Carbonates Depositional System

Lecture-1

Carbonate platform
Example from Samana Suk Formation

Factors favouring carbonate Precipitation

No clastic input

Warm water

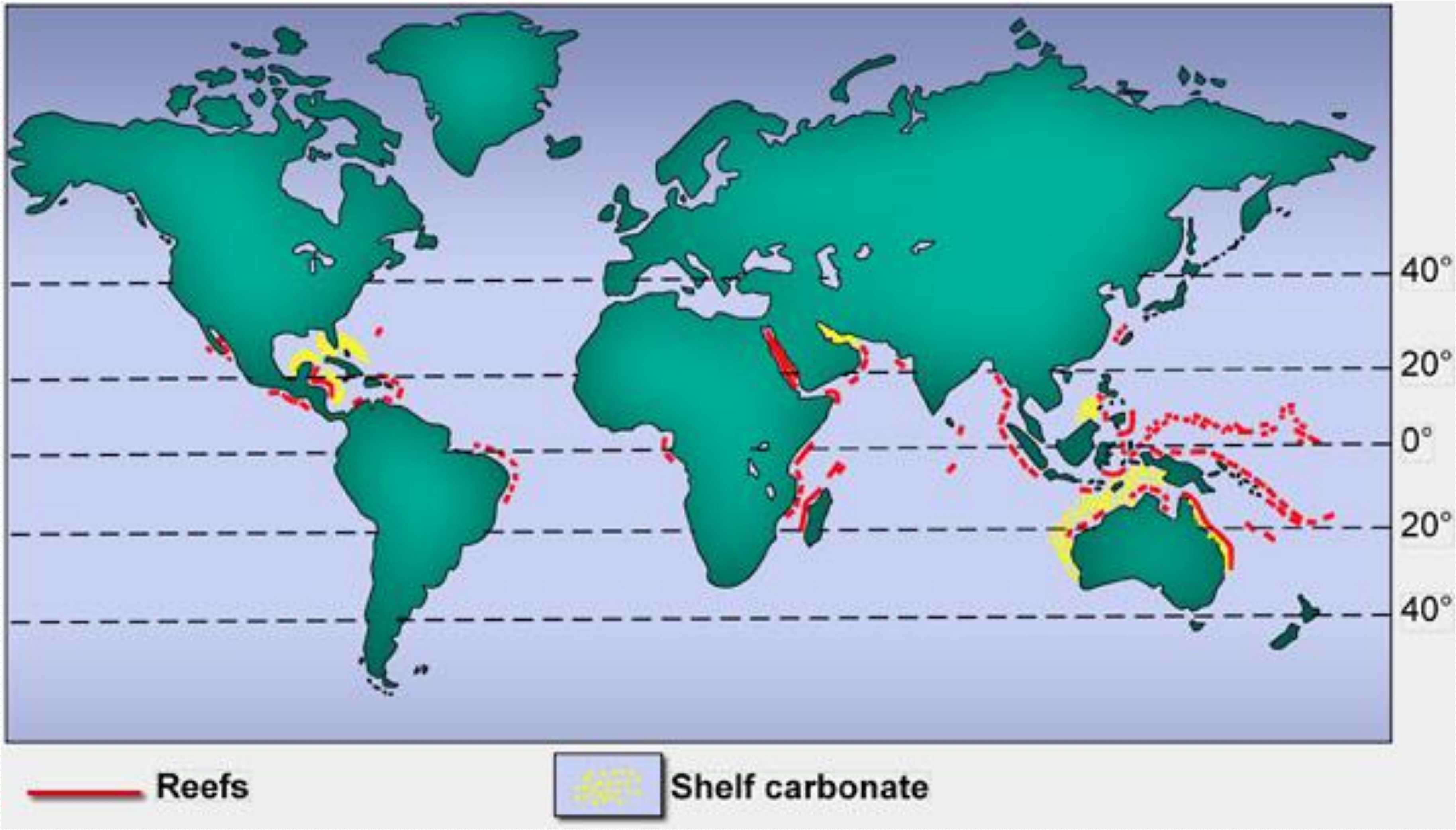
High biologic productivity

Shallow water (photic zone)

Alkalinity

Low latitude

Recent Carbonate Sedimentation



Recent Examples of Carbonate Platforms

The Trucial Coast of the Arabian Gulf

The eastern Yucatan coast of Mexico

Shark Bay in Western Australia

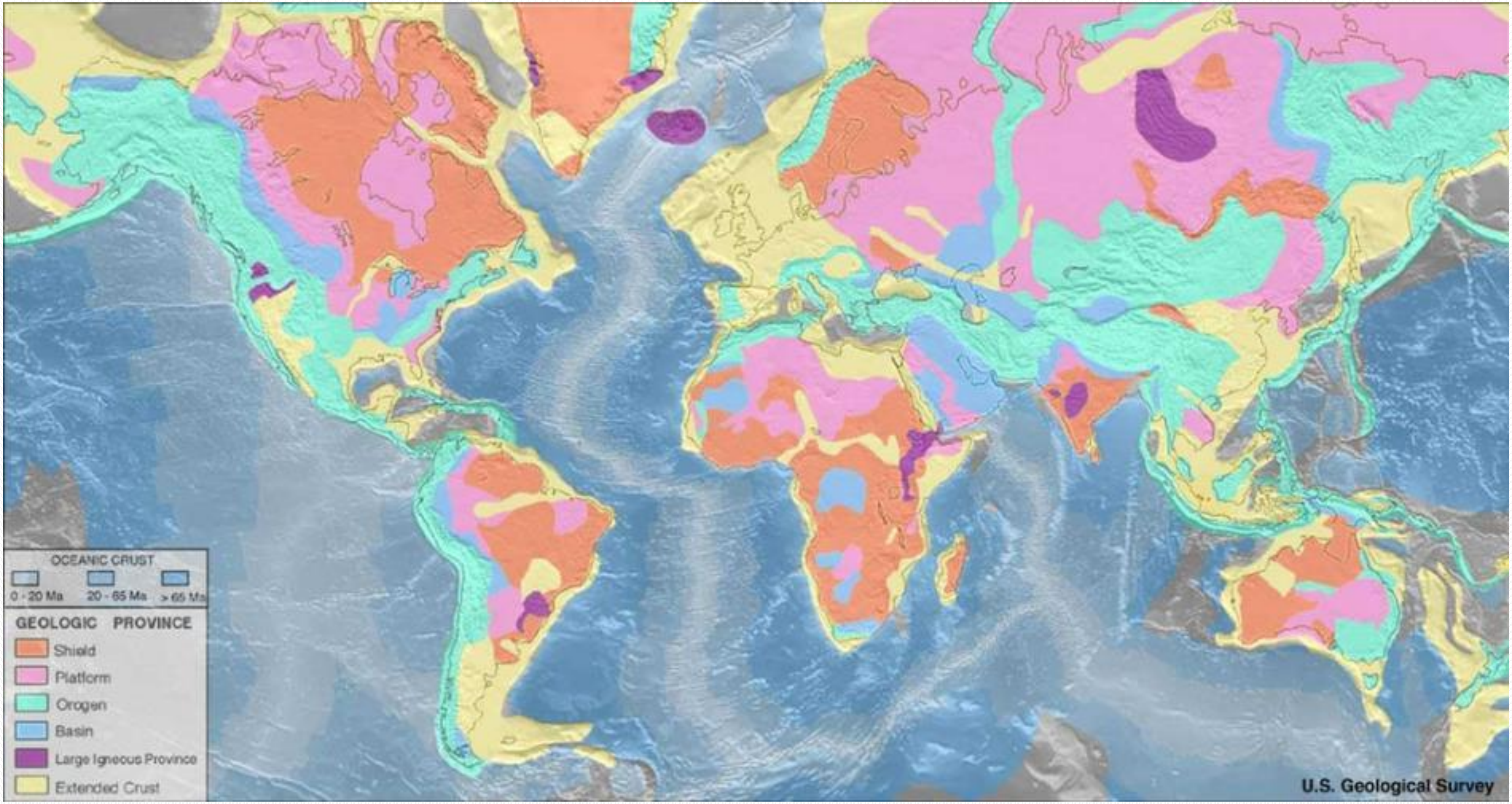
Great Bahama Bank

Florida Bay

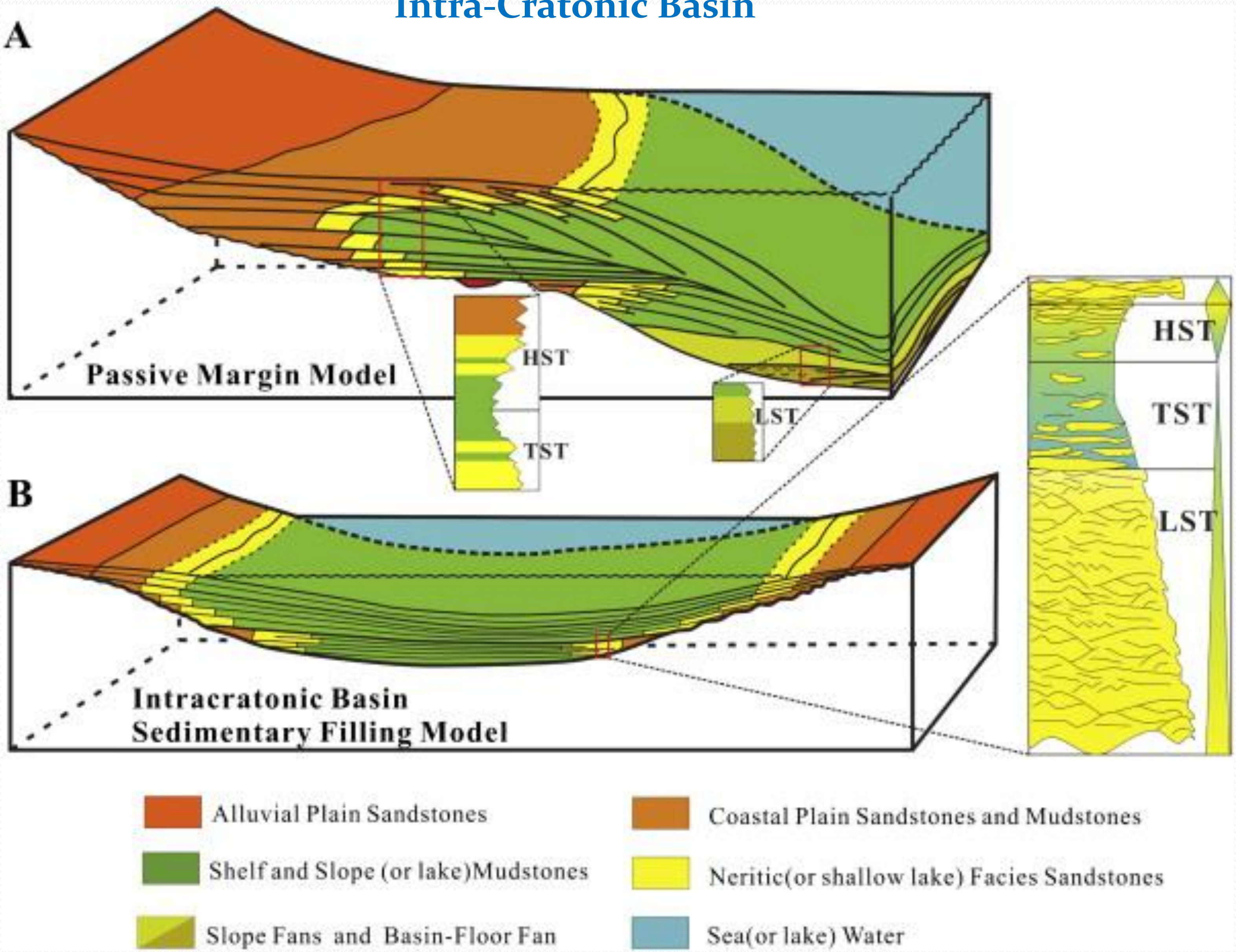
Different Basins which can host Carbonate Platforms’

