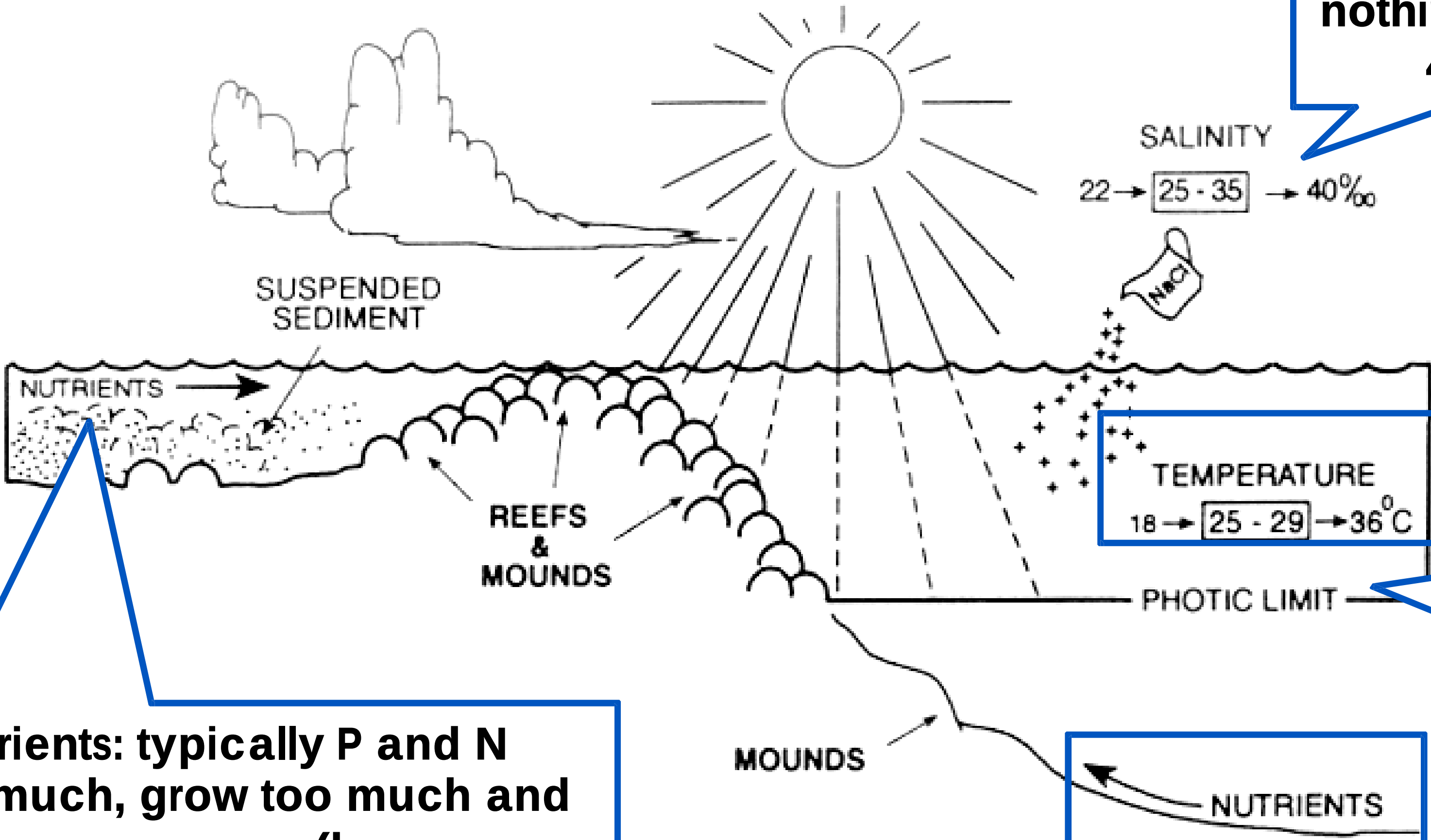


Burrow through sediment, perforate shells, eat it



Controlling factors in the tropical carbonate factory

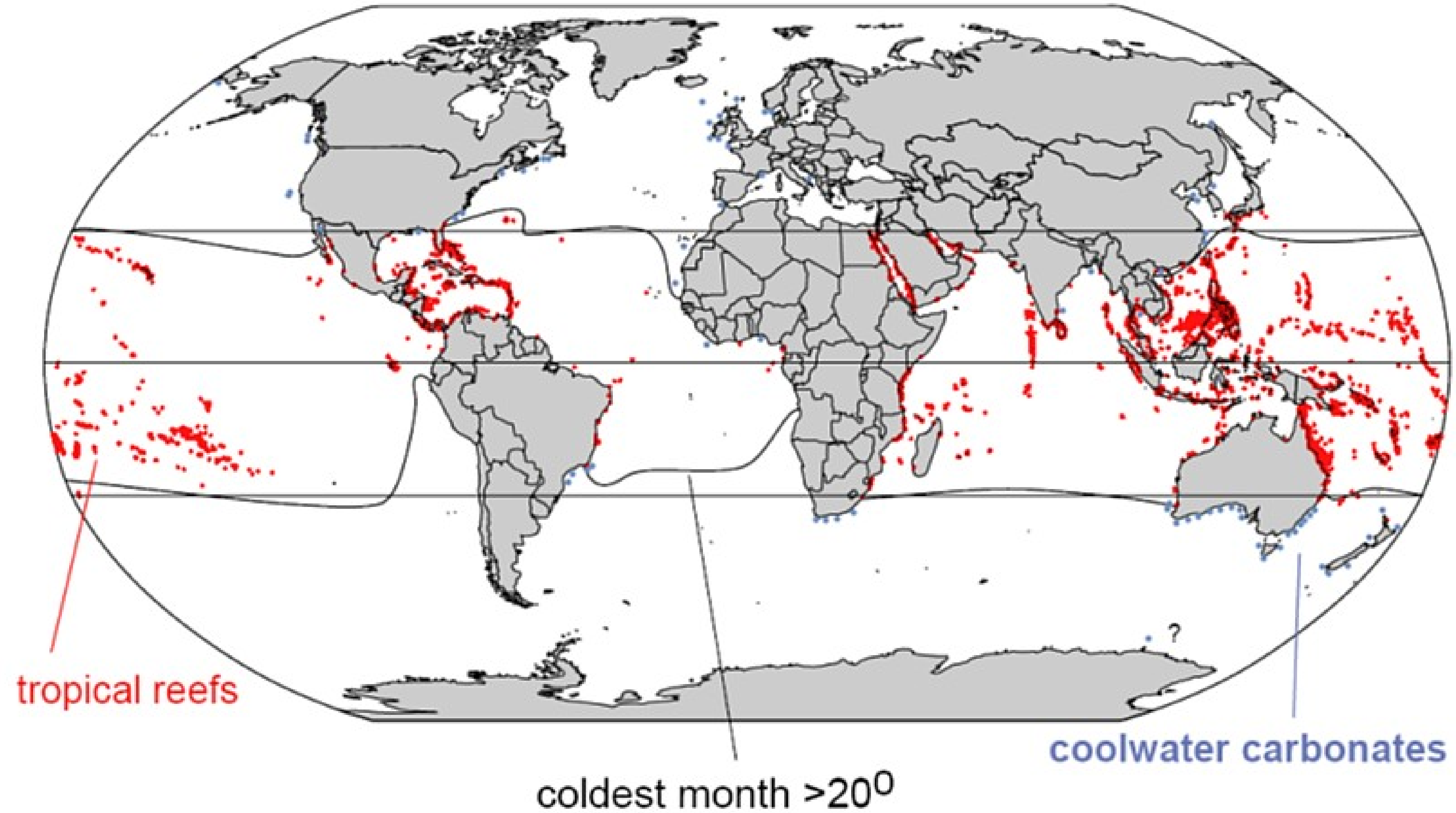
salinity: nothing above 40 ‰



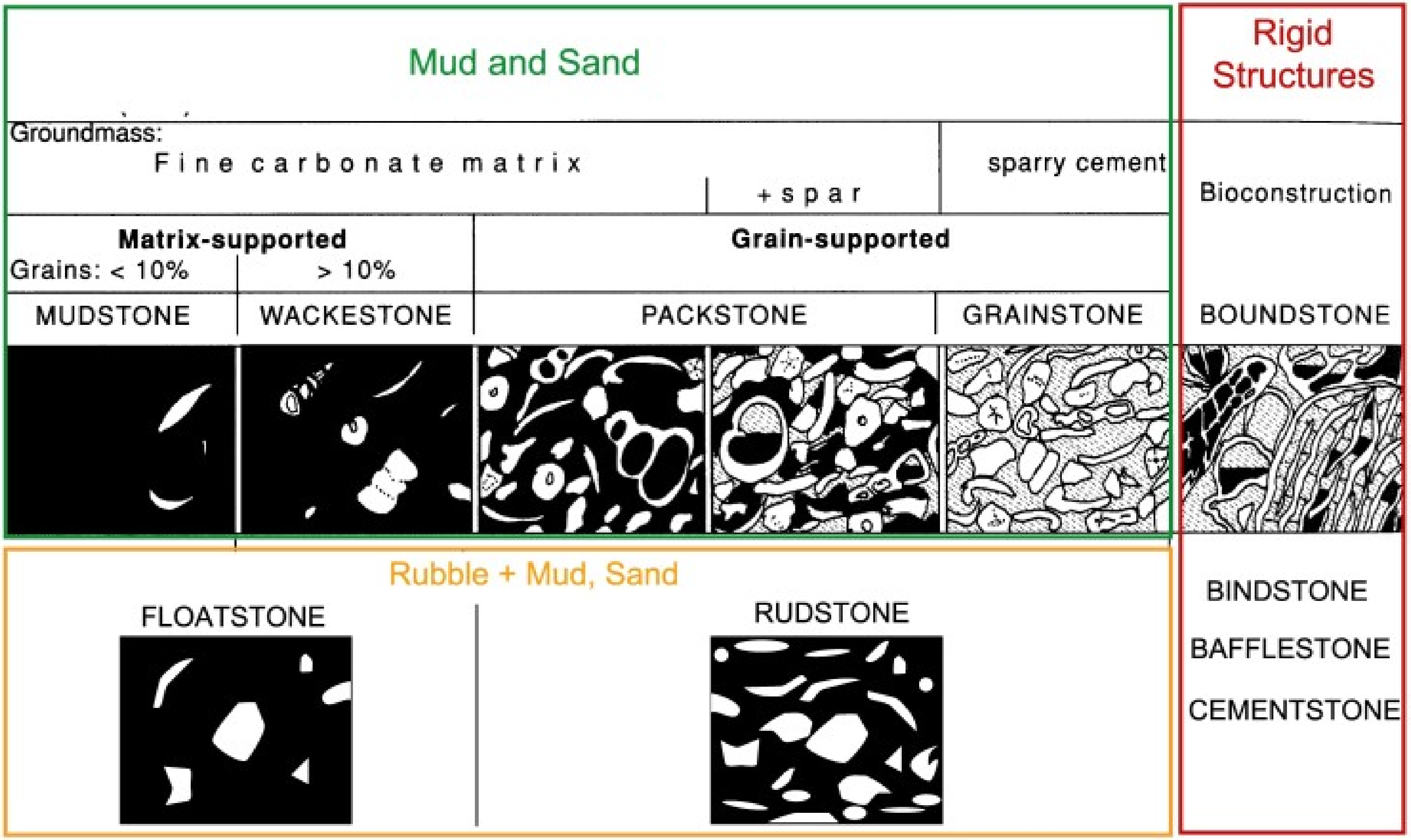
light: 10s of m in clear waters

nutrients: typically P and N
If too much, grow too much and remove oxygen (human influence)

Carbonate systems: this is where they develop



The products: principles of carbonate rock classification

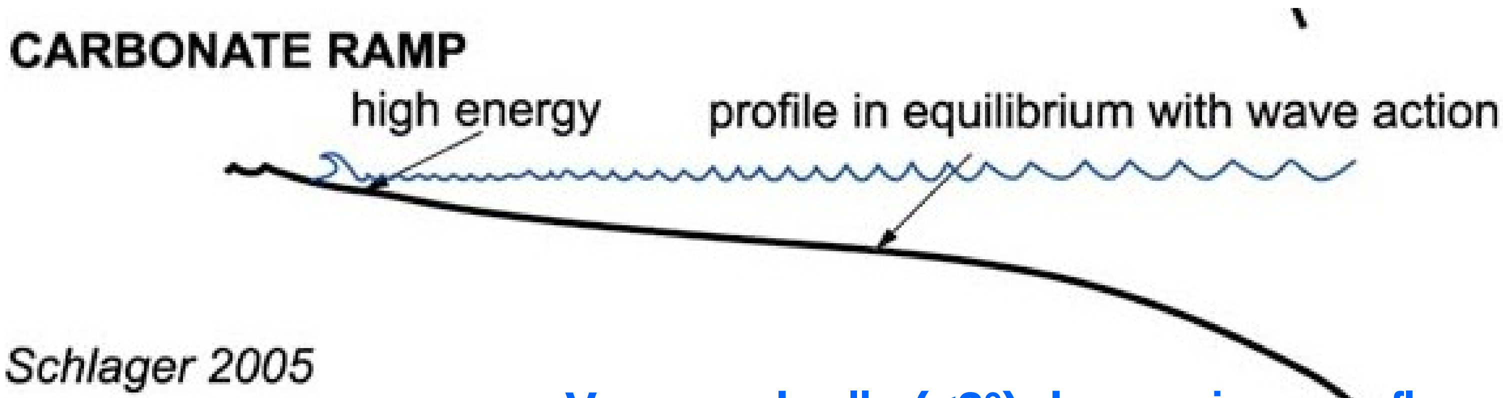


Based on Dunham, 1962; Embry & Klovan, 1971

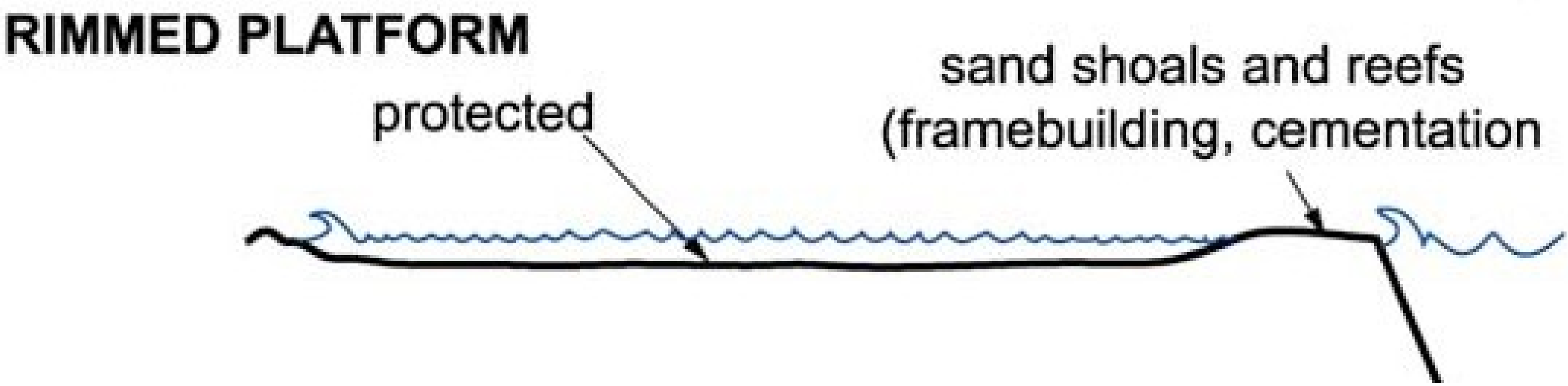
Two steps:

1. **Determine the proportion of grains (related to the hydrodynamic conditions)**
2. **Determine the nature of the grains (related to depositional environment, ecology)**