Passive vs Active Margins

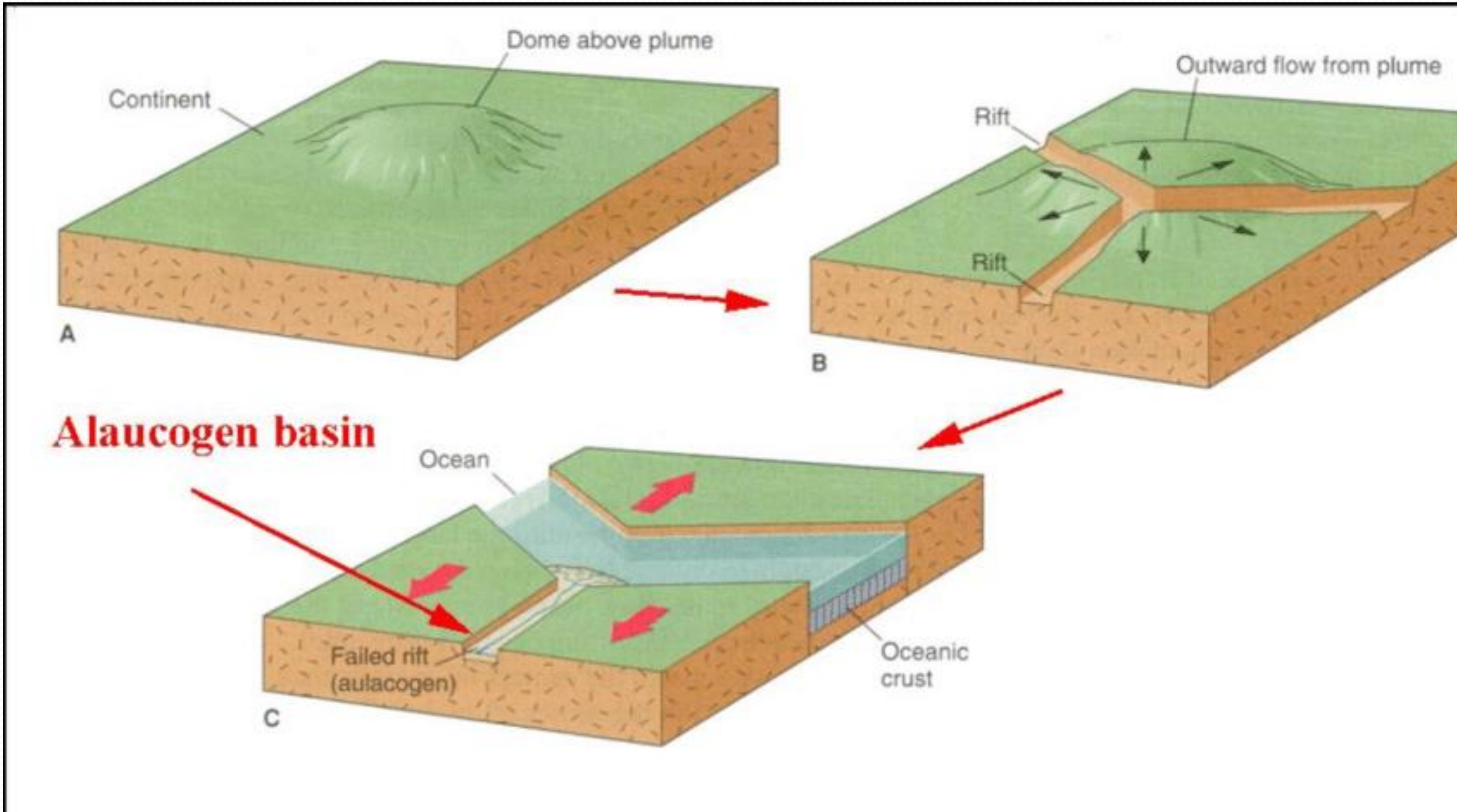
World’s Cratons



Intra-Cratonic Basin

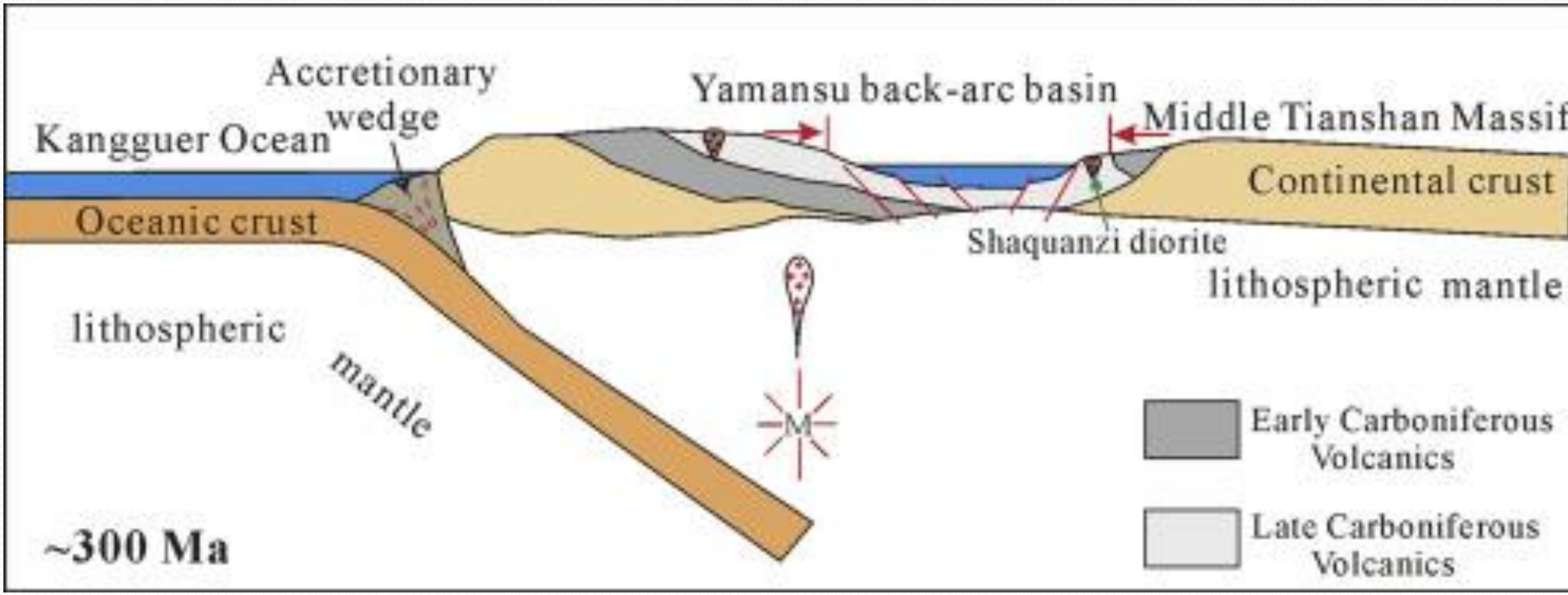


Failed Rift

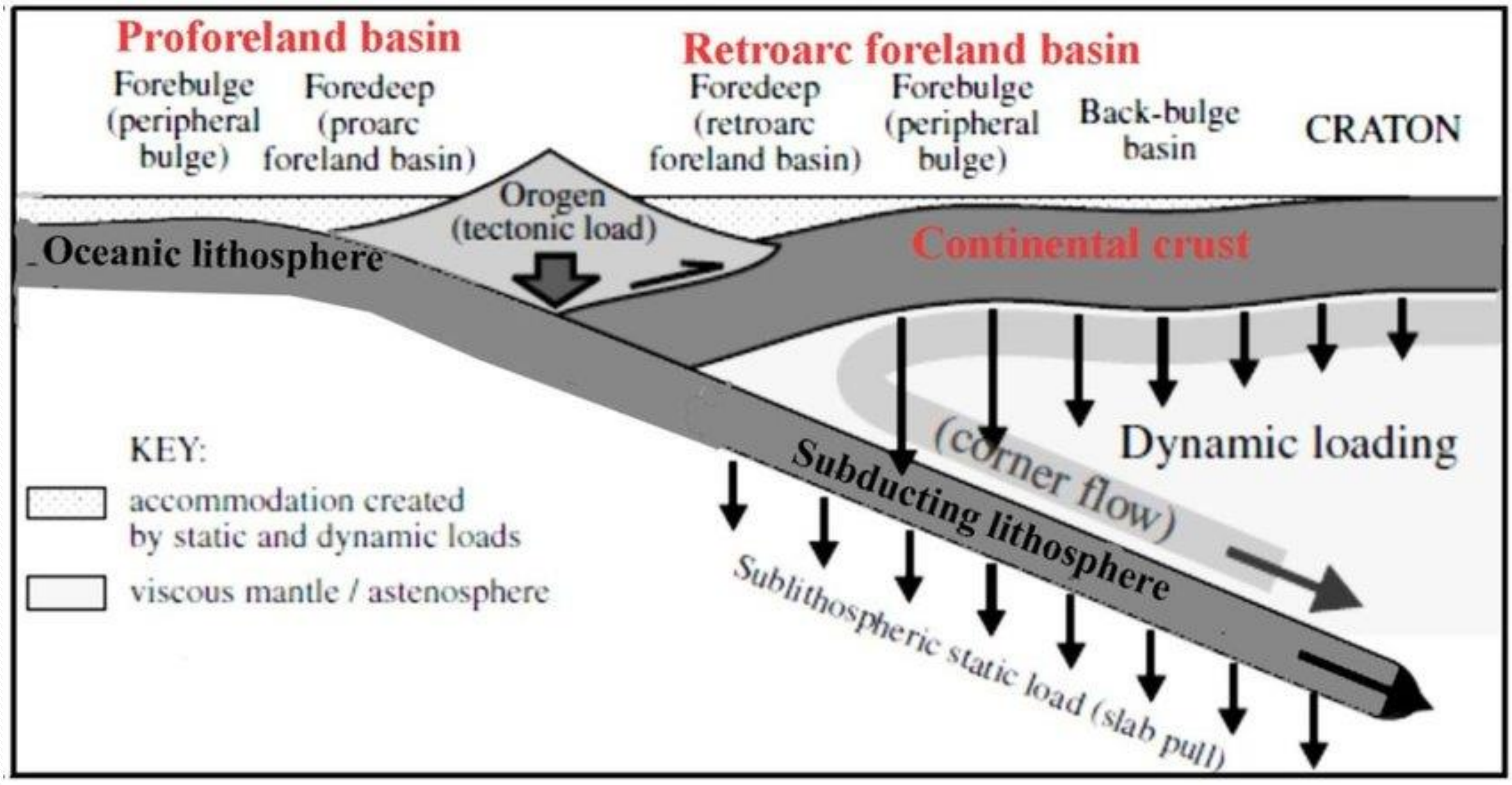


Dome above plume
Continent
A
Outward flow from plume
Rift
Rift
B
Alaucogen basin
Ocean
Failed rift
(aulacogen)
Oceanic
crust
C

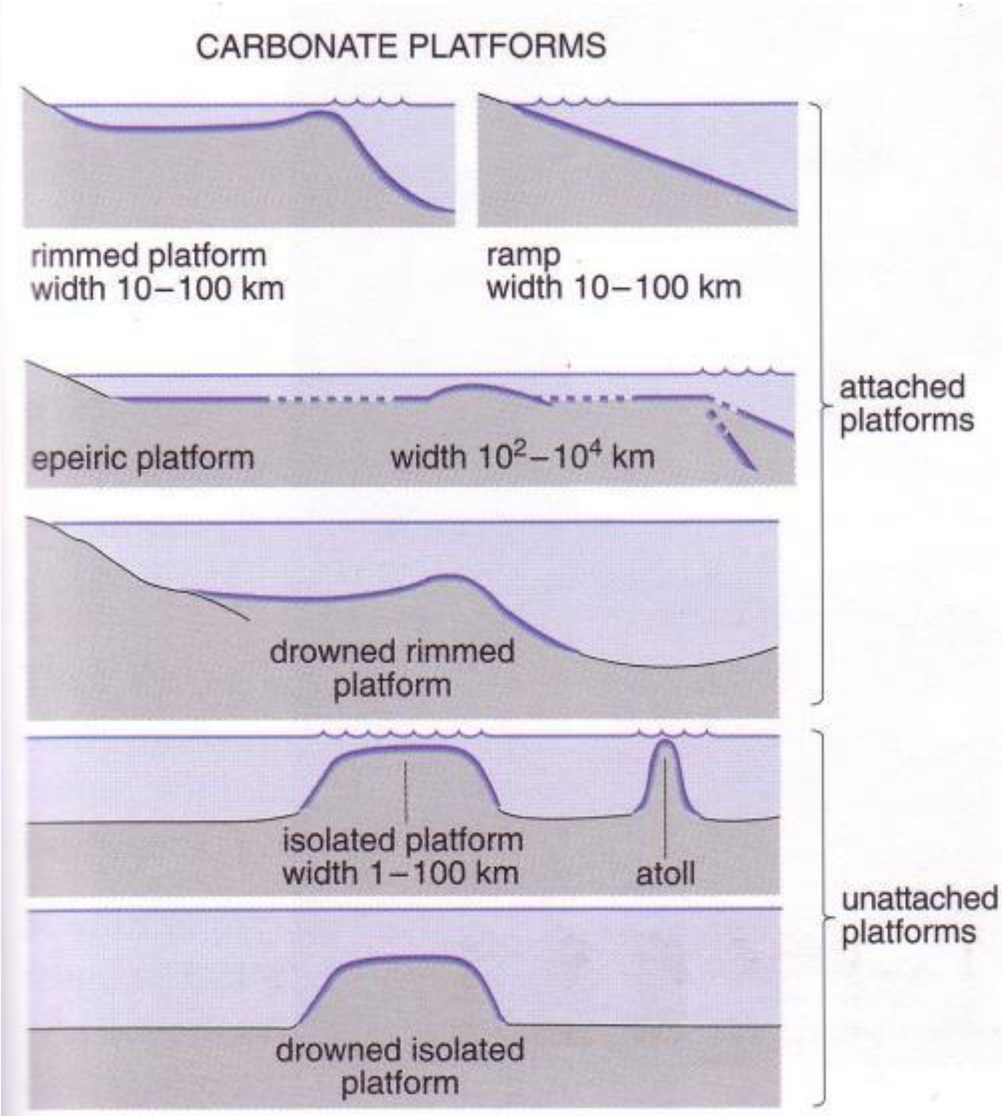
Back Arc Basin



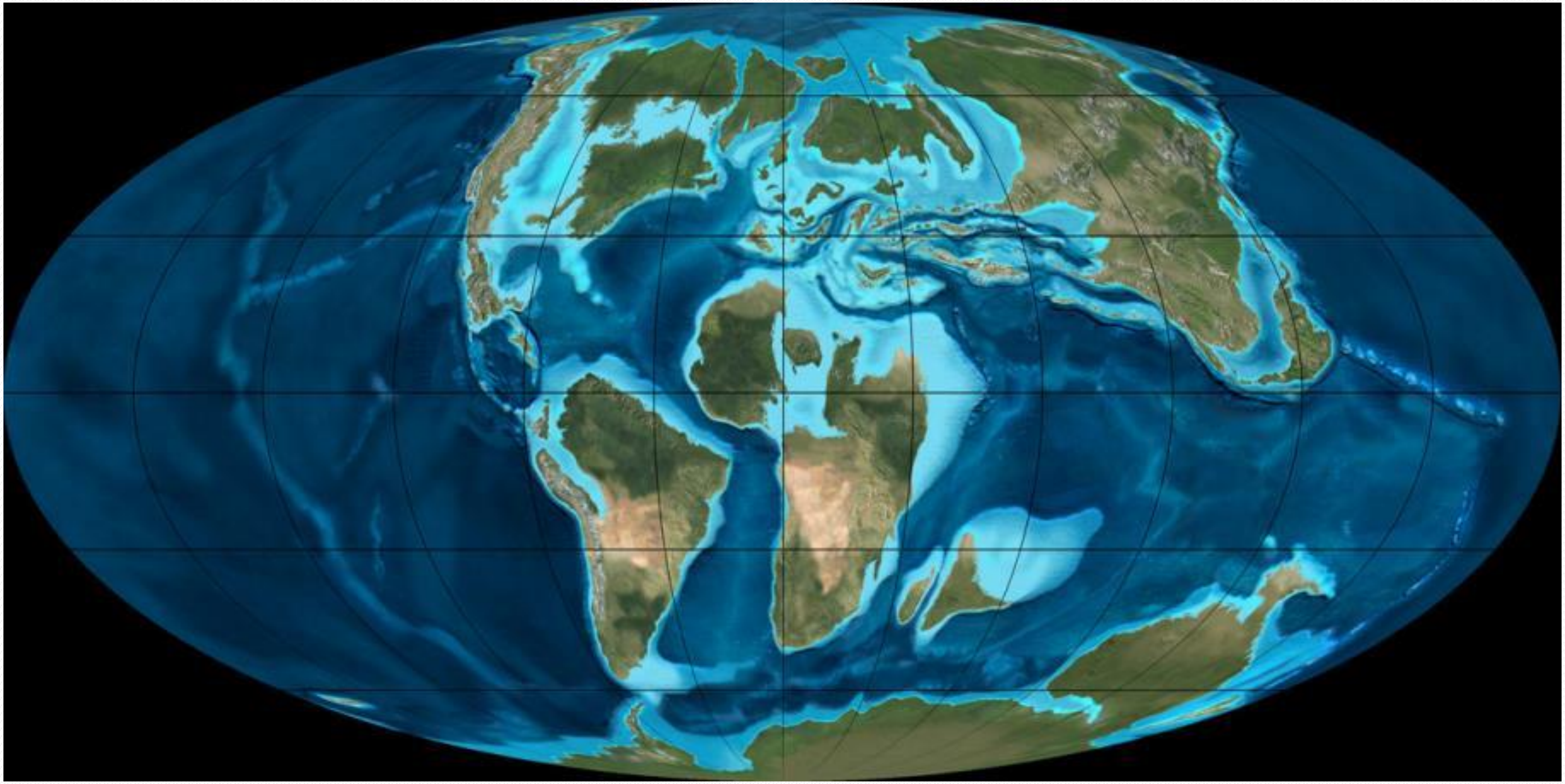
Foreland Basin



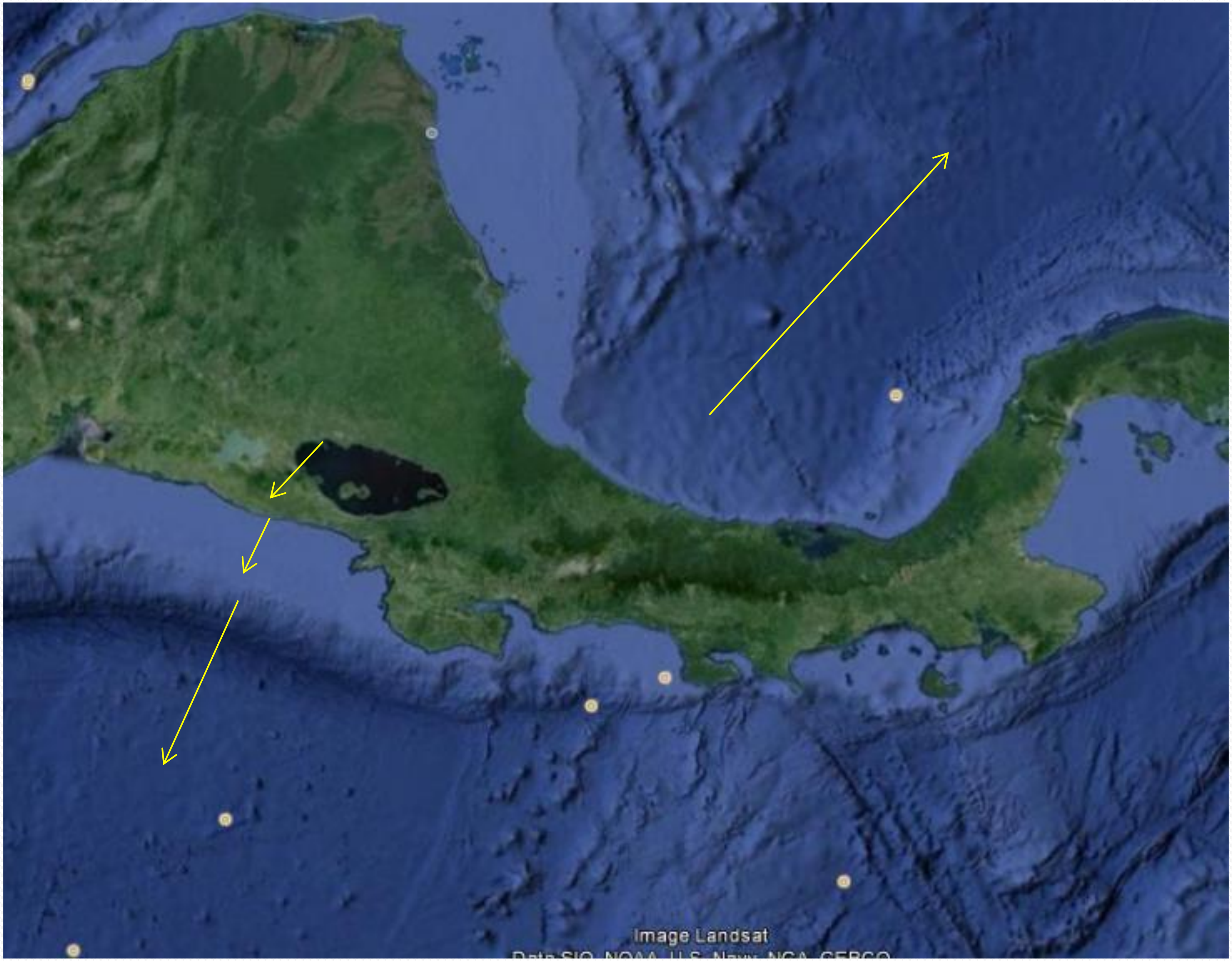
Types of Carbonate Platforms



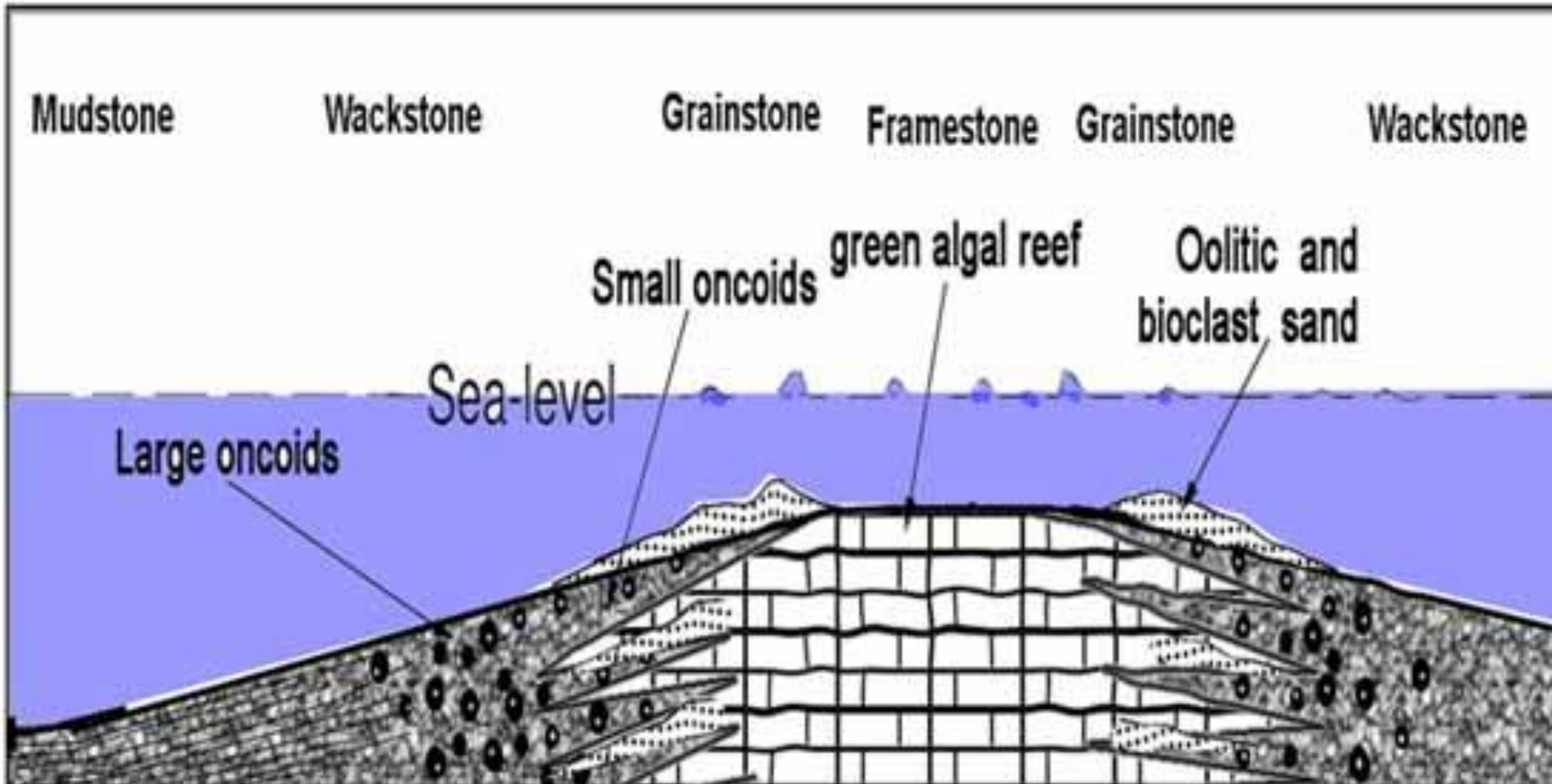
Epeiric Carbonate Platforms



Rimmed Shelf and Ramp Platforms



Isolated Platform



Isolated Platform

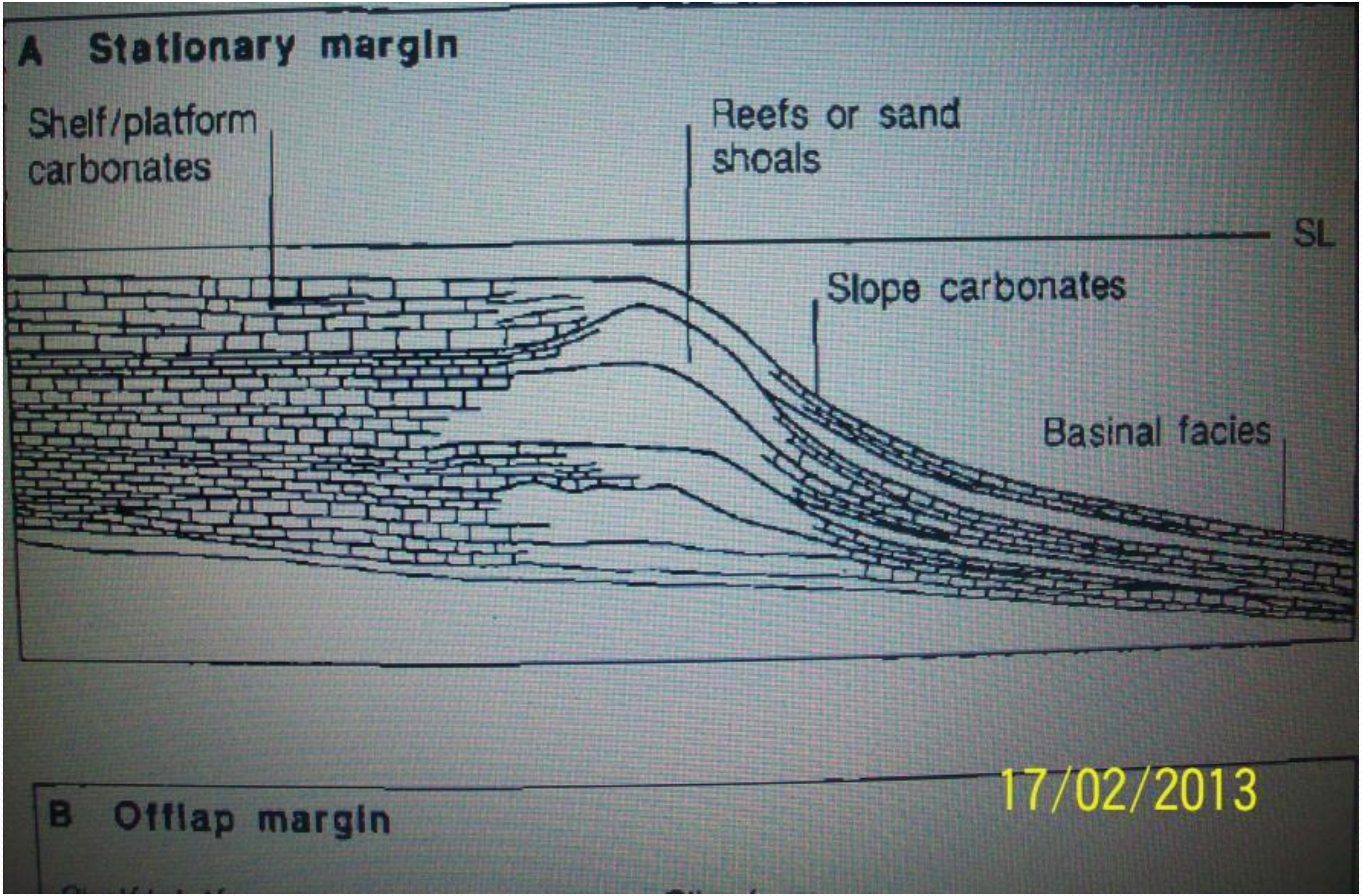
Difference between rimmed shelf and Ramp carbonate platforms