The architecture of carbonate bodies



Very gradually (<2°) deepening sea floor

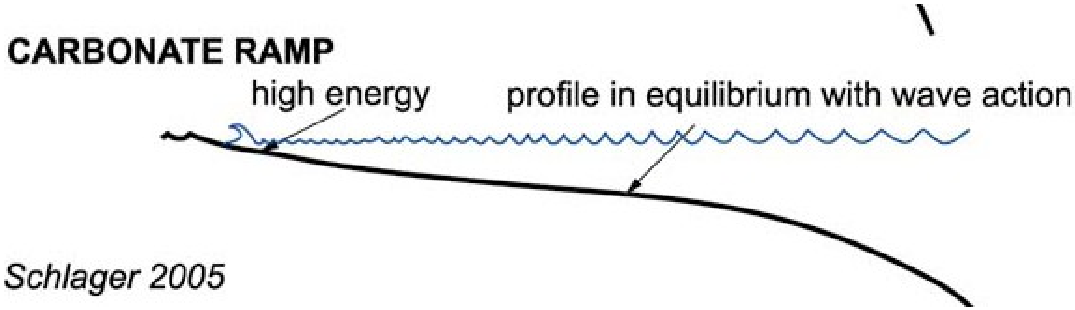


A strong margin separates a quiet domain from a much more energetic one

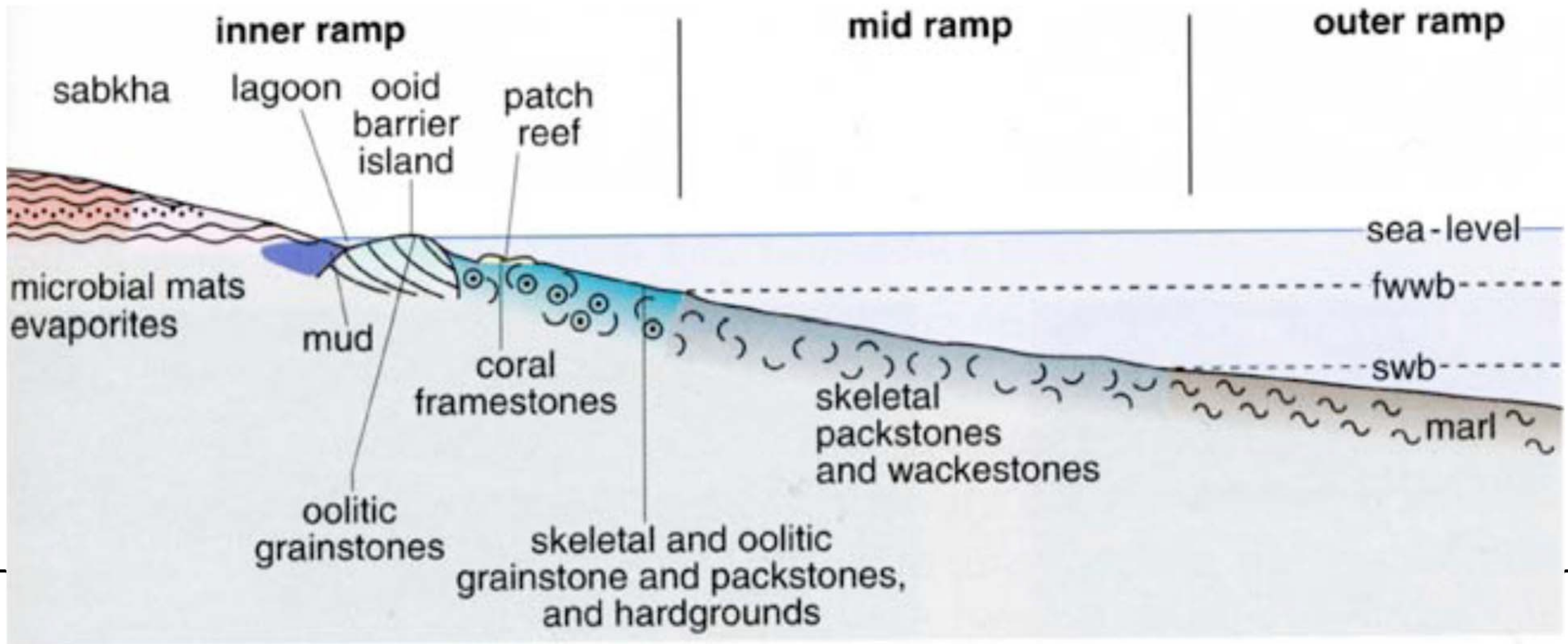
Carbonate ramps

Sediments not protected by a rim from wave activity

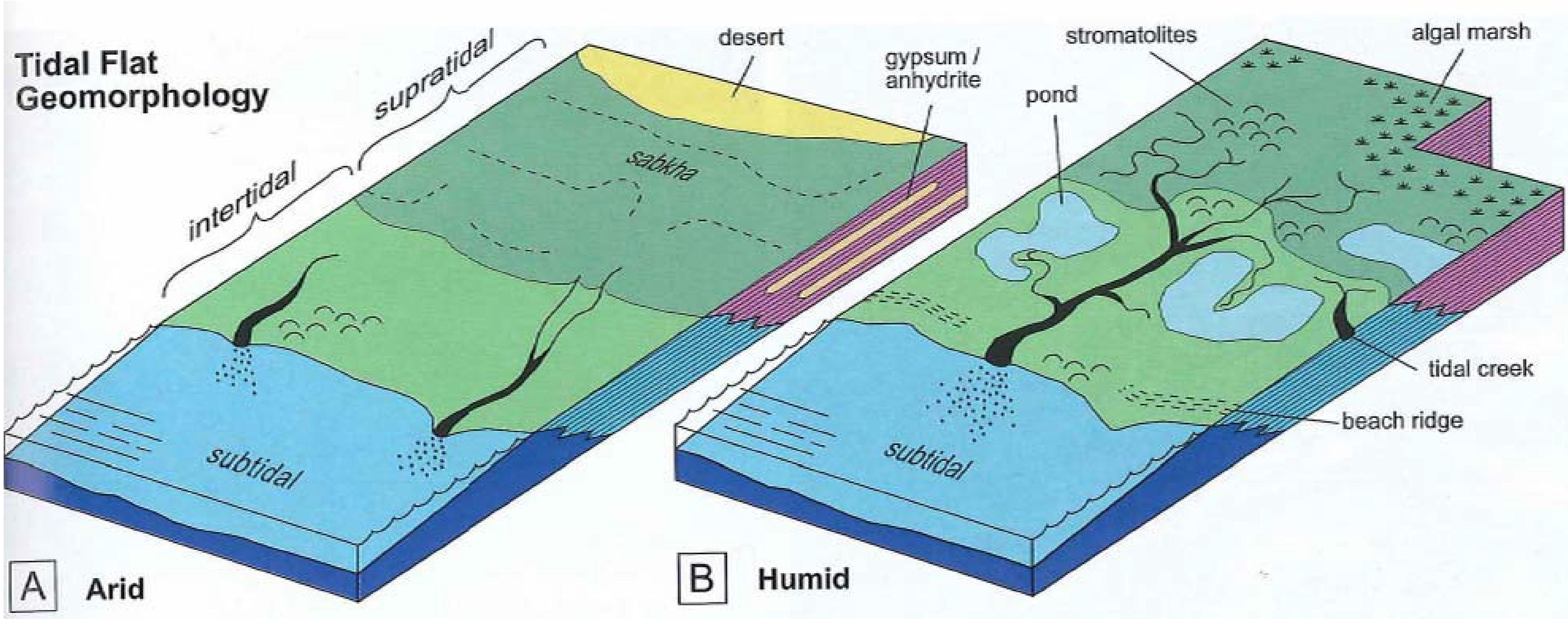
System characterized by gentle slope (typically <2º). Can be 10s km wide



- **Vary gradual facies changes**
- **high energy carbonate sands in the wave-dominated area inner shelf**
- **muddy sands in the deeper shelf with periodical storm activity**
- **only localized patch reefs**

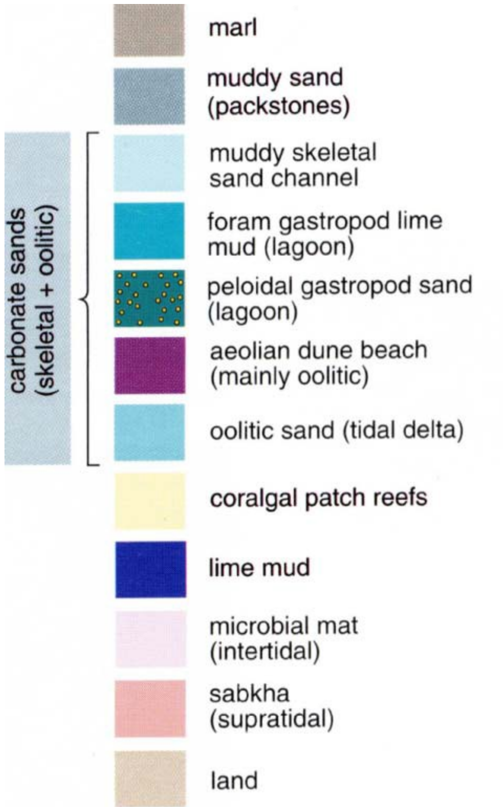


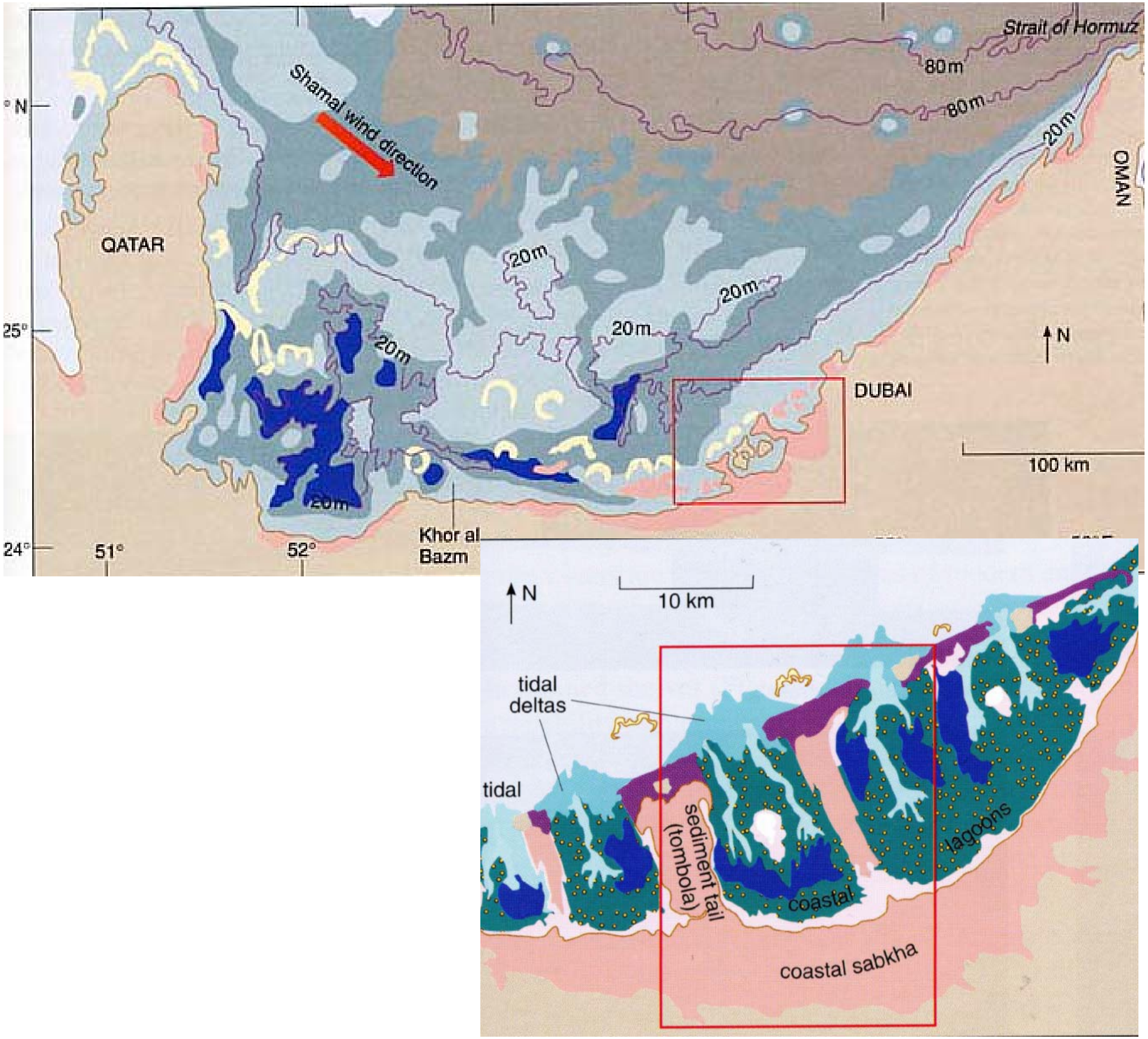
The different zones shift laterally with tides (at different wavelengths)



Because of very gentle slope, lateral movements of coastline can be of 10s km

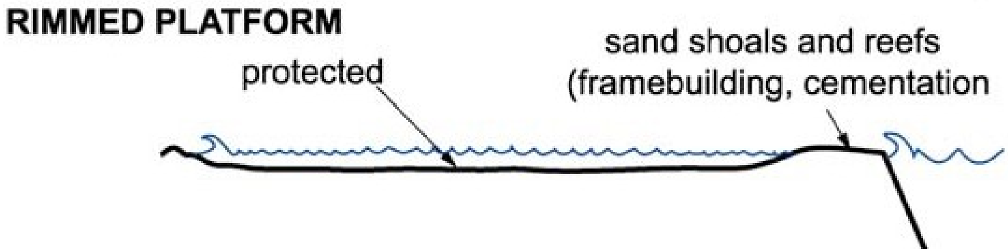
The example of the Persian Gulf

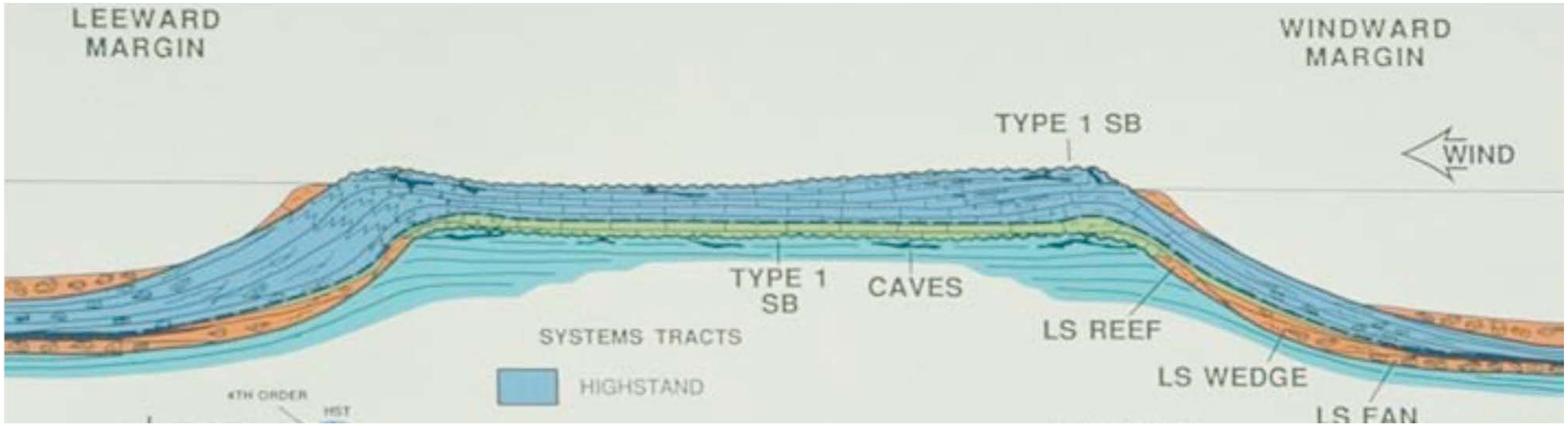




Rimmed platforms: (atoll)

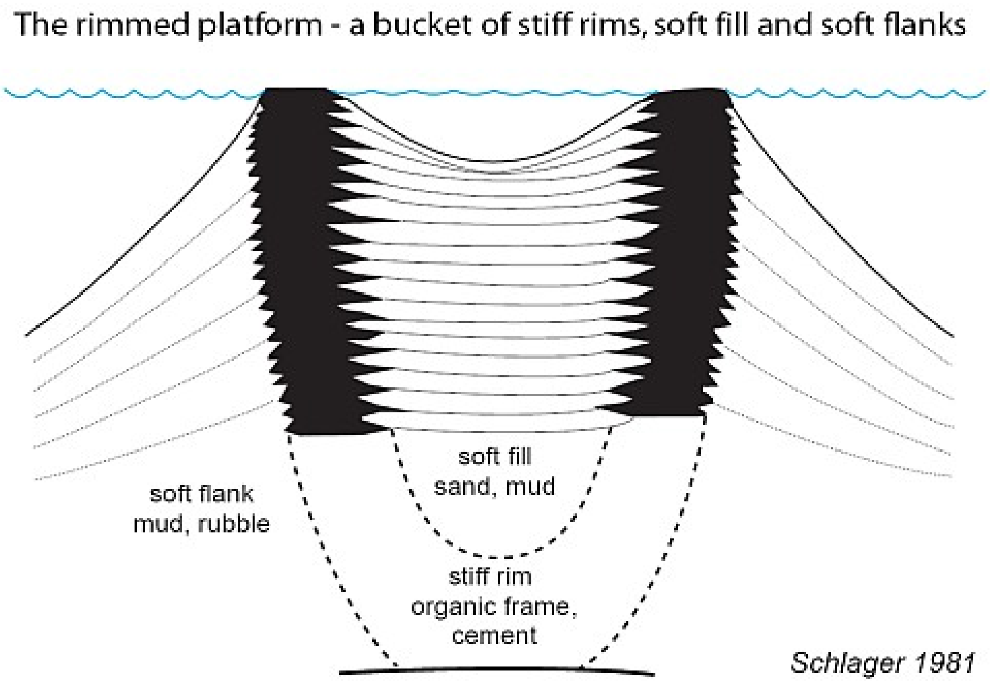
- flat tops
- barrier reefs
- can be isolated or not





A few “rules”

1. Once a production site has risen above sea floor, this will become a preferred site (positive feed-backs = the rich-get-richer principle).
2. Frame builders start constructing strong margins, thrive because of access to clean water and build further protecting the interior (bucket principle)