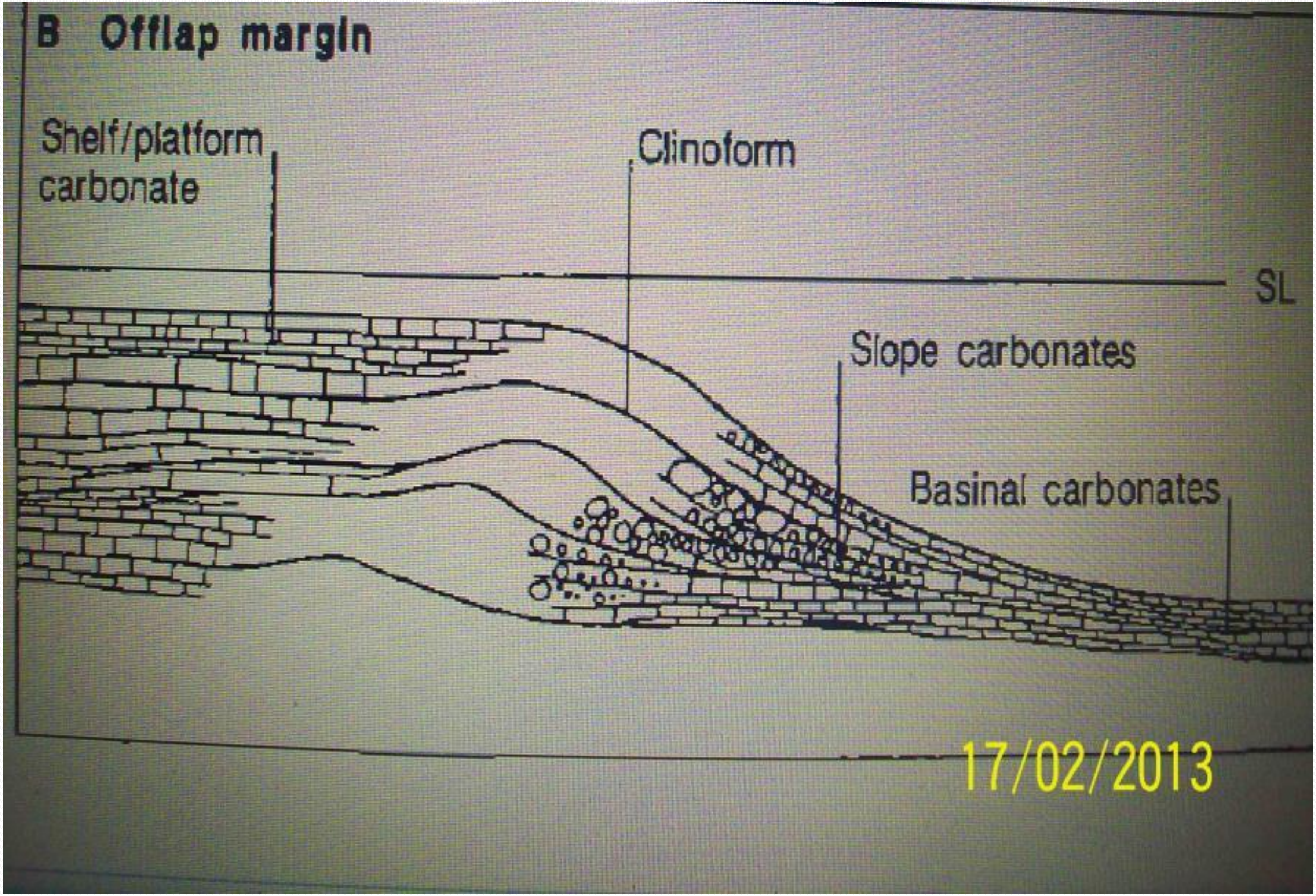
Turbidites or Resedimenated carbonates

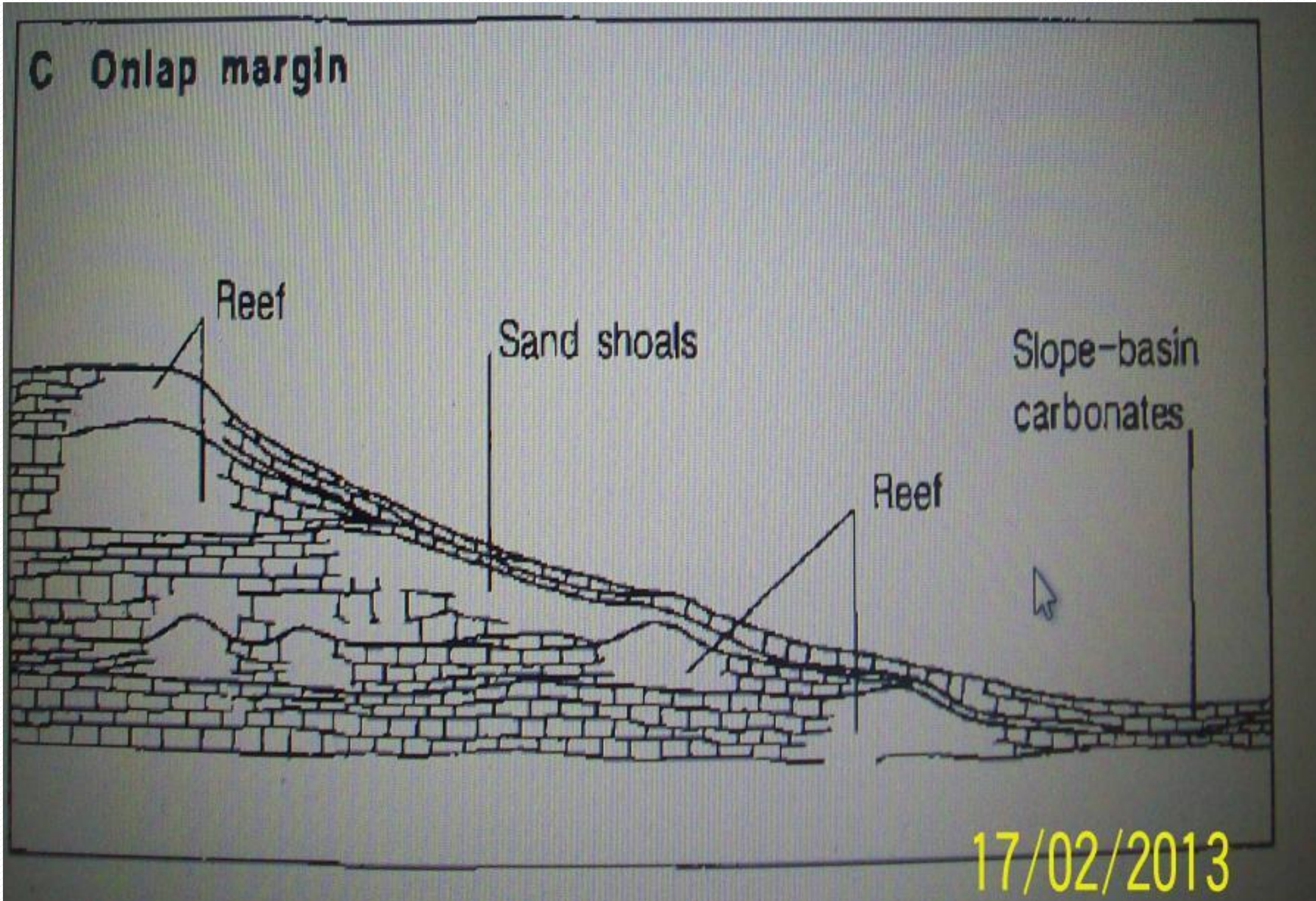
Extensive shallow marine strata on ramp

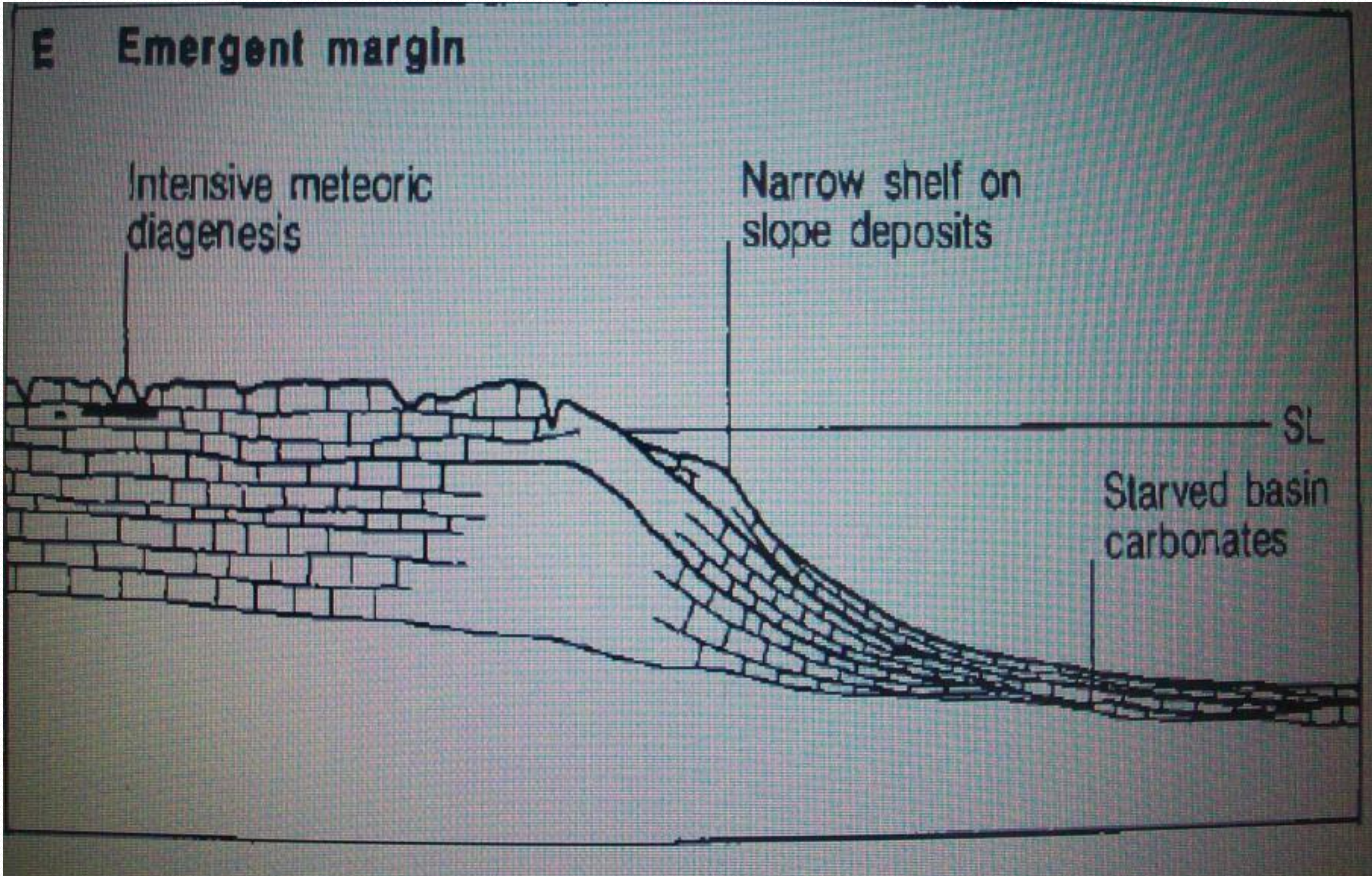
Reef facies on rimmed shelf while mudmouns on ramps

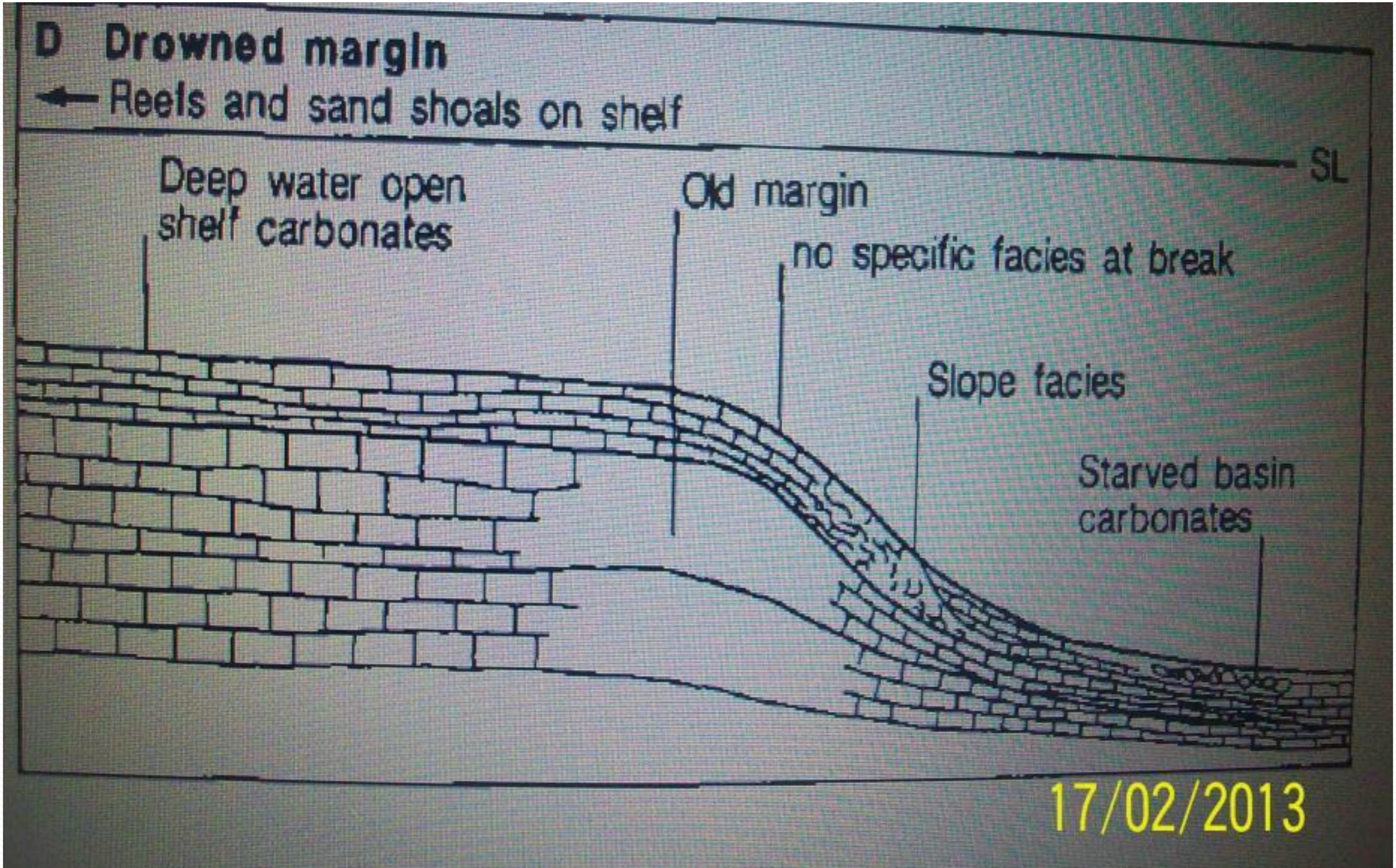
Sea Level Changes and Platform Margins



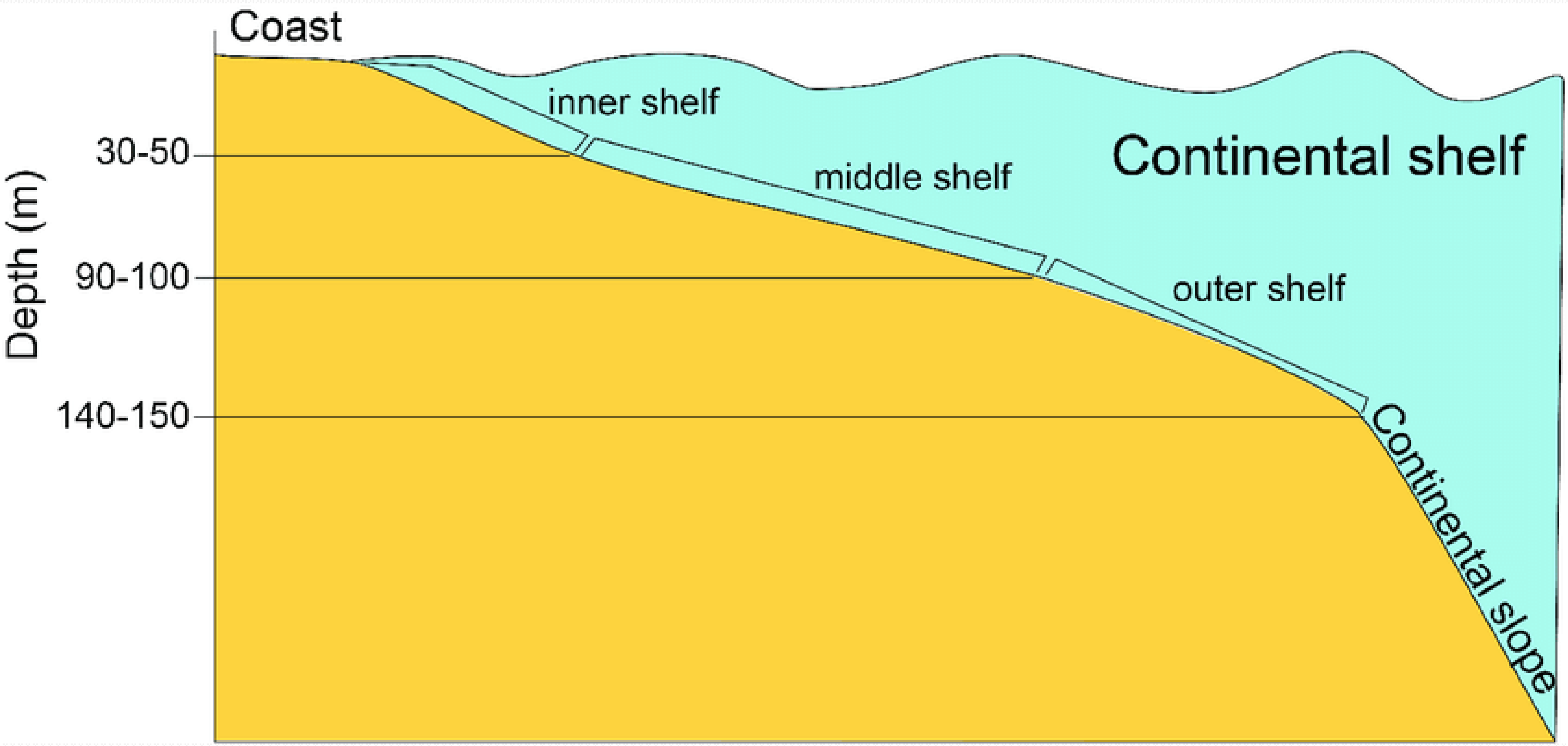

B Offlap margin
Shelf/platform carbonate
Clinoform
SL
Slope carbonates
Basinal carbonates
17/02/2013