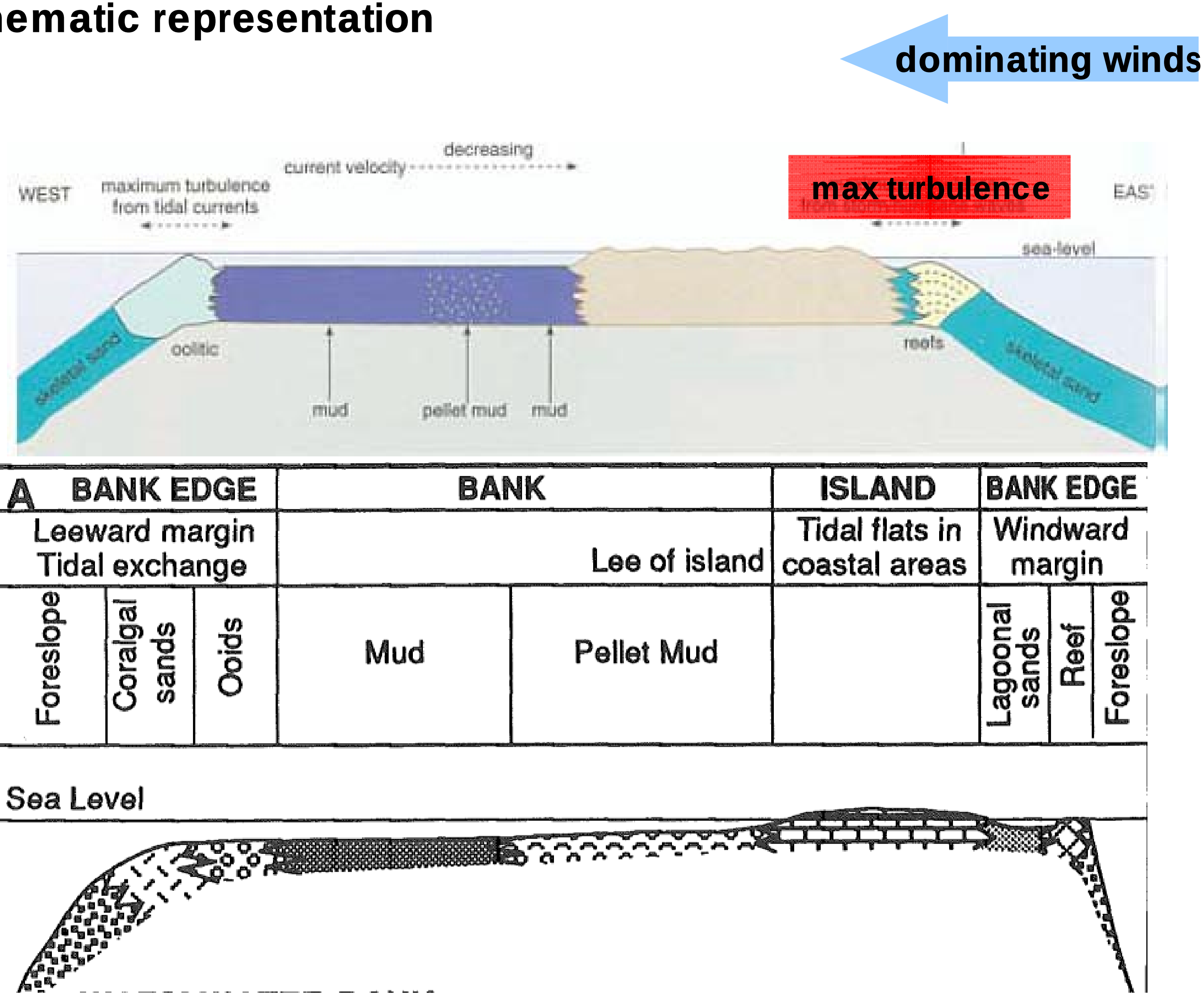


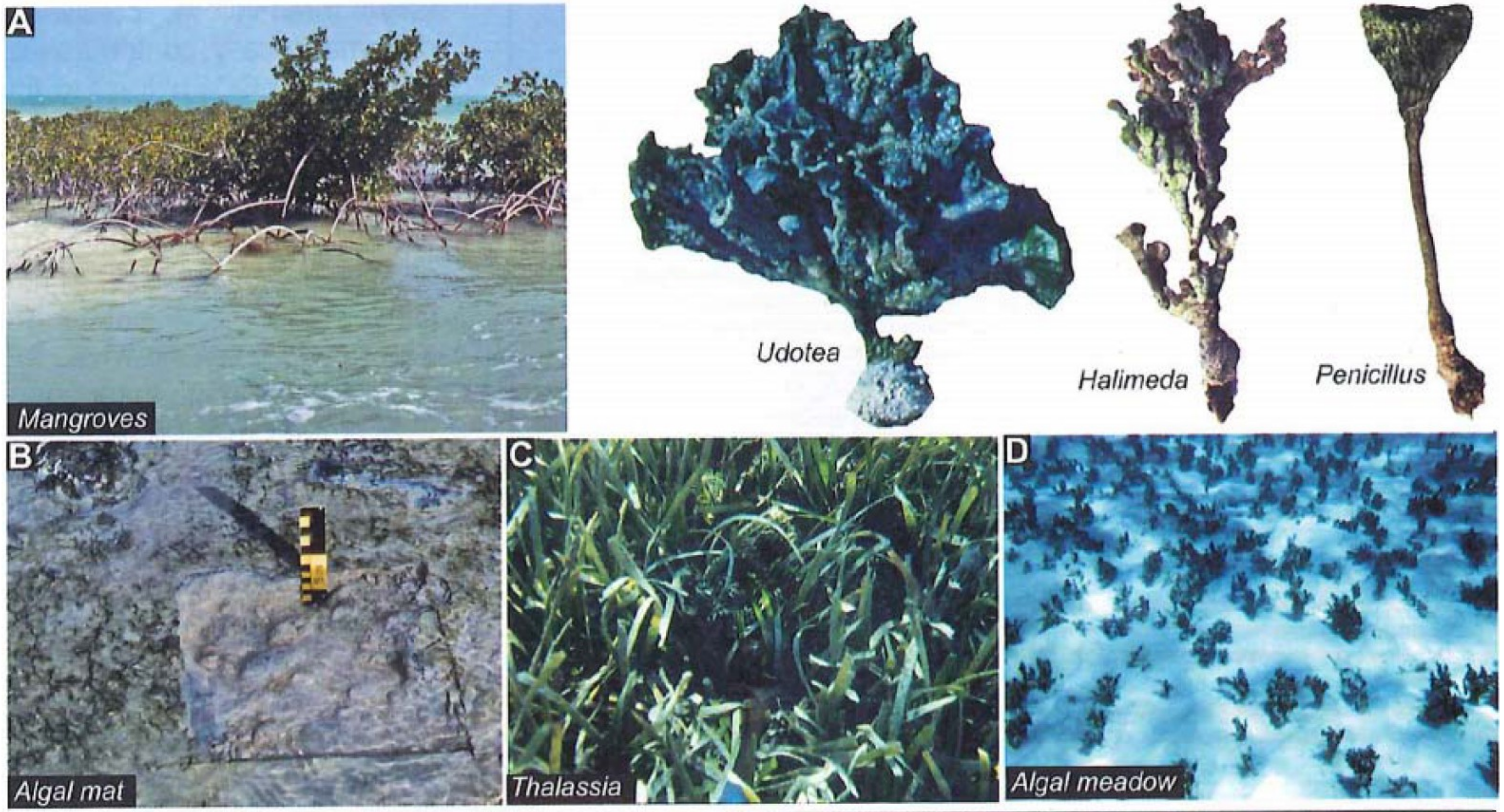
3. Carbonate production is the highest in in the uppermost part of the water column → carbonates tend to build flat-topped platforms close to sea level (the sea is the limit principle)
4. Carbonate slopes can be very steep, up to 70-80º resulting from possibly coarse grained material and frame-building activity

The example of the Bahamas (similar to the Dolomites)

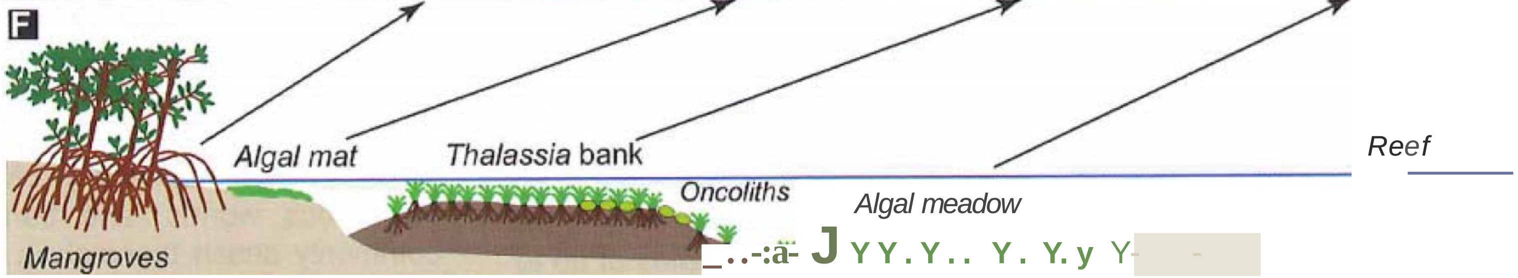
- low tidal range
- no tectonics behalf gentle subsidence
- very low platform-relief very high submarine relief
- near very >4km deep ocean
- seasonal high rainfall
- moderate temperatures
- no terrigenous input
- common tropical storms
- Westward dominant winds

A schematic representation

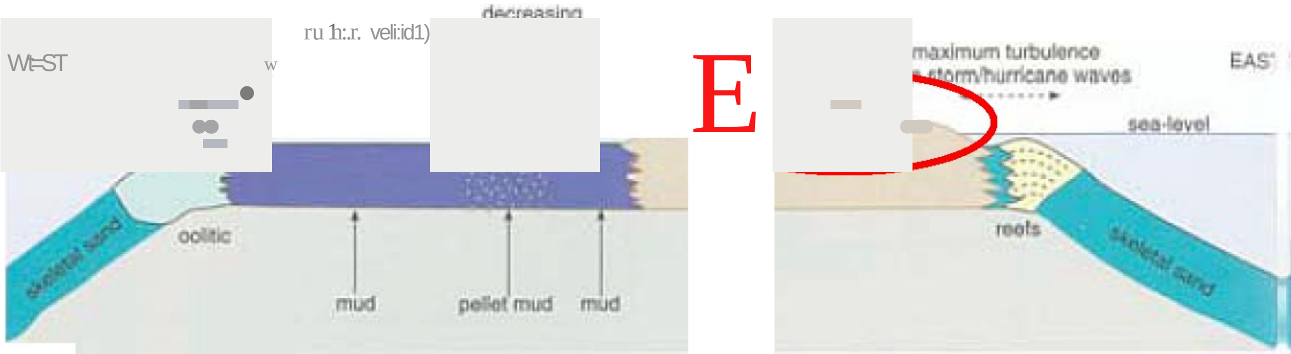




E	Mangroves	Algal Mat	*Thalassia*	Green Calcareous Algae
Sediment Production	Low	Low	High	Very high
Baffling	Very high	High	High	Low
Binding	Very high	High	Very high	Low