C Onlap margin
Reef
Sand shoals
Slope-basin
carbonates
Reef
17/02/2013

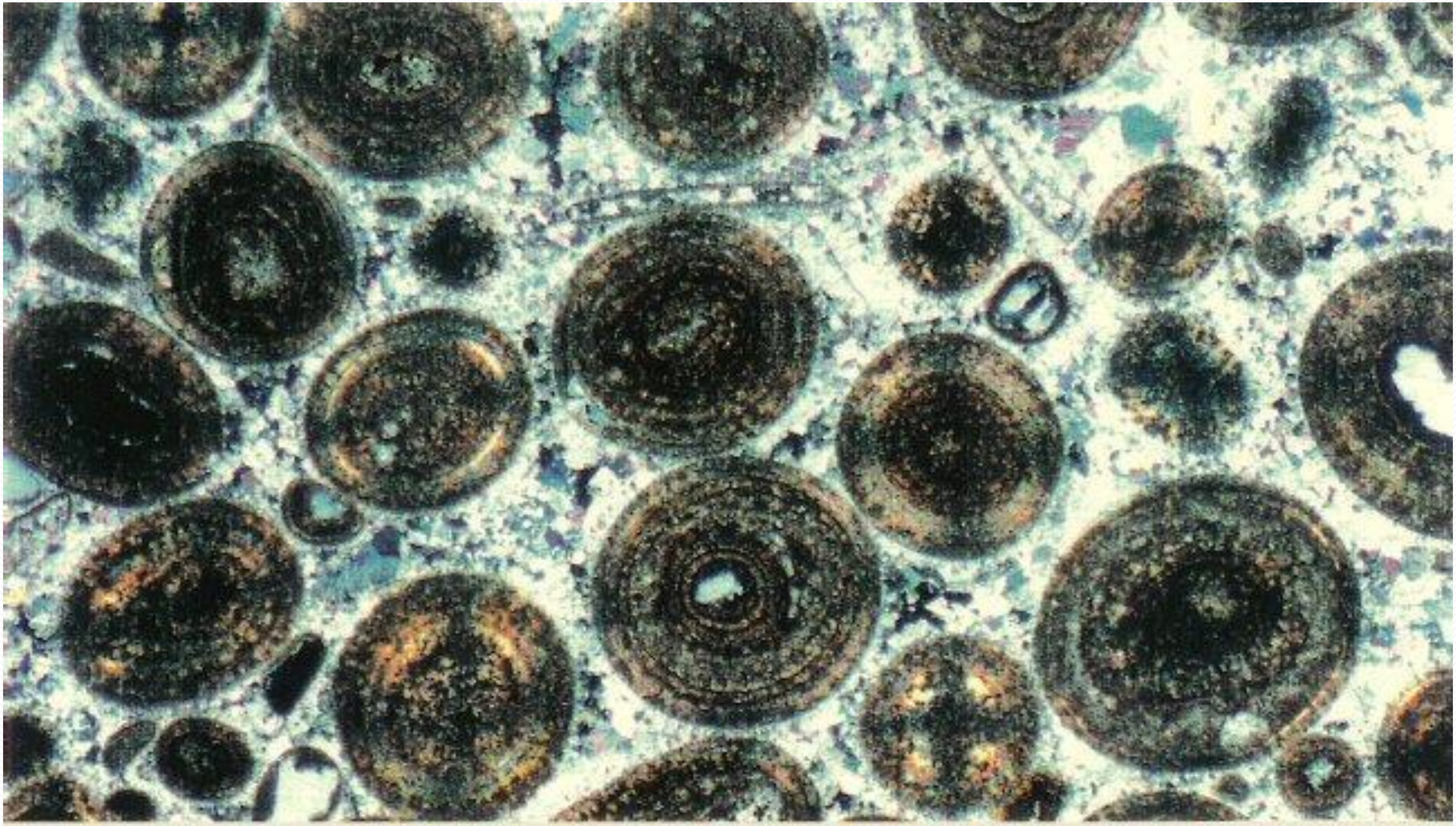

E Emergent margin
Intensive meteoric diagenesis
Narrow shelf on slope deposits
SL
Starved basin carbonates


D Drowned margin
Reefs and sand shoals on shelf
SL
Deep water open shelf carbonates
Old margin
no specific facies at break
Slope facies
Starved basin carbonates
17/02/2013

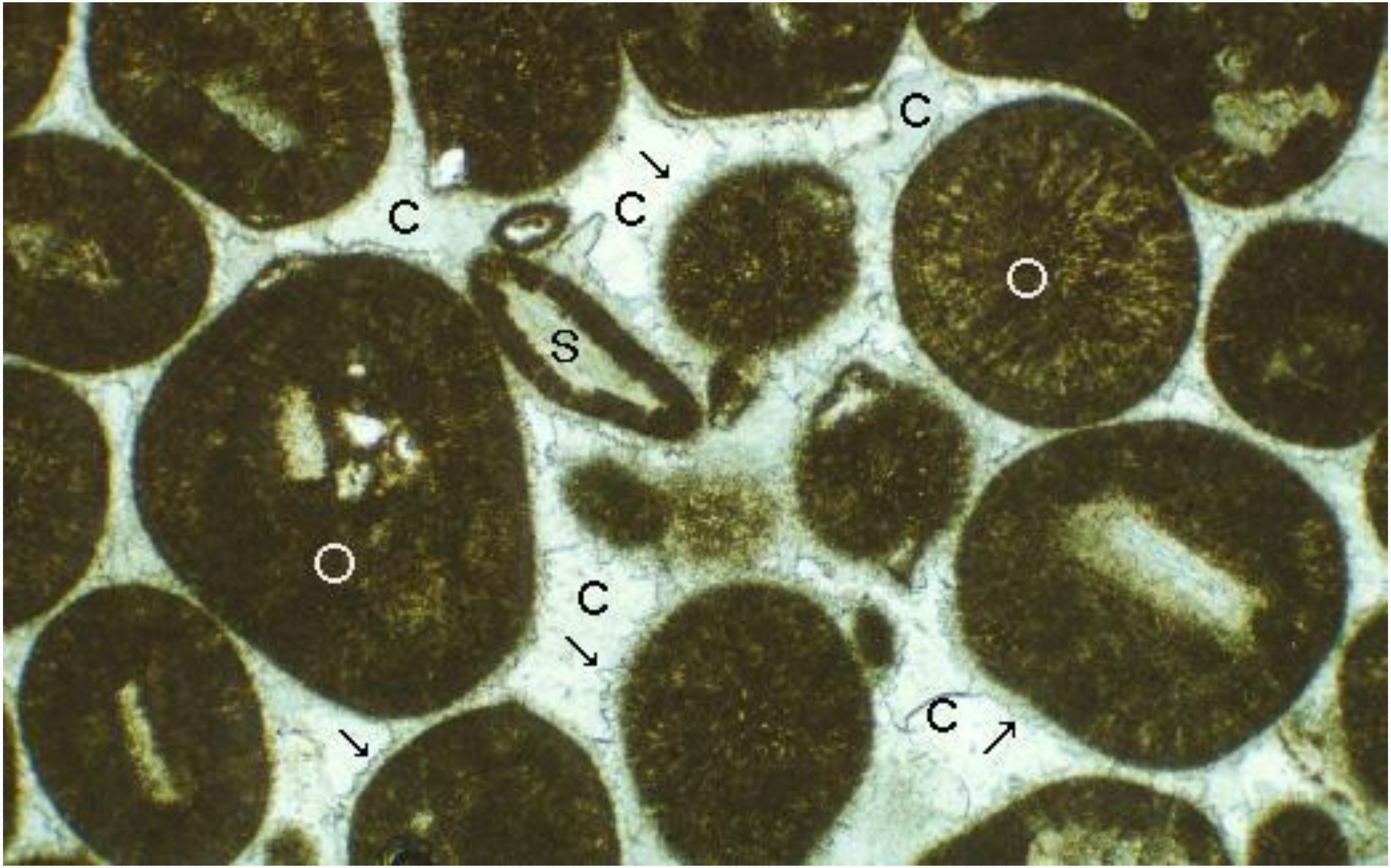
Energy Distribution of Carbonate Platforms