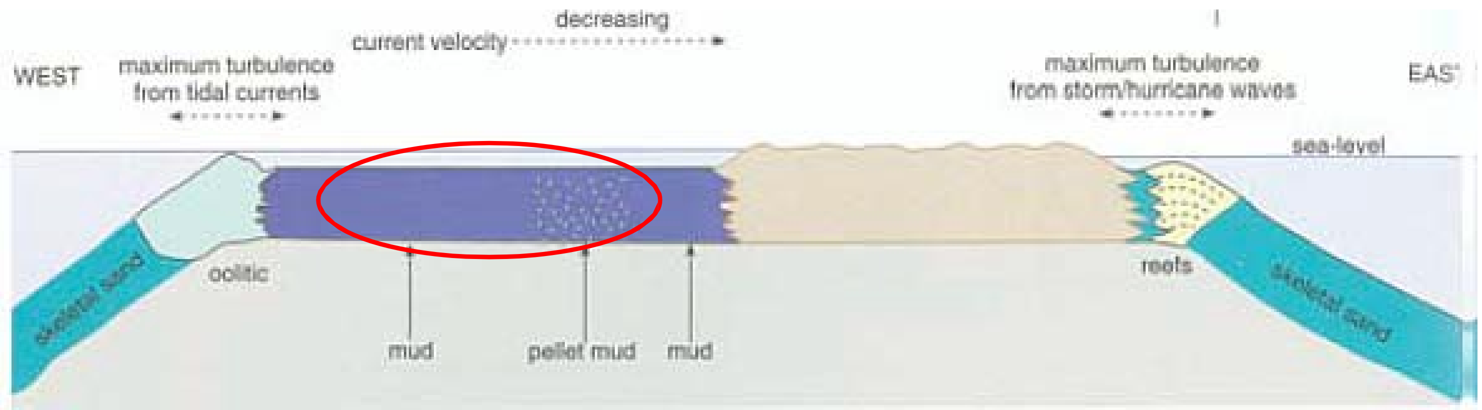


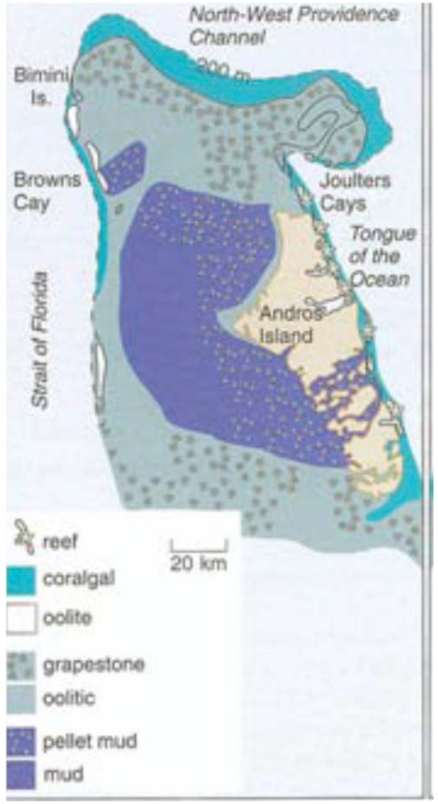
The exposed part of the platform The domain of mainly supratidal flats



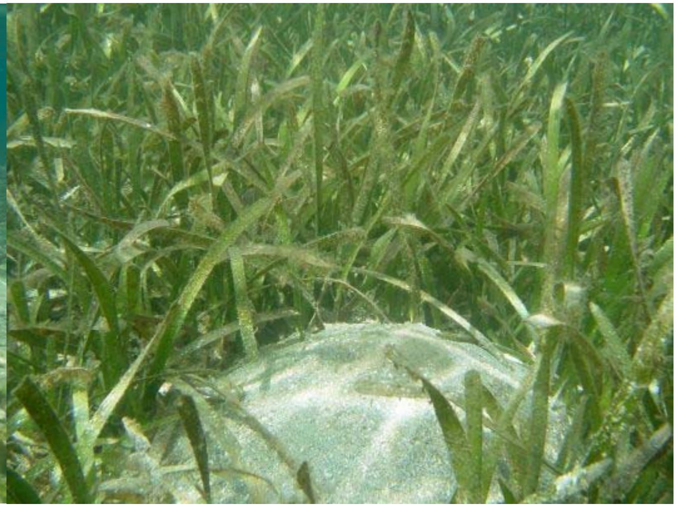
In the central part of the platform

muds (produced by algae), some coarser grained material





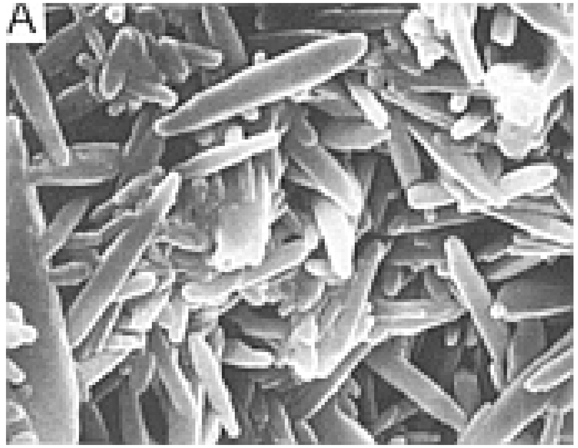
mostly skeletal material from plant and animal



Very fine-grained particles mainly resulting from the skeletons of algae (carbonate mud = micrite)

Most of the sediment remain in the mud-flats.

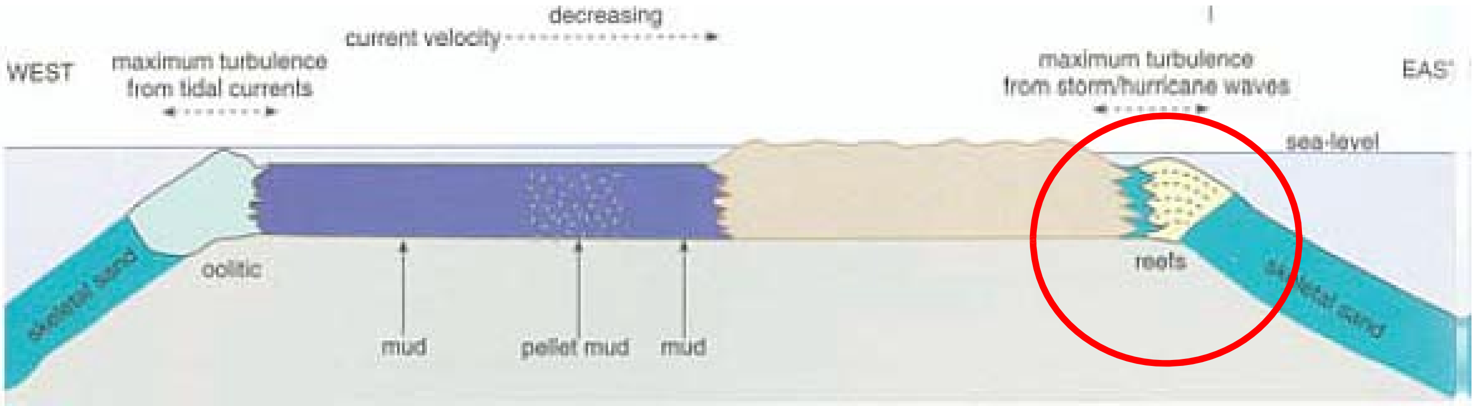
5 x

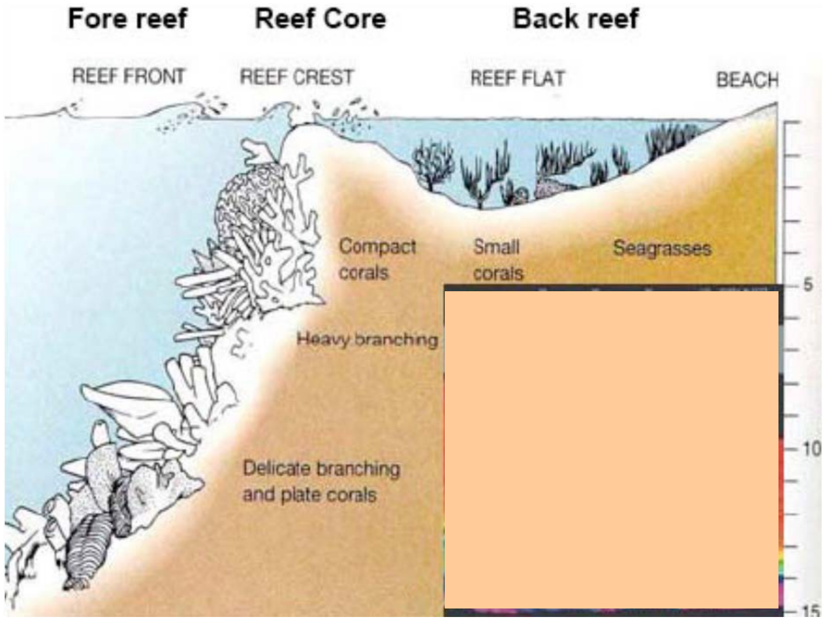


Once in a while, big storms bring coarser grained sediments from the margins into the interior

The margins: the windward side

The rims of the platforms protect the soft muddy interior.
Can be steep when formed by frame builders or gentler when built by sand bars with early diagenesis

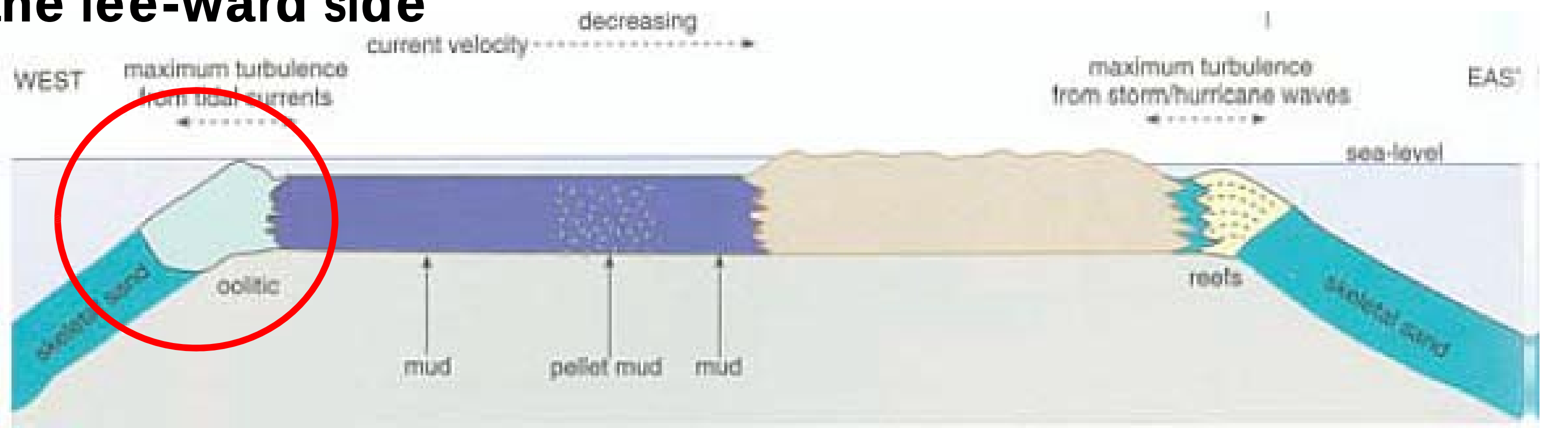




Reef core: crest in very shallow water, faces the strongest currents and is therefore resistant, rubble is produced and shed towards the deep basin

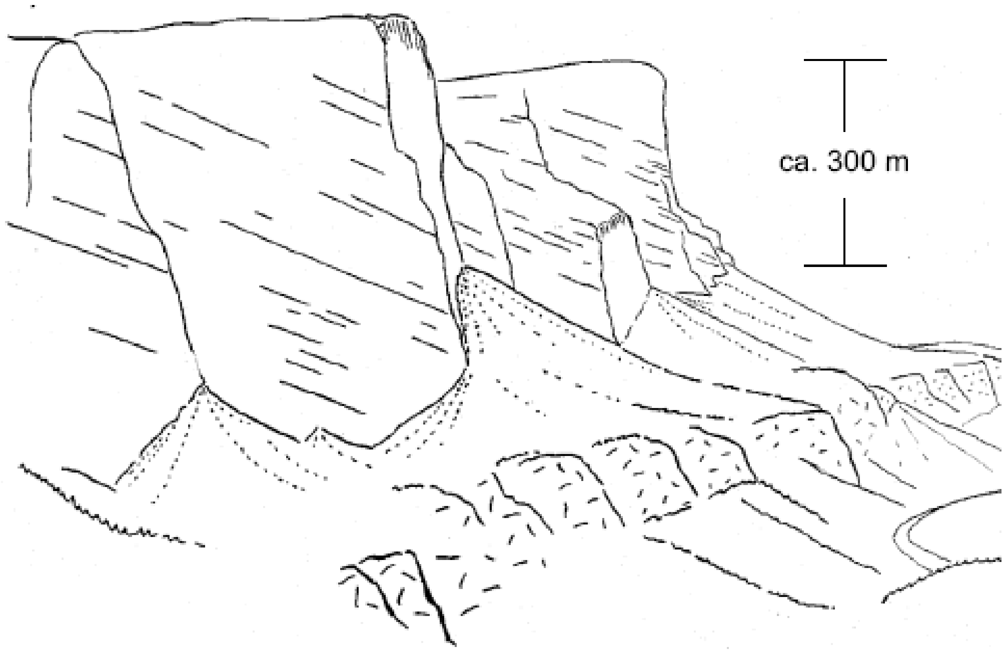
Fore reef: steep descend to the deep sea, forms and exports rubble

The margins: the lee-ward side



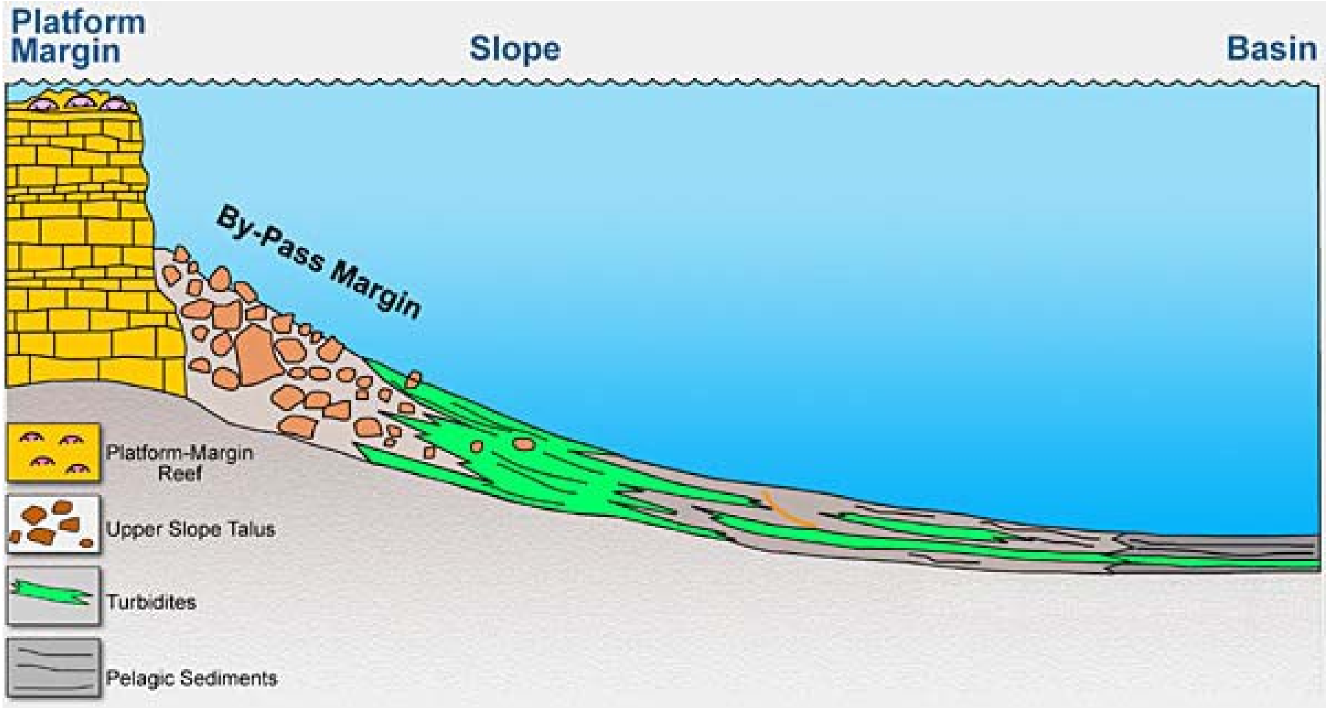
Sands composed only of organic grains, rapid diagenesis

If you go skiing in the Dolomites, pay attention to inclined bedding!



The slope

Material produced in the platform margin (especially the steep ones) fall towards the deep sea



The Latemar slope

Evolution of carbonate platforms through time

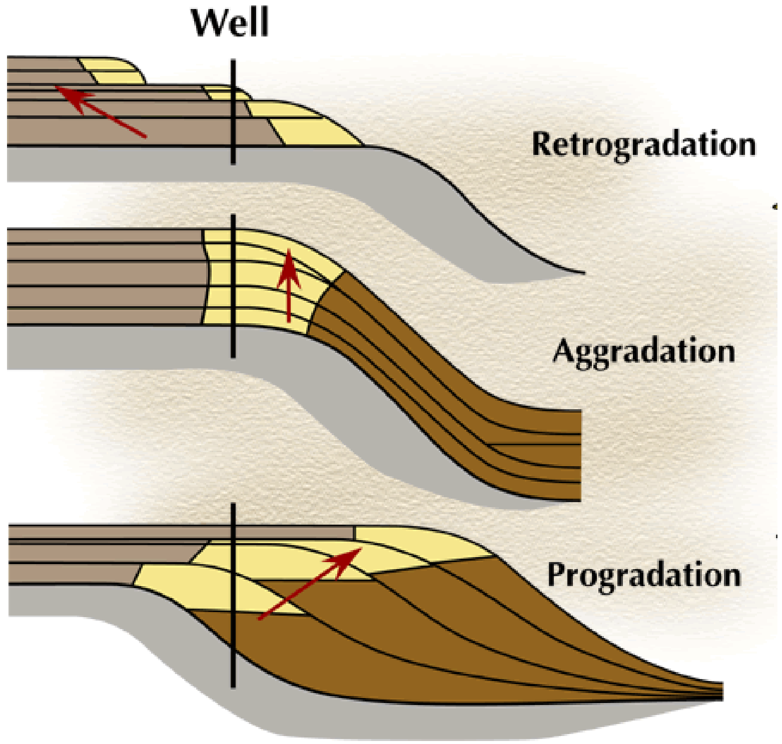
The interplay between creation and filling of accommodation space