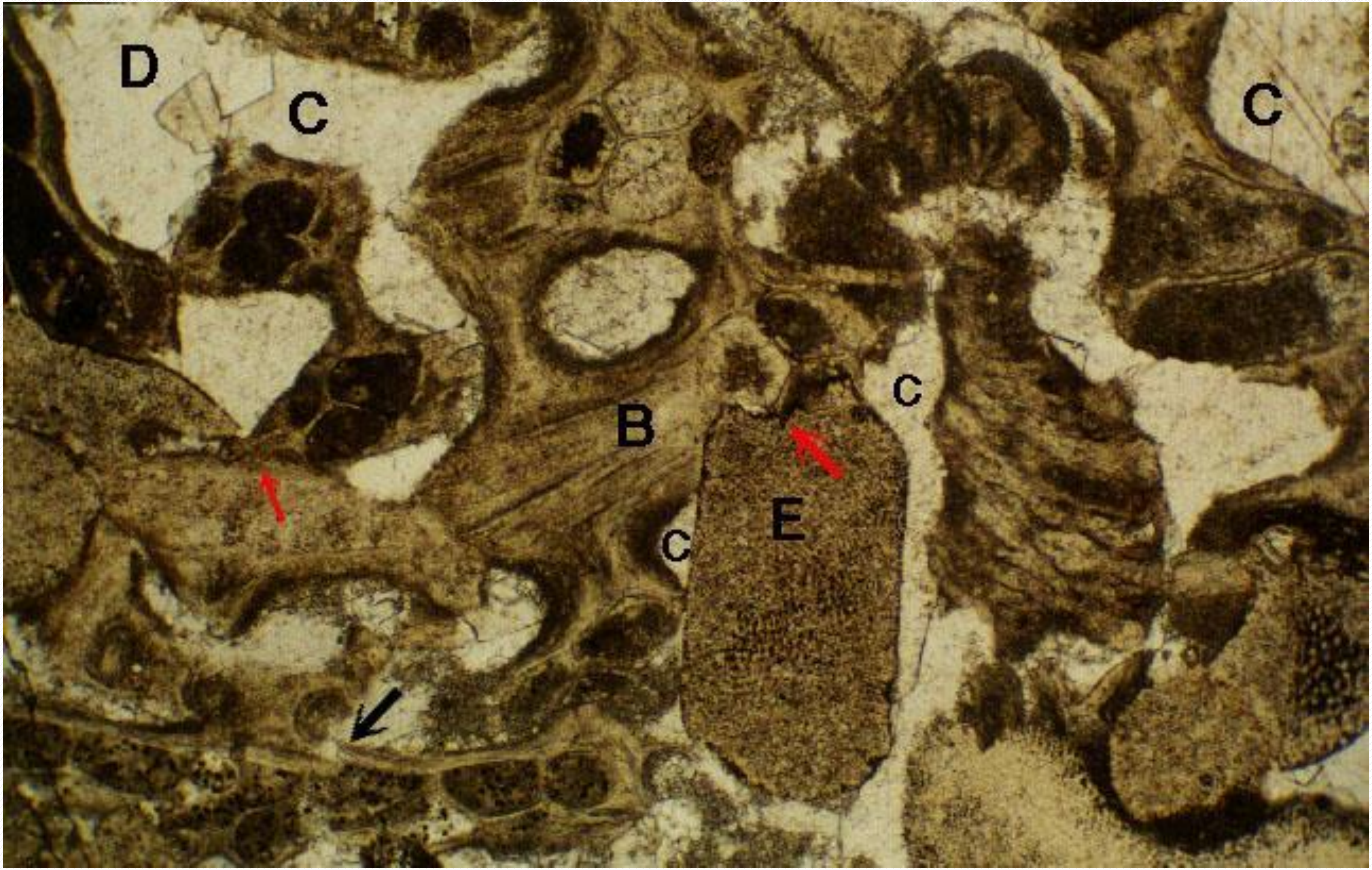
Oolitic grainstone of Inner Shelf



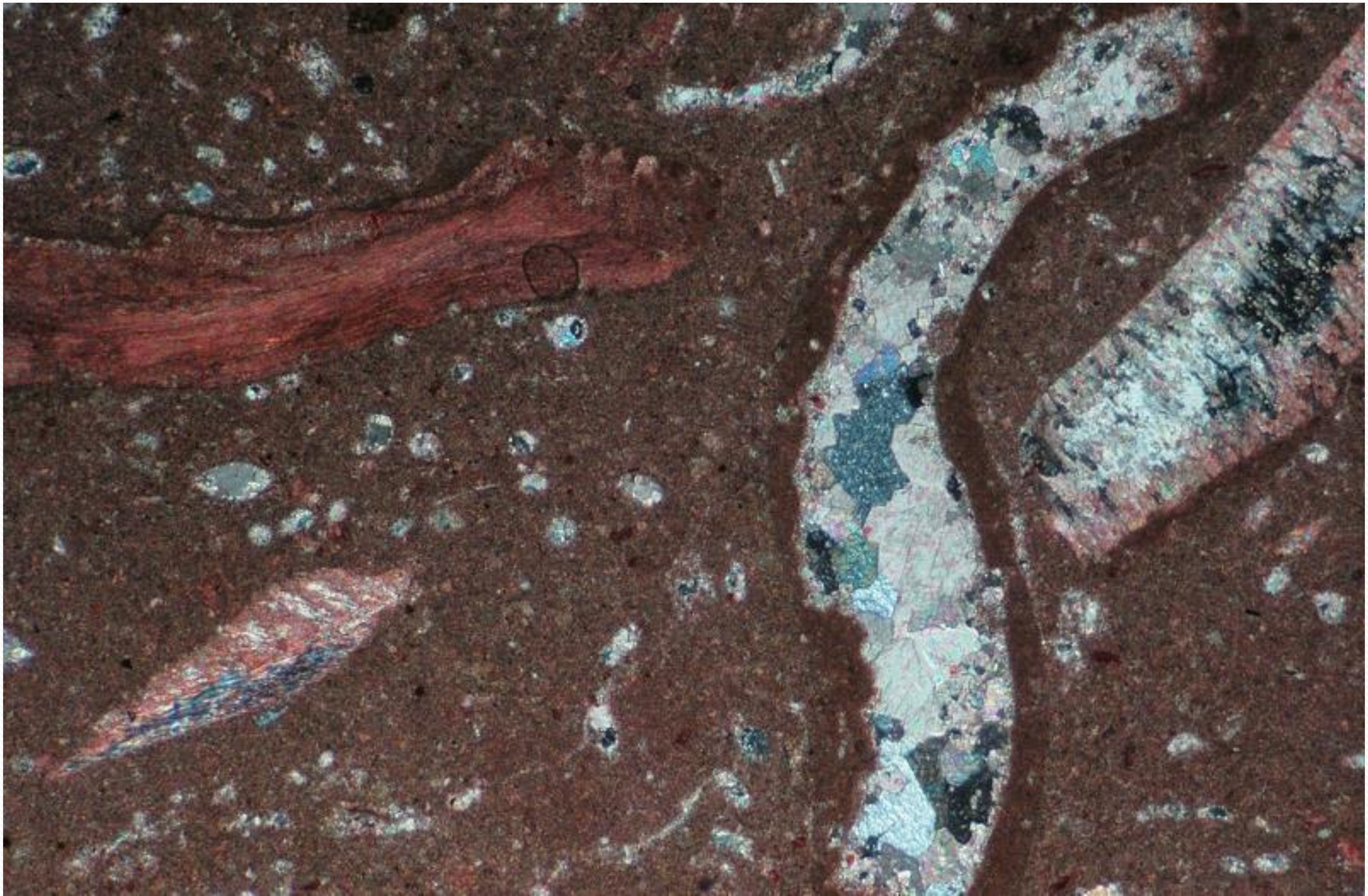
Peloidal grainstone of Inner Shelf



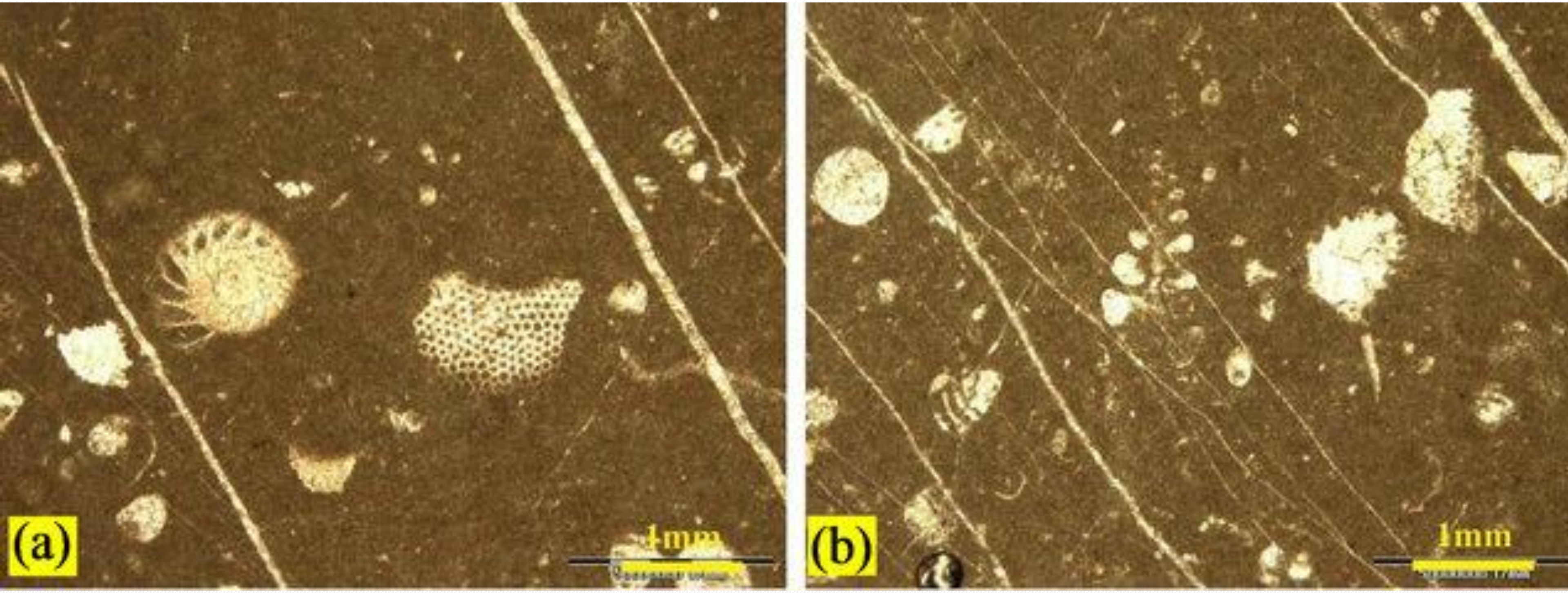
Bioclastic packstone of Inner Shelf



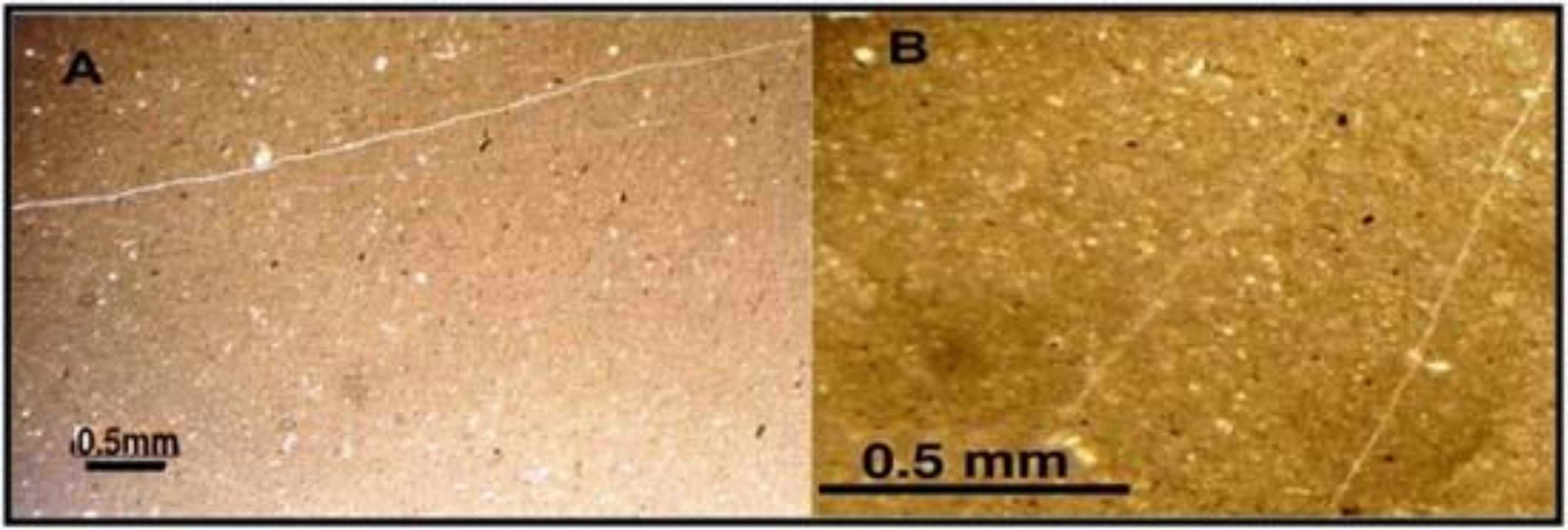
Bioclastic Wackestone of Middle Shelf



Smaller Benthic Foraminiferal Wackestone of Outer Shelf



Mudstone of Lagoon



Carbonates Reef

Lecture-2

Reef: Biologically formed wave resistant rigid body of carbonate having high relief

Reef can be skeletal i.e. frame-built or reef mound

The skeletal reef: are formed by metazoans which posses a rigid calcareous frame. Such reef can be recognized in geological record by the presence of in situ frame builder

The skeletal reef composed of robust metazoans which are wave resistant and make high relief and are called walled reef i.e. modern barrier reefs

The reef mounds: can be either mud mound or knoll reef. The knoll reef have greater skeletal components than the mud mounds

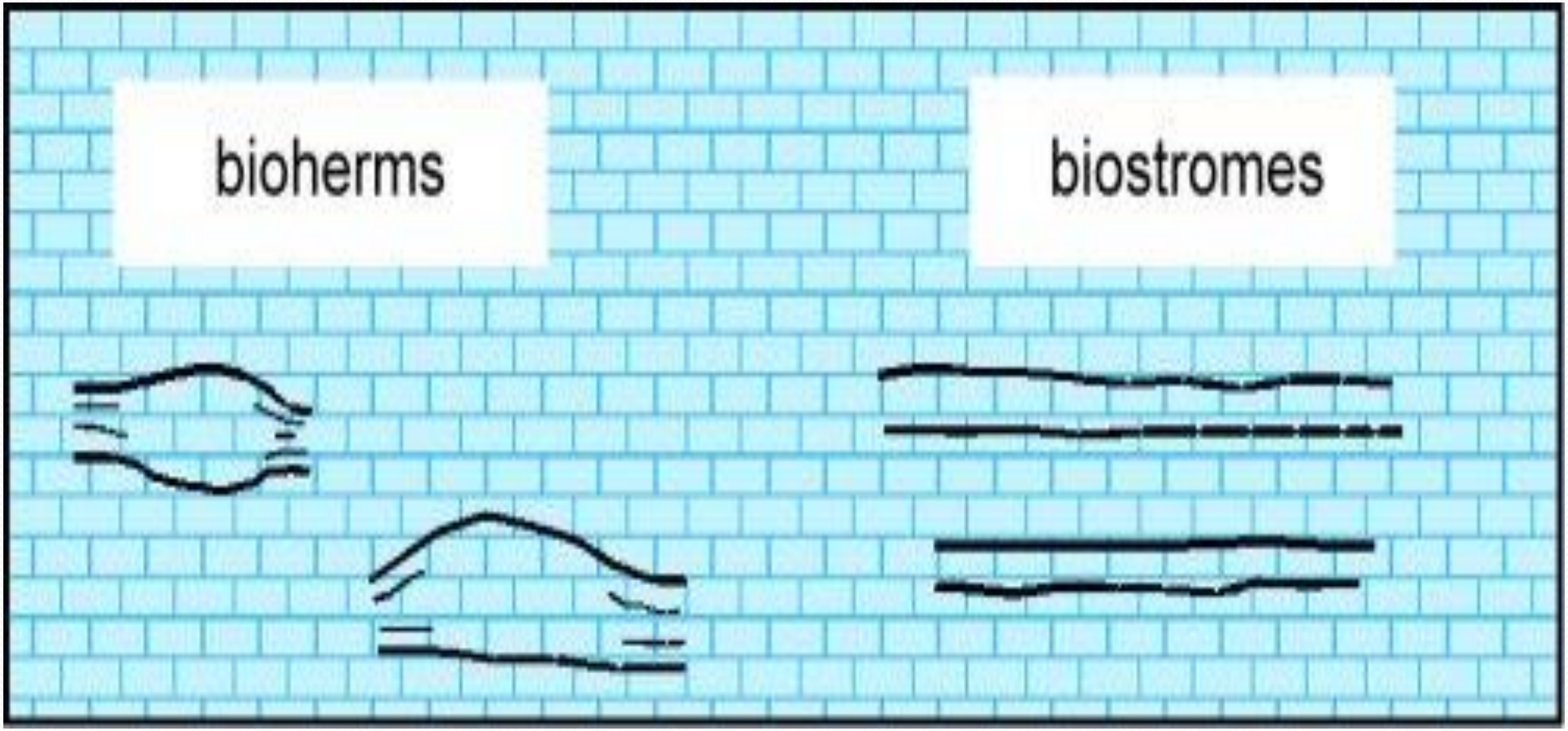
Reef complexes: are large reefal build ups which can be classified into reef core, fore-reef and back reef

Great Barrier Reef Australia

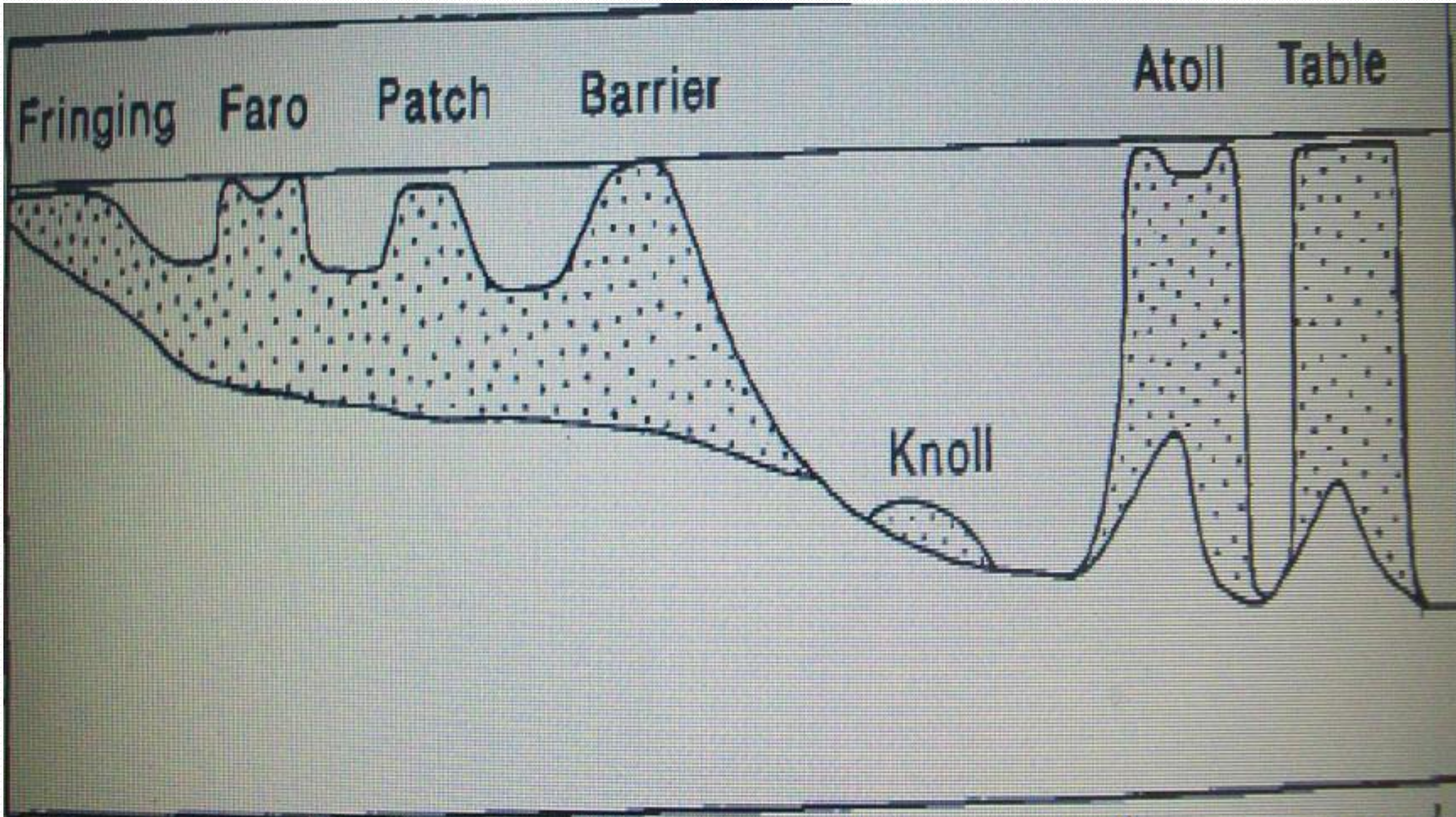
Close Up View of Coral Reef

Mud Mound of Ramp Setting

Synonyms of Reef



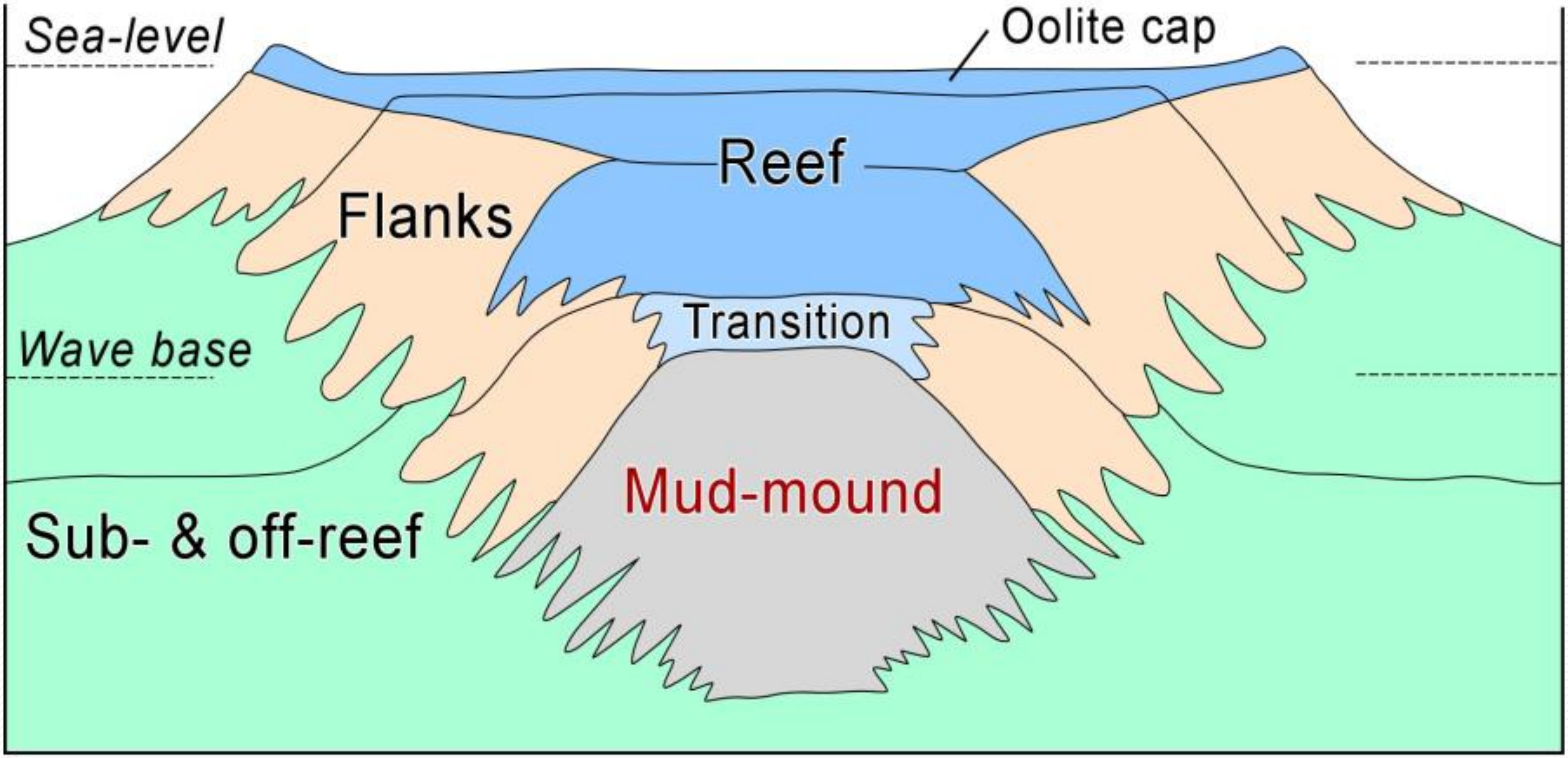
Types of Reef



Atoll Reef

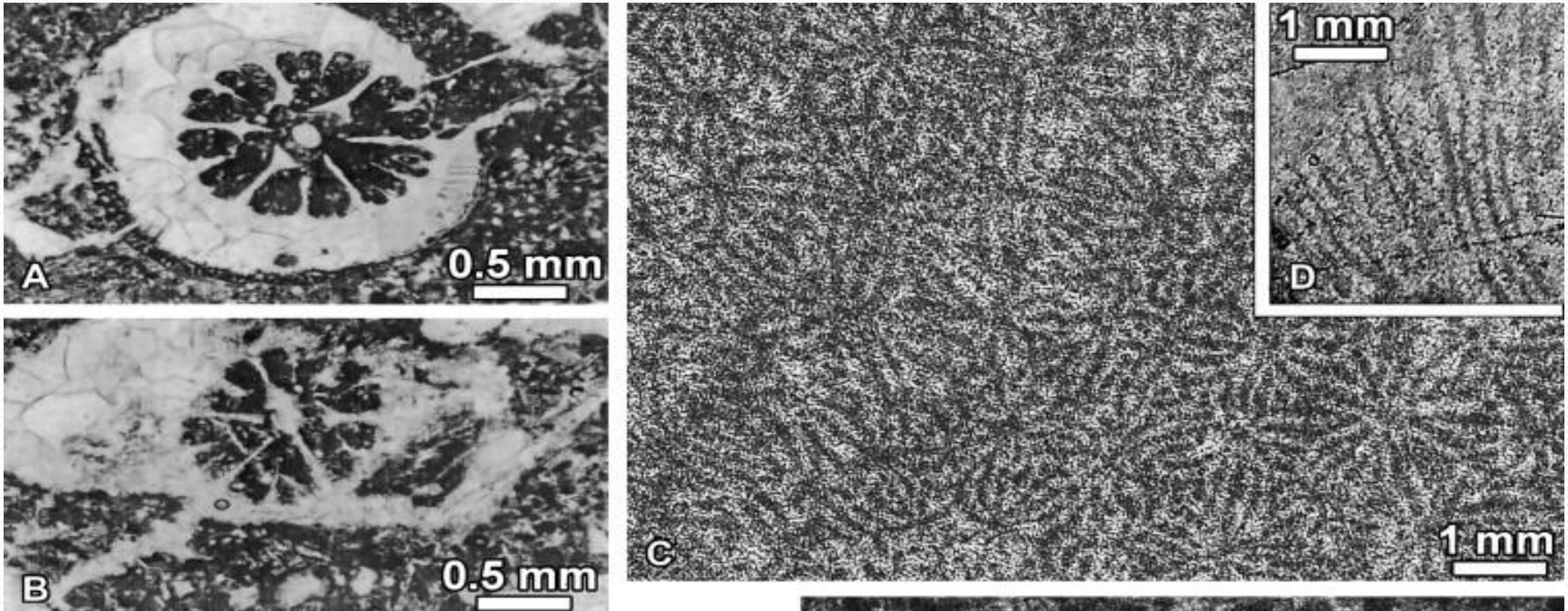
Fringing Reef

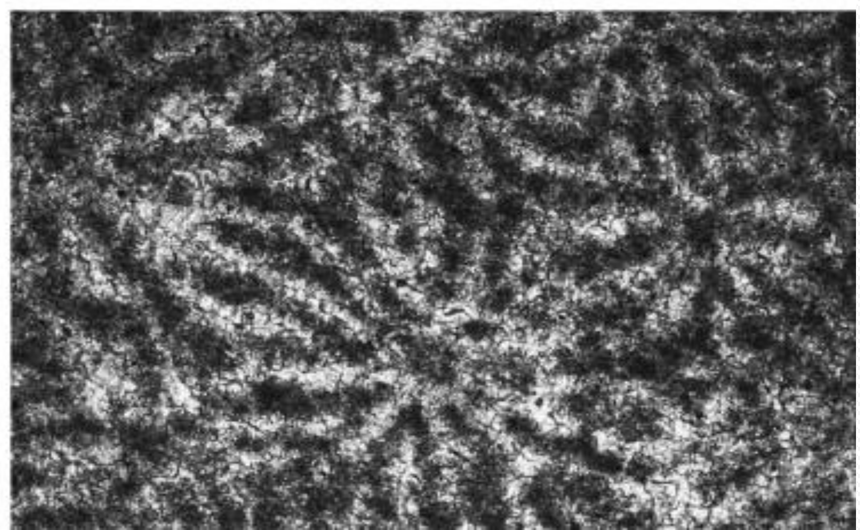
Change in Reef with change in ocean depths