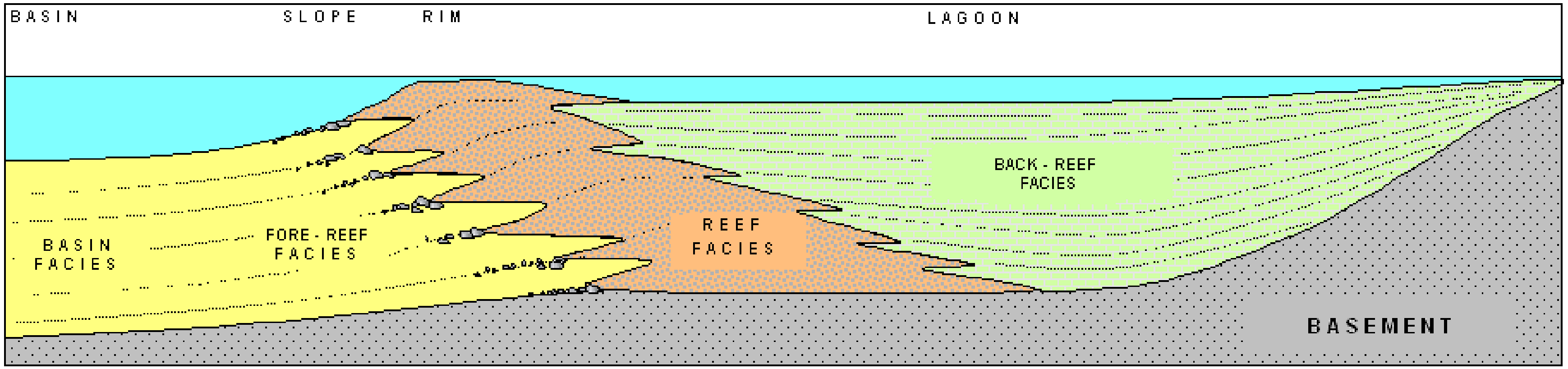
First order pattern

Production < subsidence: retrogradation

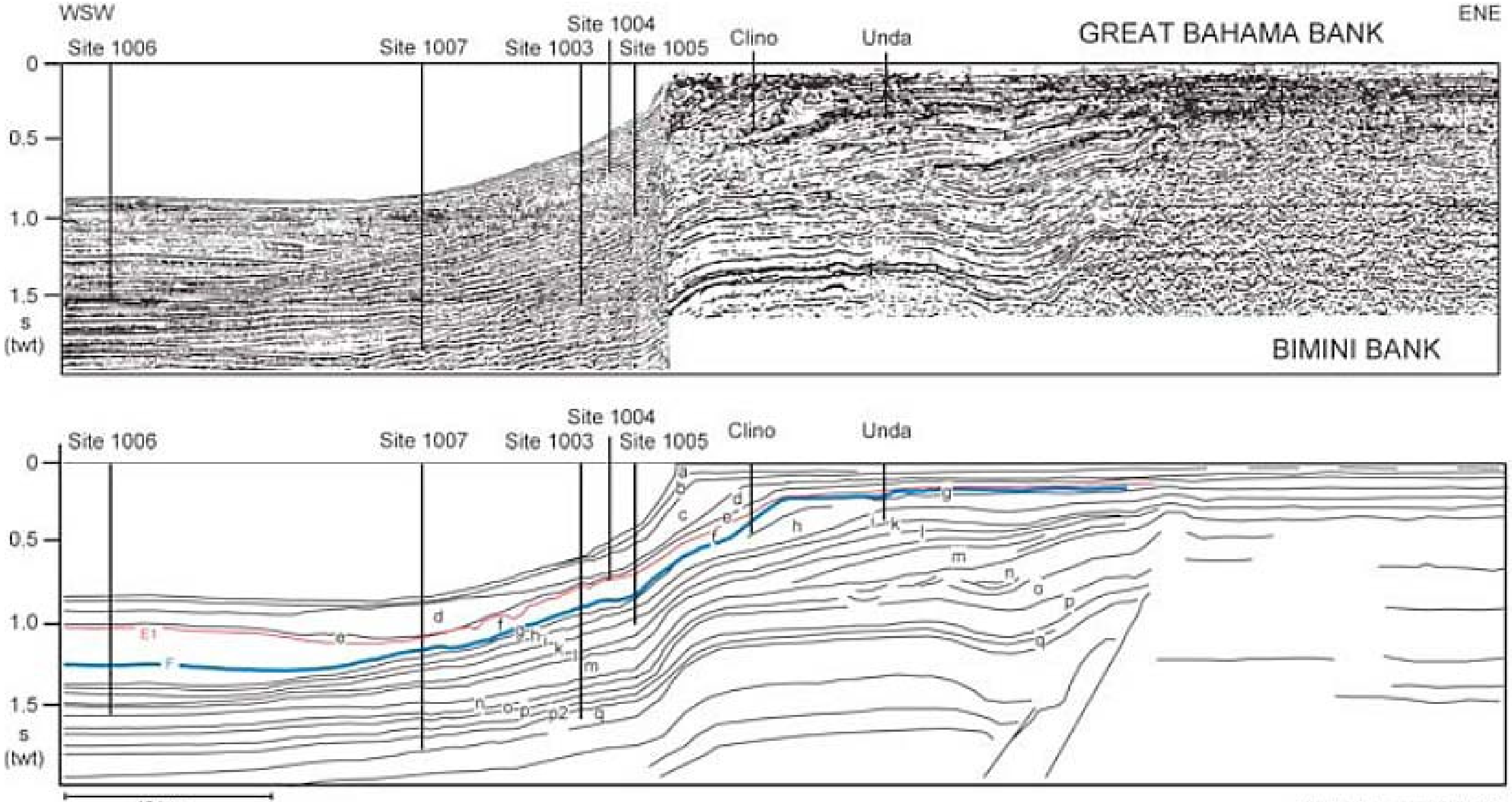
Production ≈ subsidence: aggradation

Production > subsidence: progradation



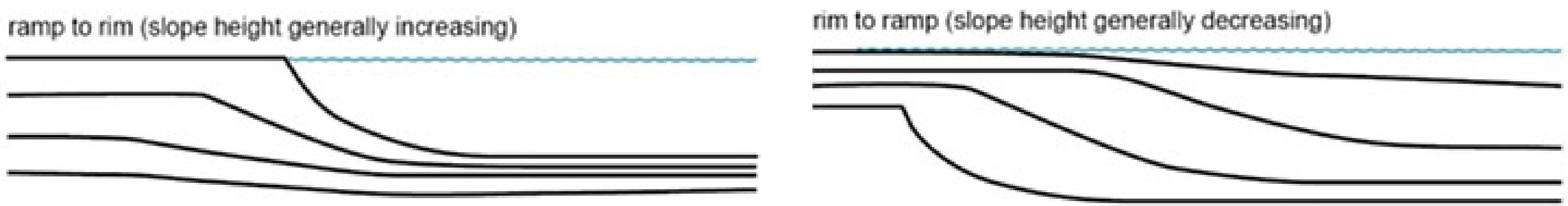


The growth of the Bahama platform

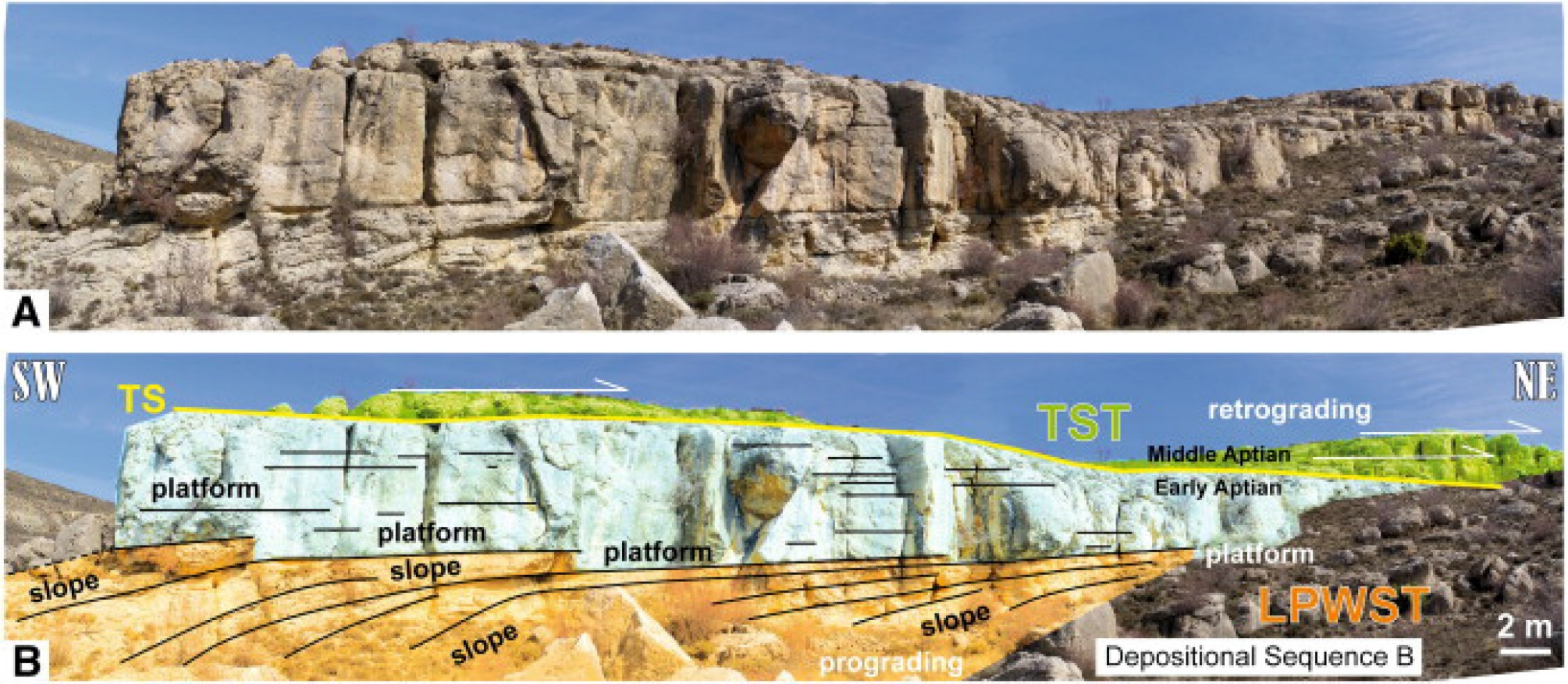


(Betzler, Reijmer et al. 1999)

Note transitions



Schlager 2005


A
SW
NE
TS
TST
retrograding
Middle Aptian
Early Aptian
platform
platform
platform
platform
slope
slope
slope
slope
prograding
LPWST
2 m
Depositional Sequence B
B

See you in part 3!

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