Textoris & Carozzi, 1964

Sclerectenian corals



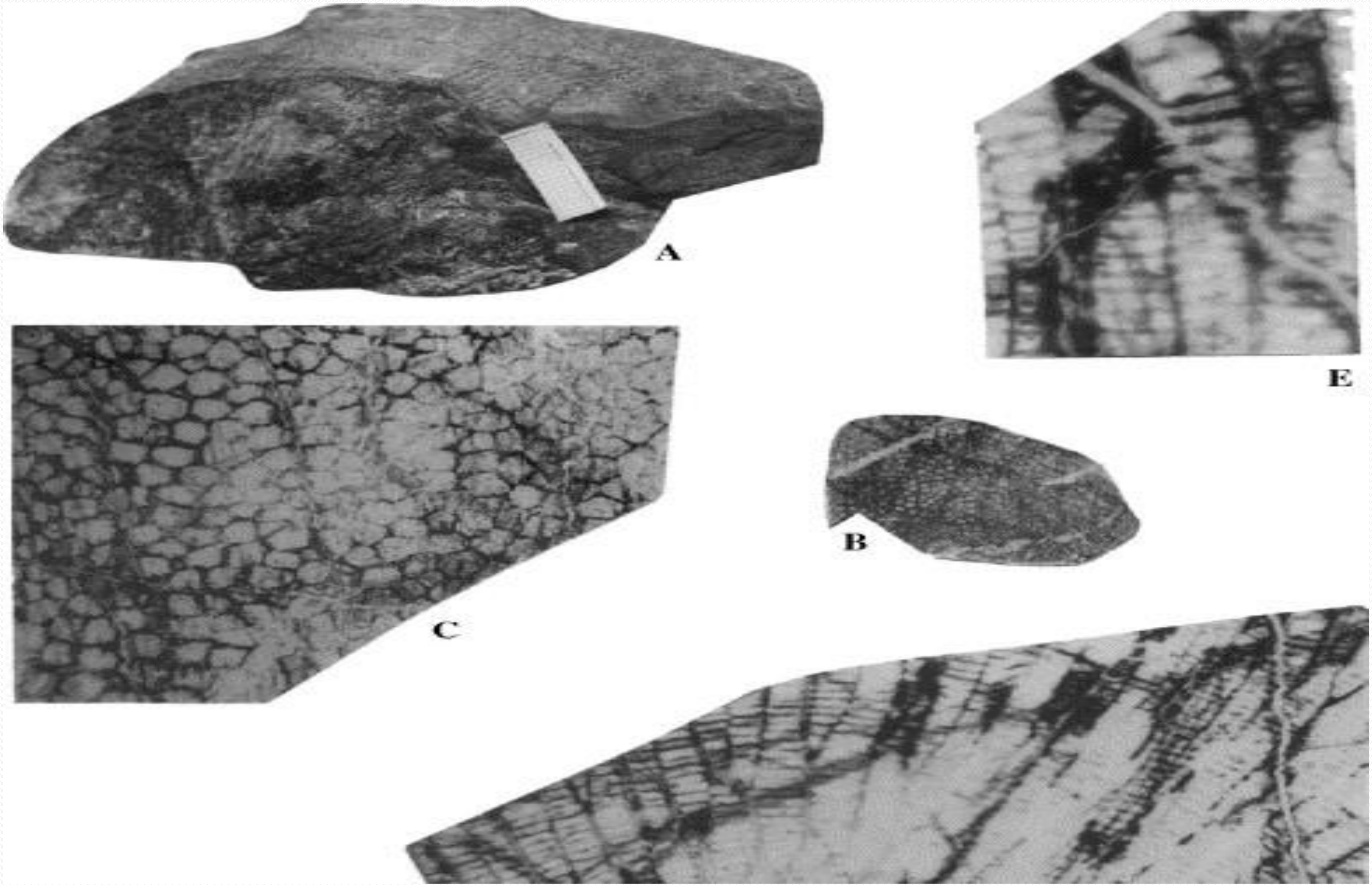


Rugose corals

Rugose corals

Stromatoporoids

Stromatoporoids



Vermitid gastropods

Cretaceous rudist reef facies, Oman

Reef Biota

Reef can also be classified based on the presence of dominant organisms rudist reefs and stromatoporoid reefs

Other terms such as bioherm is used for laterally restricted lensoidal biogenic deposits while biostome relates to tabular and bedded biogenic deposits

Reef Processes

Constructive processes These are the biological processes, such as the direct growth of calcareous organisms, or the effects of organisms such as sediment baffling or binding

Destructive processes: Various processes can damage and destroy the growing reef. These include physical effects such as waves, as well as biological destruction (bioerosion)

Cementation: In many reefs, ancient and modern, extensive early cementation has occurred, directly from marine porewaters. Such cementation is an important factor in influencing reef form

Sedimentation: The high degree of biological activity on and around reefs leads to the accumulation of biogenic matter as well as reef-derived detritus

Reef organisms contribute to reef growth in a number of different ways

Heavily calcified forms, especially large individuals or colonies, may act as the building blocks of the reef, constituting primary framebuilders

The primary builders includes scleractinian corals, crustose coralline algae and Millepora, a hydrozoan, while in ancient reef this role was played by scleractinian, rugose and tabulate corals, stromatoporoids, various calcareous algae and stromatolites

Other calcareous forms may encrust these frame units and bind them together i.e. secondary framebuilders

The encounters are referred to as secondary frame-builders, and today consist of crustose coralline algae, serpulids, bryozoans, corals, foraminifers and vermetid gastropods

Many of these secondary frame-builders also occur in cavities within the reef

However, other organisms are also important, and small or lightly skeletalized epibenthos or nonskeletal organisms can also act as sediment bafflers (trappers) or binders

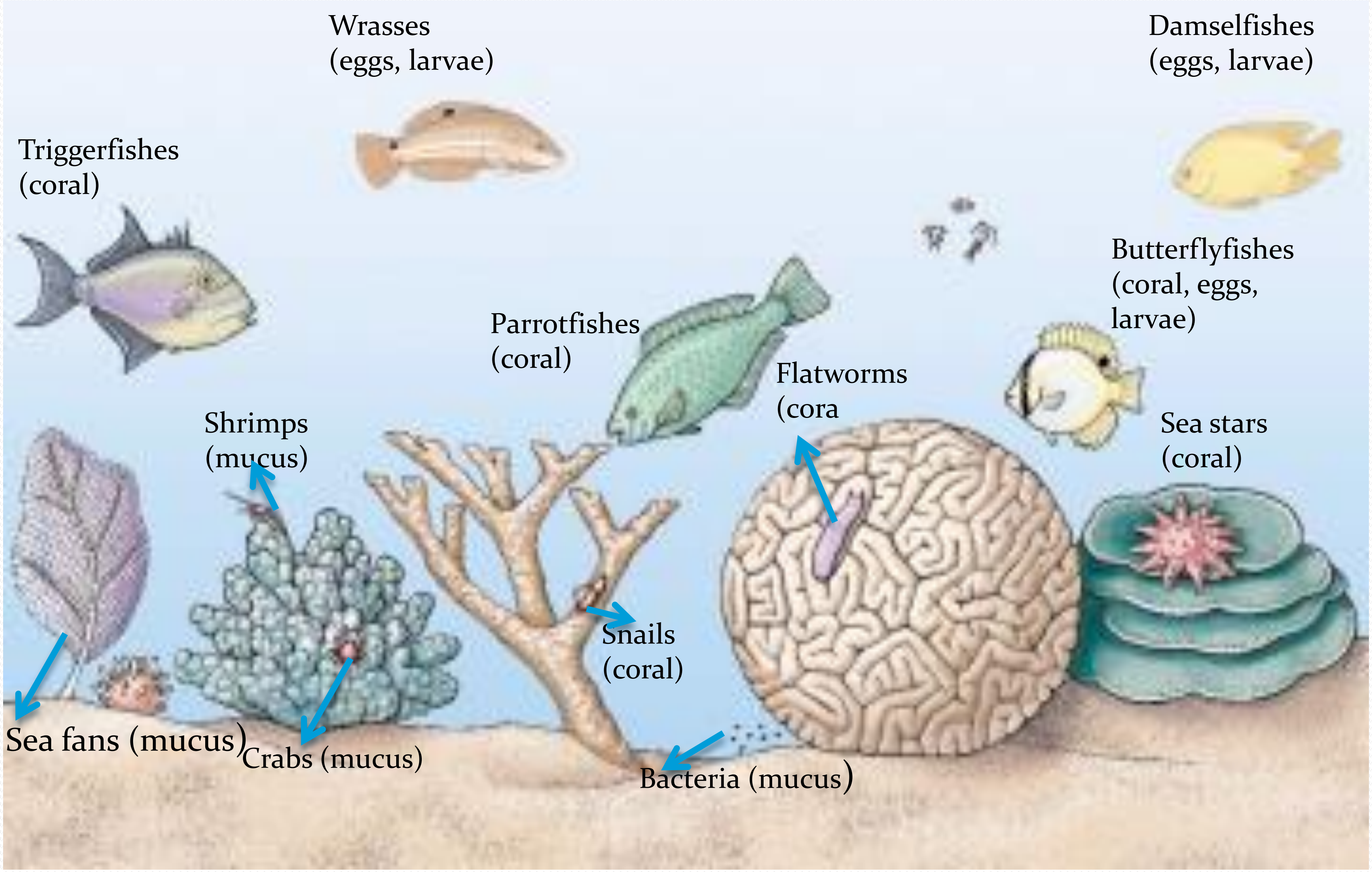
Sea-grasses are important binders in modern seas

Other calcareous organisms act as sediment contributors, such as sessile epibenthic organisms like the calcareous alga Halimeda.

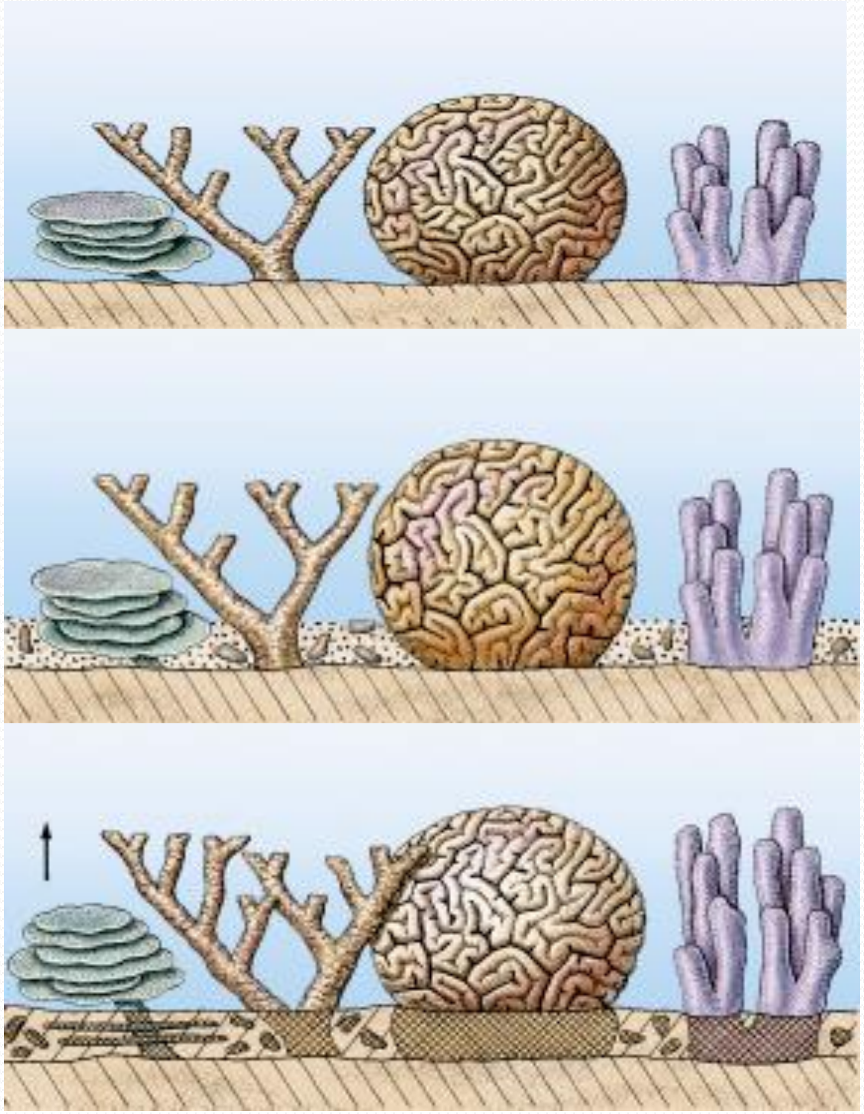
Major reef complexes only develop when suitable large frame-building organisms are present, but this has only occurred some six or seven times during the geological record

Such sediment contributors are especially important in the formation of reef mounds where the accumulation of locally produced calcareous sediment results in reef growth

Feeding Pattern on Reef

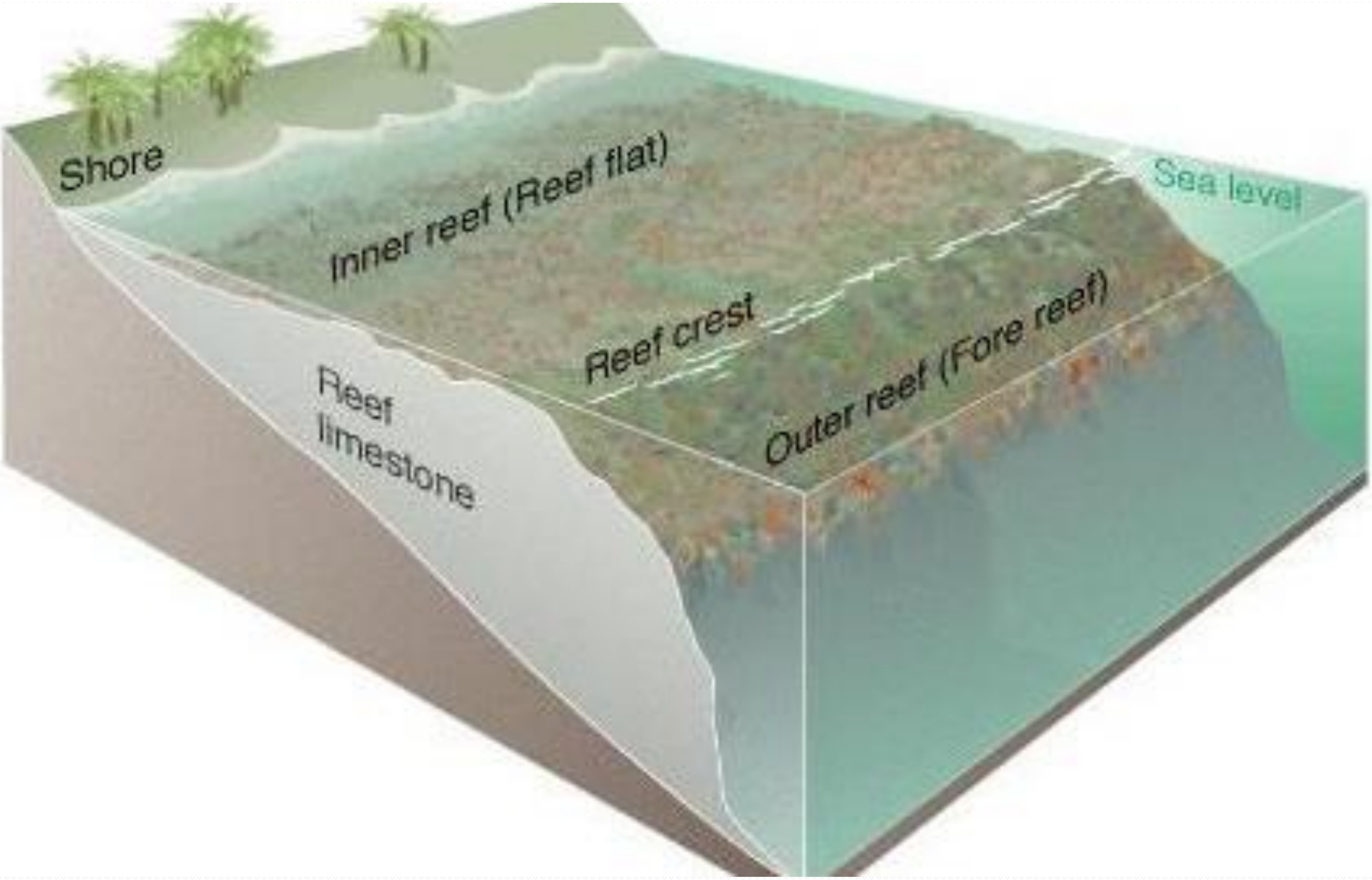


Sedimentation in Reef

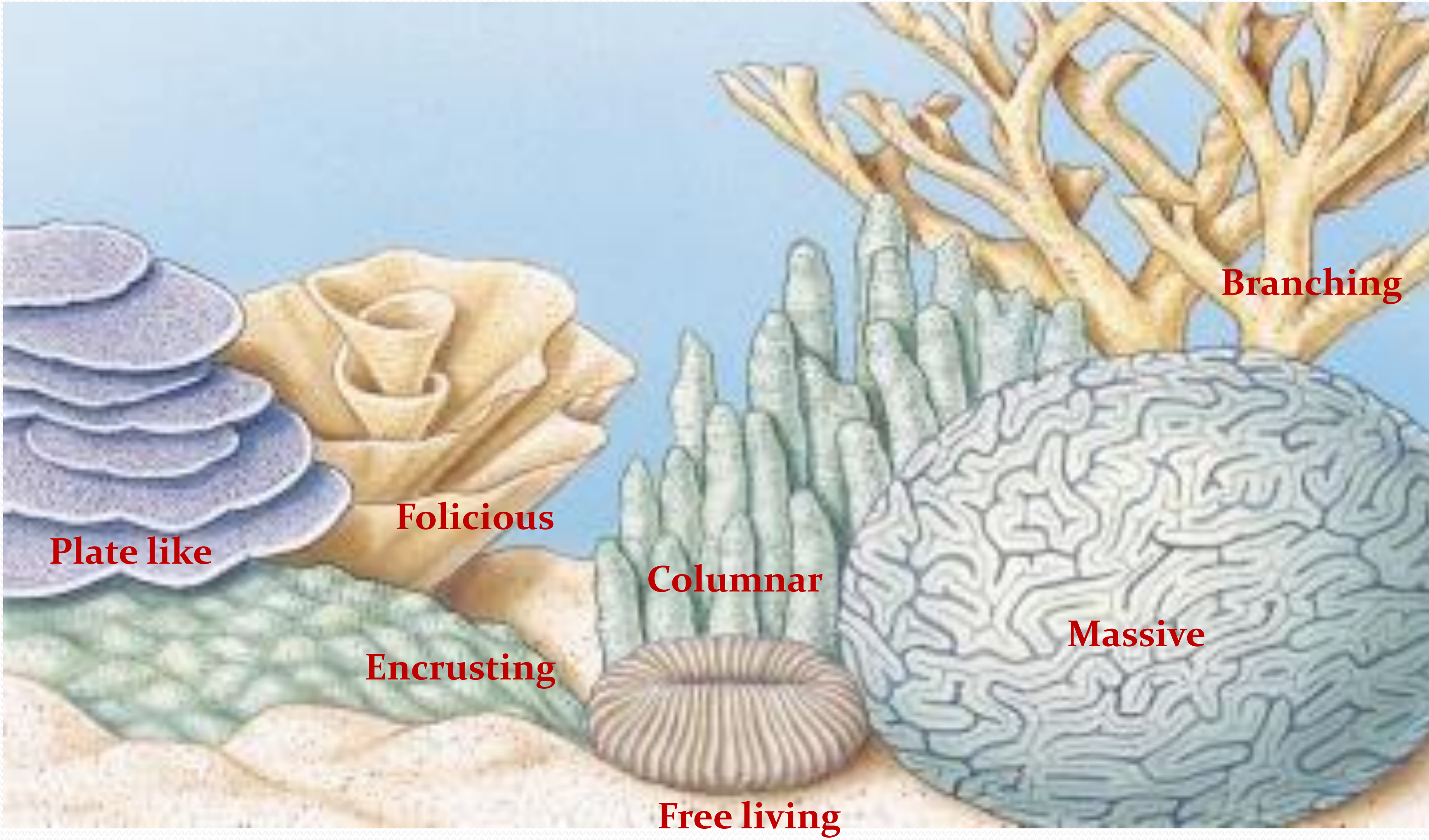


Tabulate corals

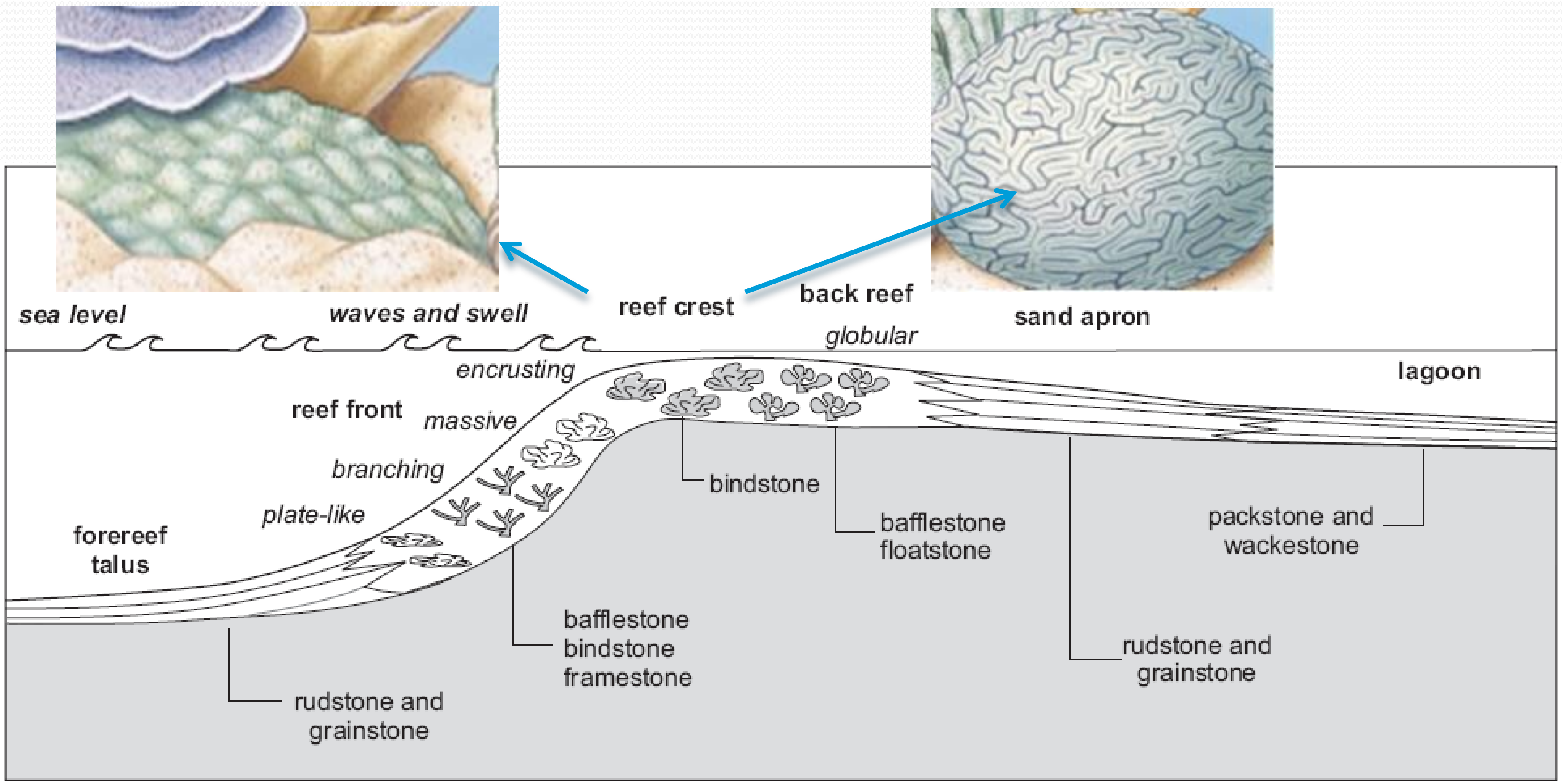
Sub-Environments of Barrier Reef



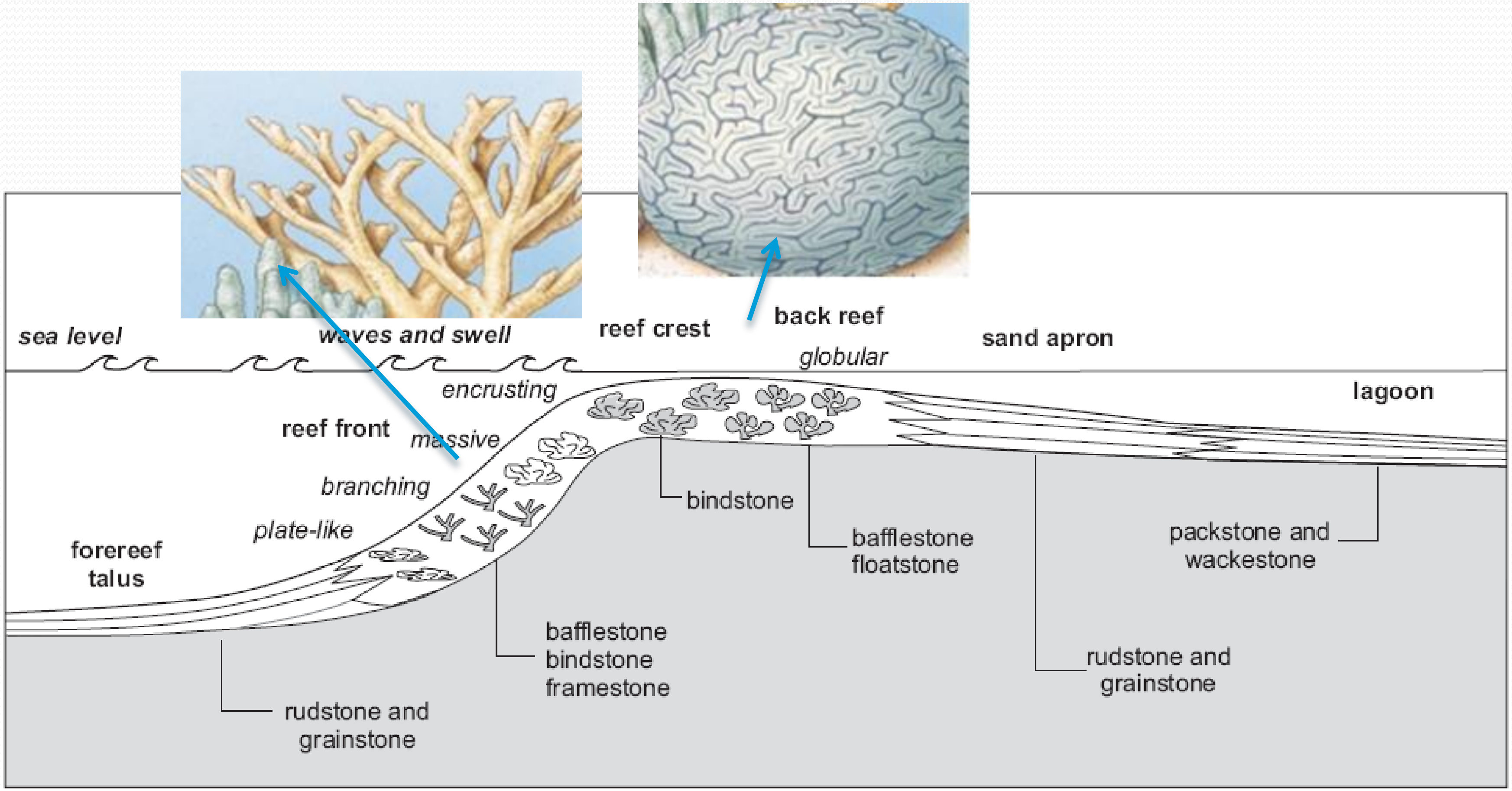
Nature of corals changes with depth



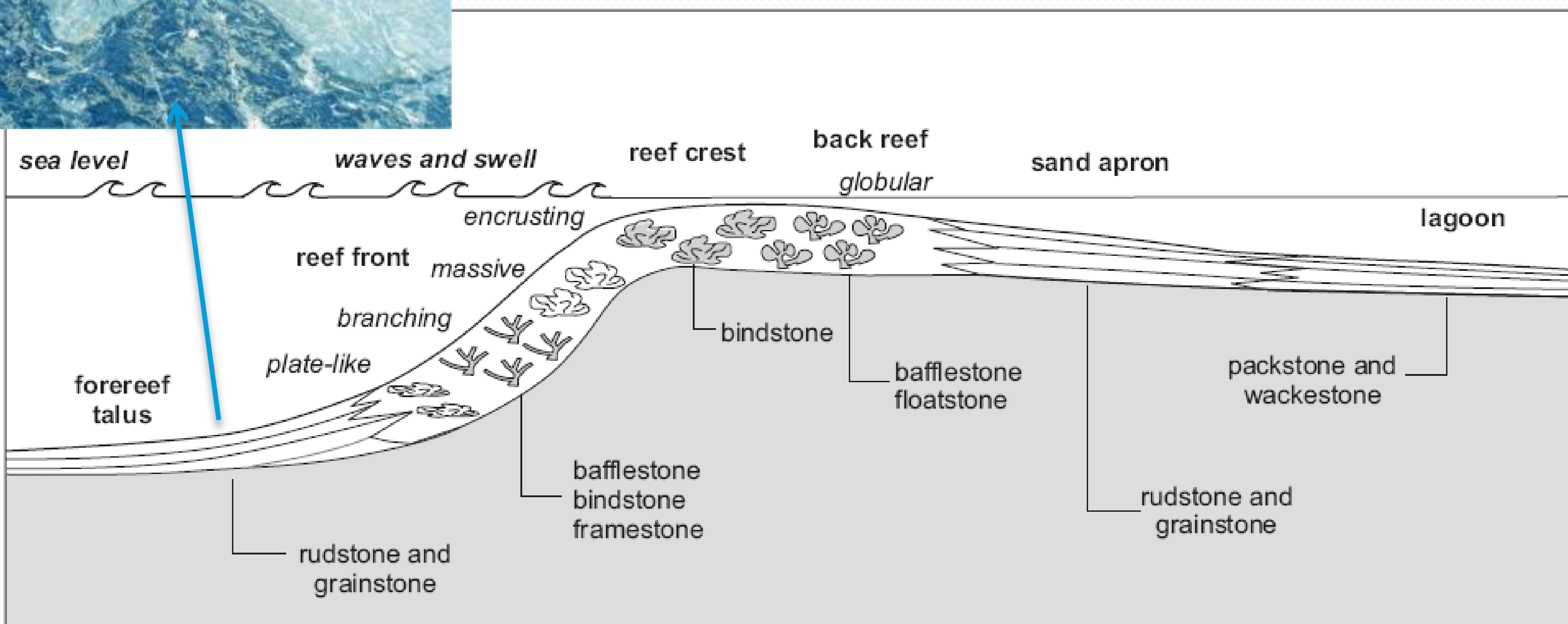
Reef Structure



Changes in Reef structures with Ocean Depth



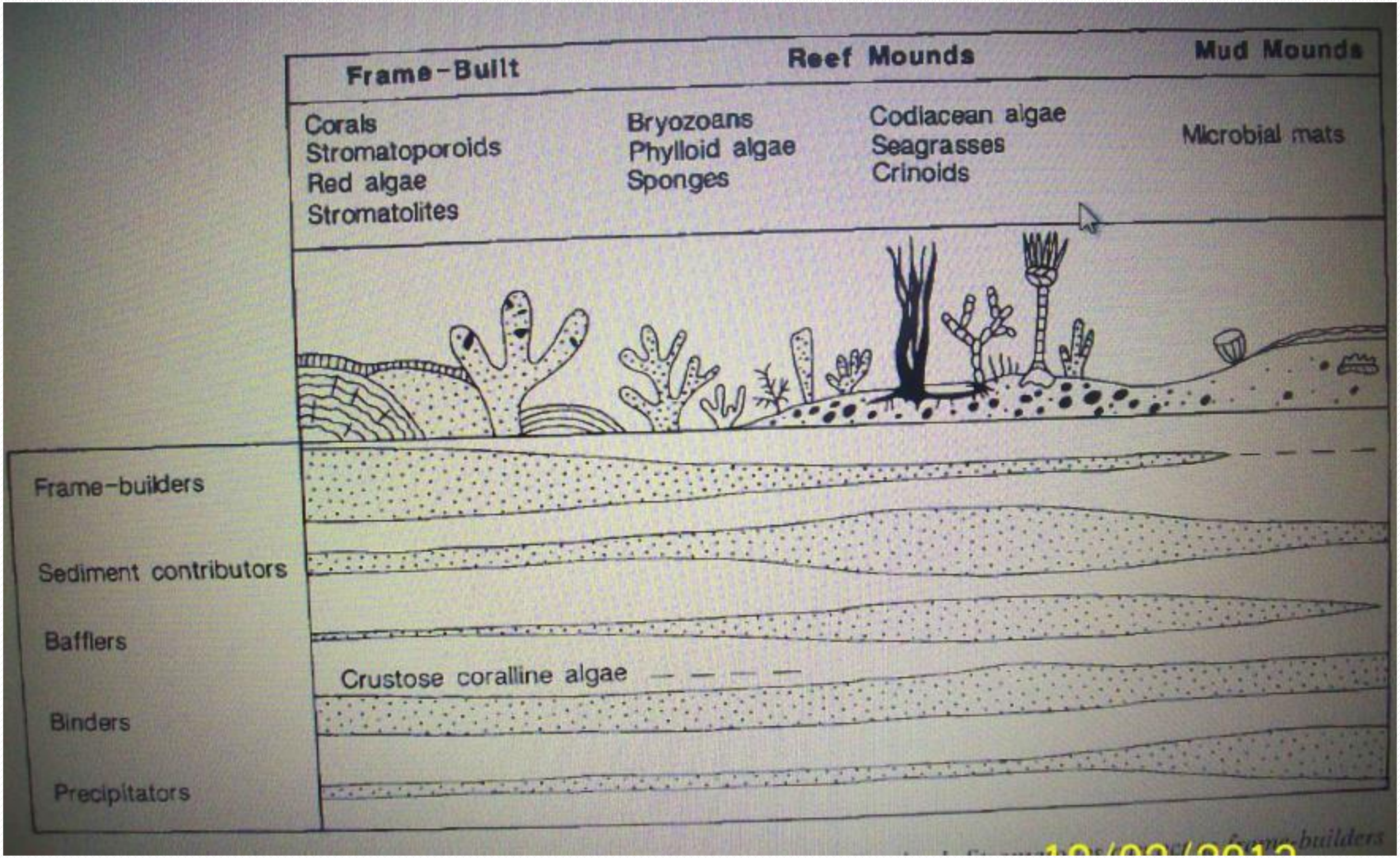
Break-up of the reef core material by wave and storm action leads to the formation of a talus slope of reefal debris. This forereef setting is a region of accumulation of carbonate breccia to form bioclastic rudstone and grainstone facies.

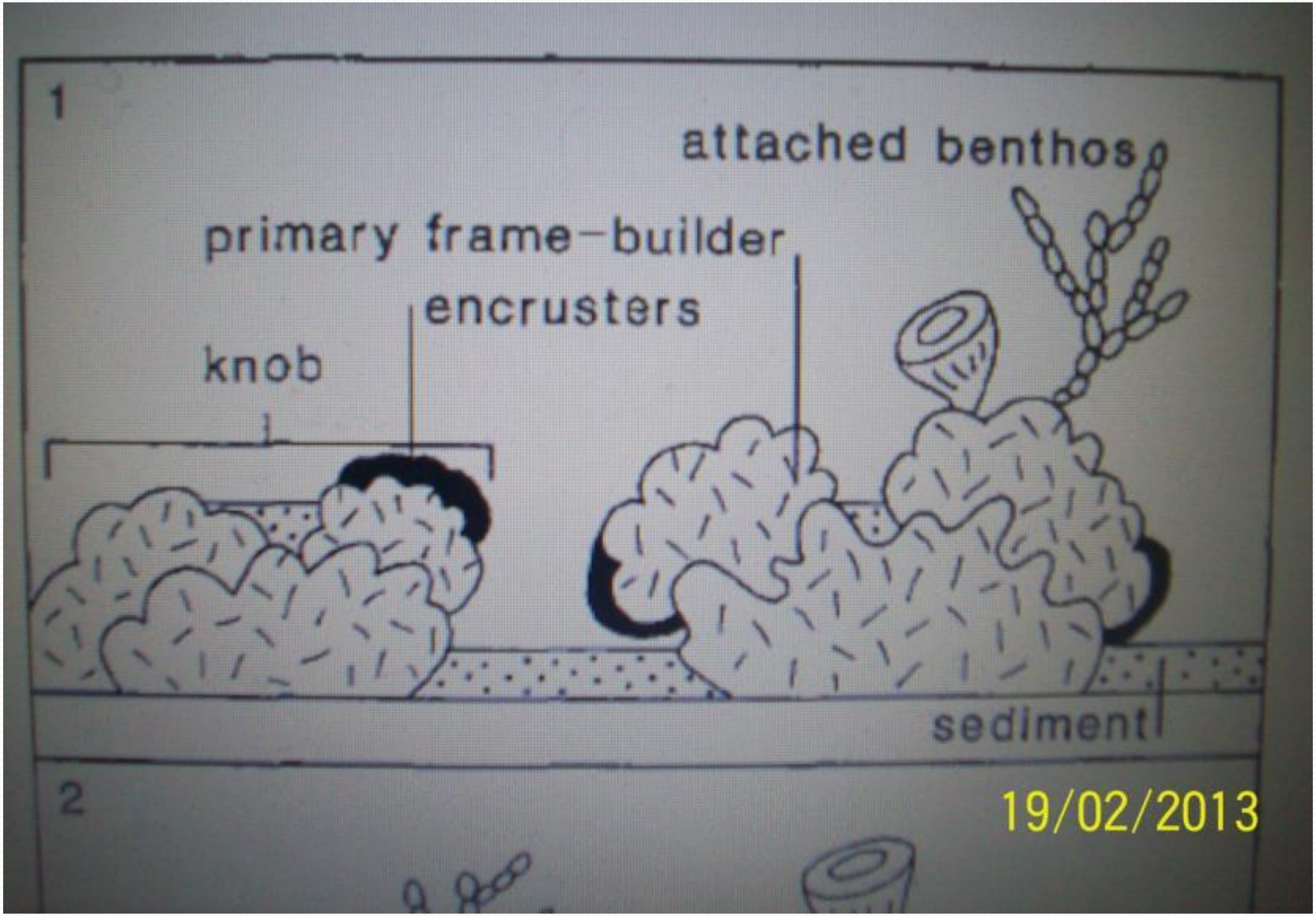


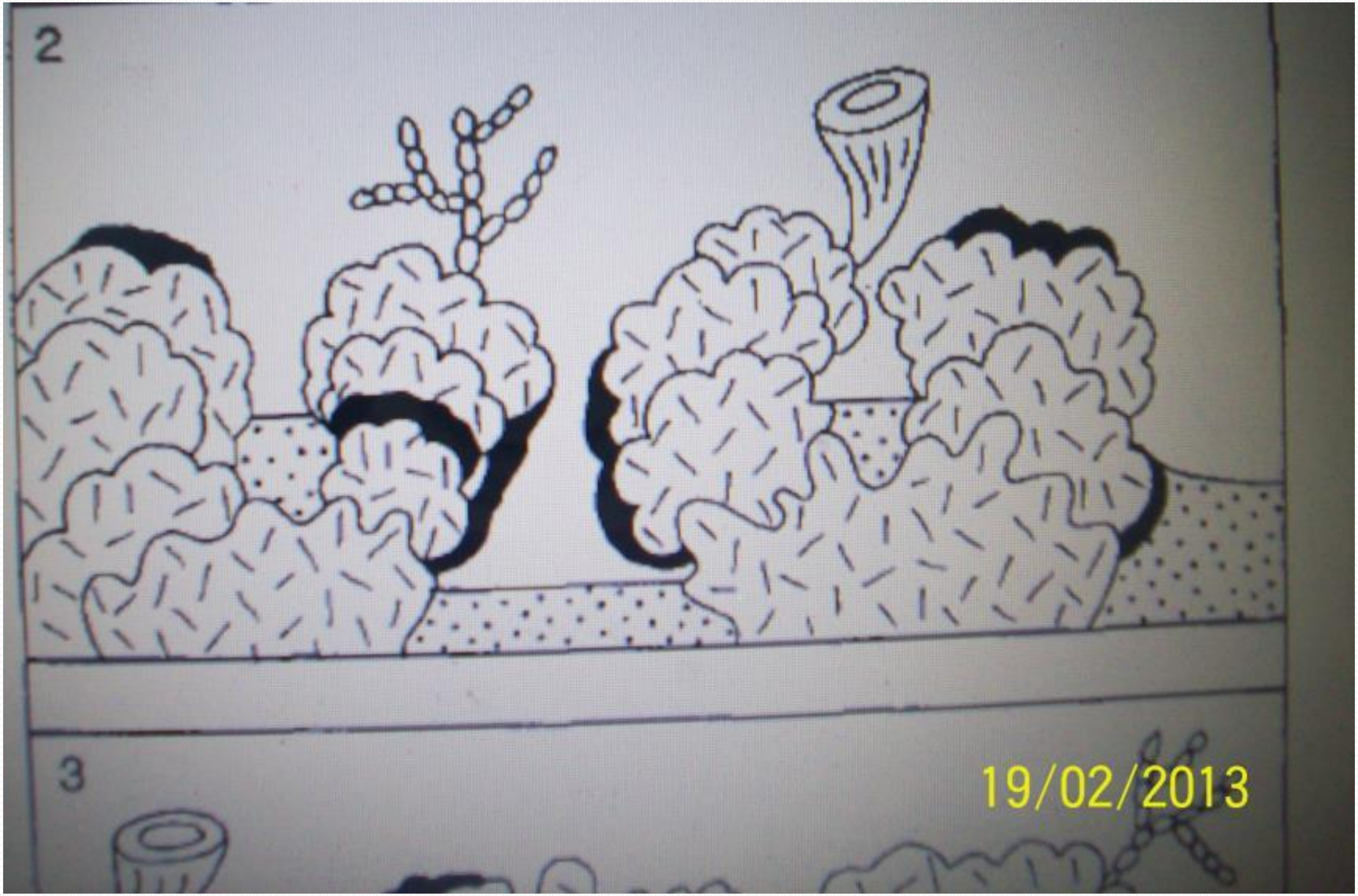
Carbonates Reef

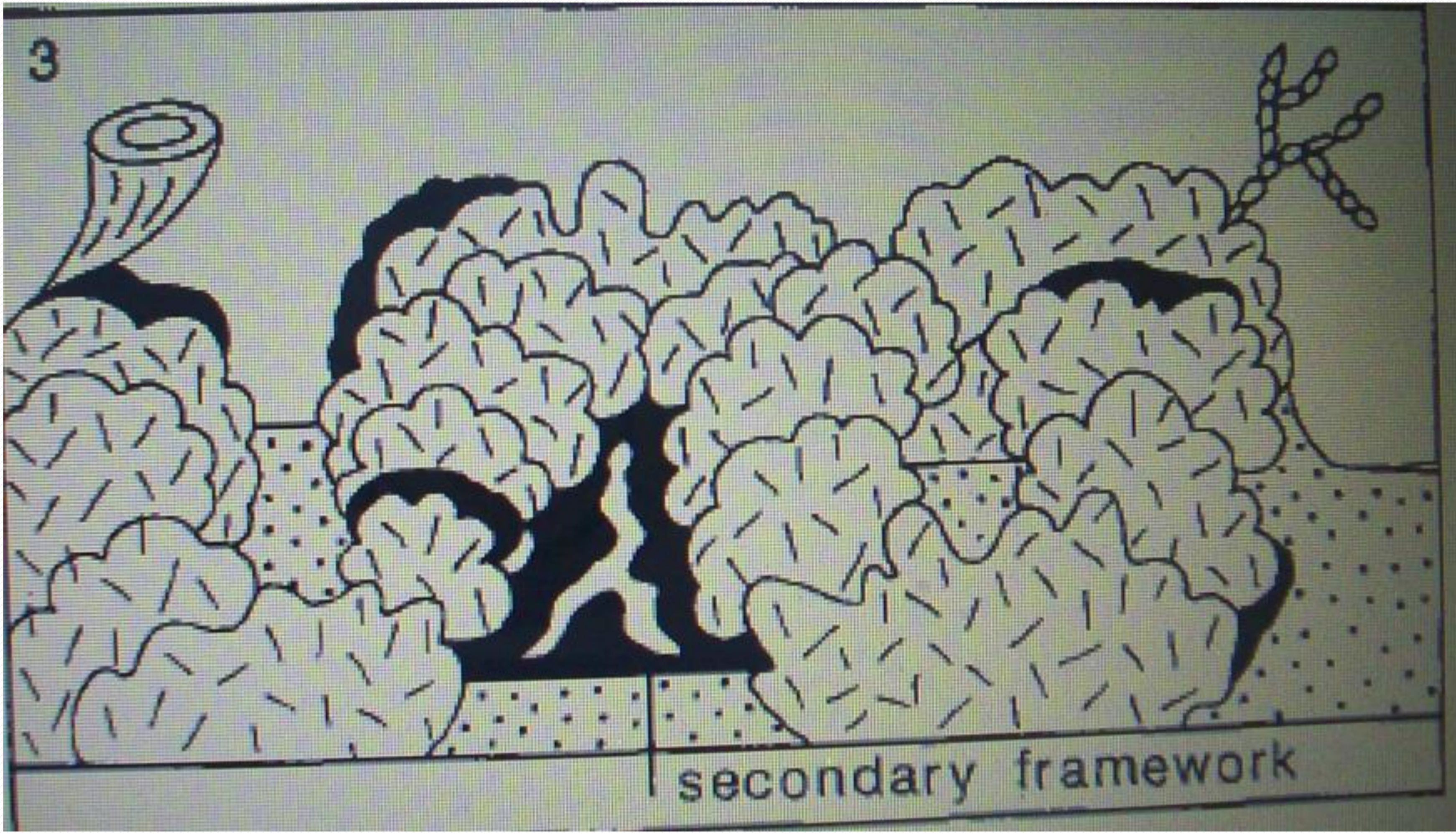
Lecture-3

Types of Reefs and its constituents

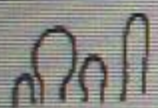
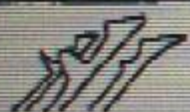
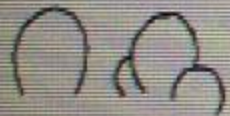



1
attached benthos
primary frame-builder
encrusters
knob
sediment
2
19/02/2013

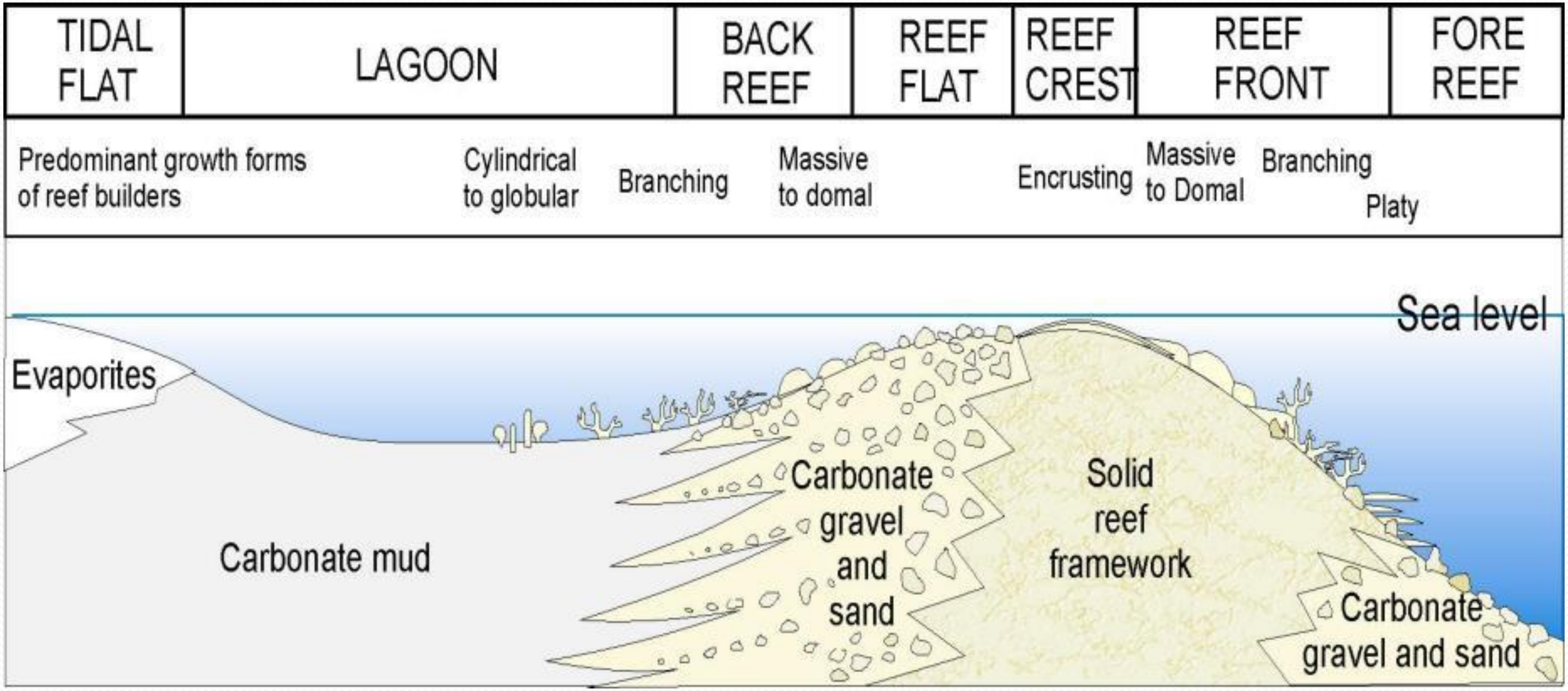

2
3
19/02/2013


3
secondary framework

Reef Morphology and Energy

A	Growth form	Environment	
		Wave energy	Sedimentation
	Delicate, branching	Low	High
	Thin, delicate, plate-like	Low	Low
	Globular, bulbous, columnar	Moderate	High
	Robust, dendroid, branching	Mod-high	Moderate
	Hemispherical, domal, irregular, massive	Mod-high	Low
	Encrusting	Intense	Low
	Tabular	Moderate	Low

Sub-Environments of Reef and Sediments types



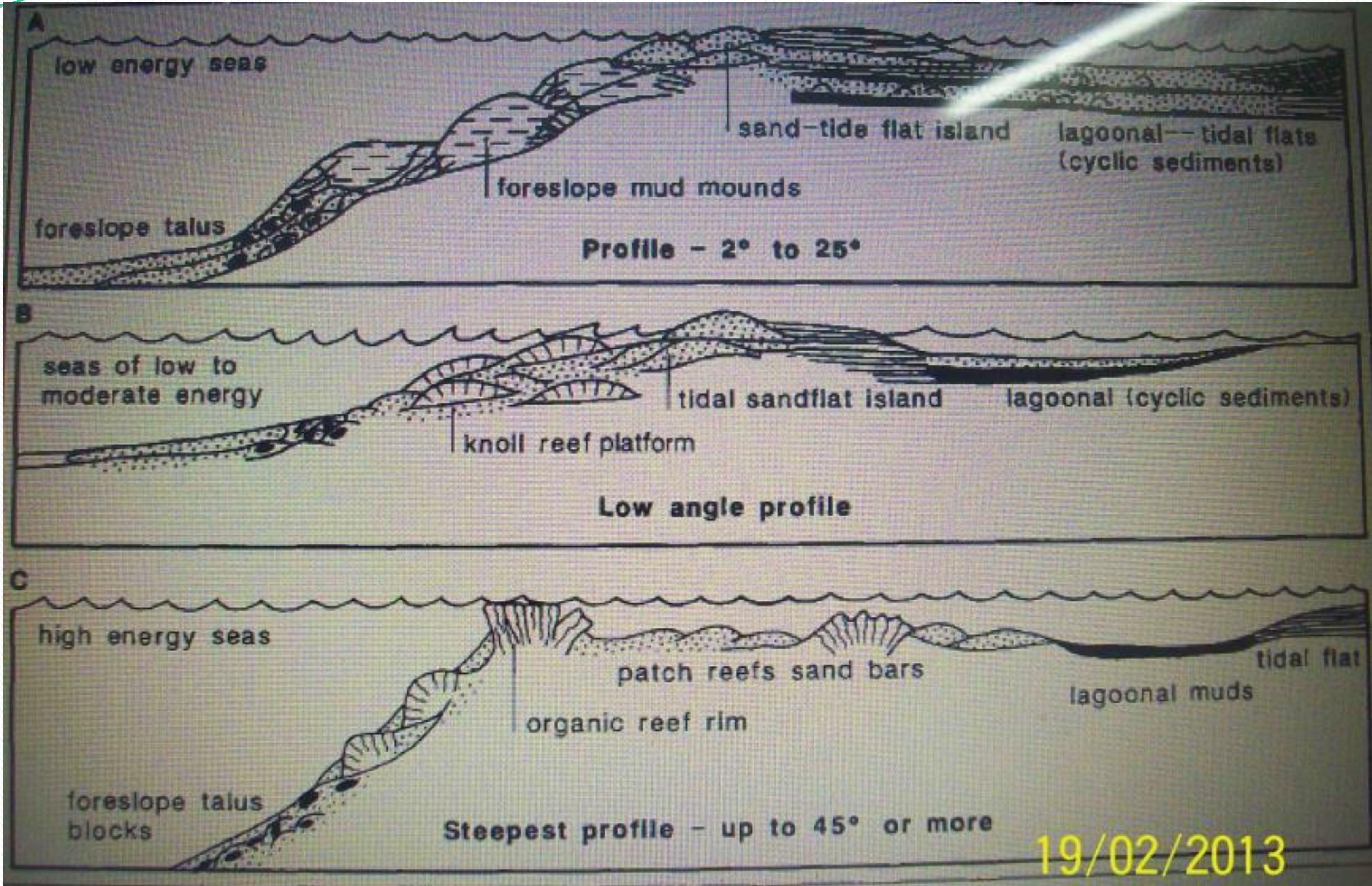


Fig. 4.87 Three types of reef development on carbonate platform/shelf margins. After Wilson (1974). **Type 1.** *Downslope ... located on the foreslope of the*

Destructive Processes

Two types of destruction need to be considered: physical destruction and bioerosion

Physical destruction is a constant process caused by wave and current activity on reefs

The effects of such (storms and hurricanes) rare events are difficult to assess in ancient reefs but bioerosion, are ubiquitous

The rate of bioerosion almost equals the rate of calcification for modern coral reefs

Borers are particularly important in reef destruction and dead coral on reefs typically exhibits fringes, several centimeters thick, formed by multiple borings

- The most important borers in reefs include the algae, cynaobacteria, fungi, sponges, sipunculids, polychaetes, molluscs, barnacles and echinoids

- These range from small cavities formed by clionid sponges to irregular cavities up to 50 mm in diameter created by *Siphonodictyon*

- A succession of bioeroders attack dead coral skeletons, initially microborers and later macroborers

- Burrowing is not an important bioerosive process in frame-built reefs, but becomes significant in reef mounds.

- Raspers are browsing organisms, such as gastropods and echinoids, which scrape the calcareous subsubstrate to remove mainly algal material

- Bioturbation by callianassid shrimps is a significant process in many back-reef settings

- **Bioerosion can destroy the reef and it can produce sediments**

Sedimentation

- **Material is supplied to reefs from three main sources: mechanical breakdown of framework material by physical or biological processes, material contributed by the decomposition of reef dwellers, and material supplied from outside the reef.**

- **The most important sediment contributors in modern reefs are *Halimeda, coralline algae, corals, foraminifera* and molluscs (Milliman, 1974).**

- **Cavities formed on and in the reef by irregular growth and bioerosion are quickly filled by sediments**

- **Fine-grained material can be transported and pumped into the network of cavities near the surface of the reef, and the result is an abundance of geopetal, internal sediments**

- **Such sediments tend to be most common in the reef-front and reef-crest zone**

Cementation

- **Cementation is a major process and is partly responsible for the steep, wave-resistant profiles of many reefs.**
- **It is pervasive in the reef-front and reef-crest zone where high water flux occurs as a result of the pumping action by waves**
- **One interesting feature of cement distribution is its relationship to reef form i.e. Reefs with steep profiles, such as modern walled reef complexes, present a prominent surface to wave and current action so that the force of seawater flux is high and extensive cementation occurs**

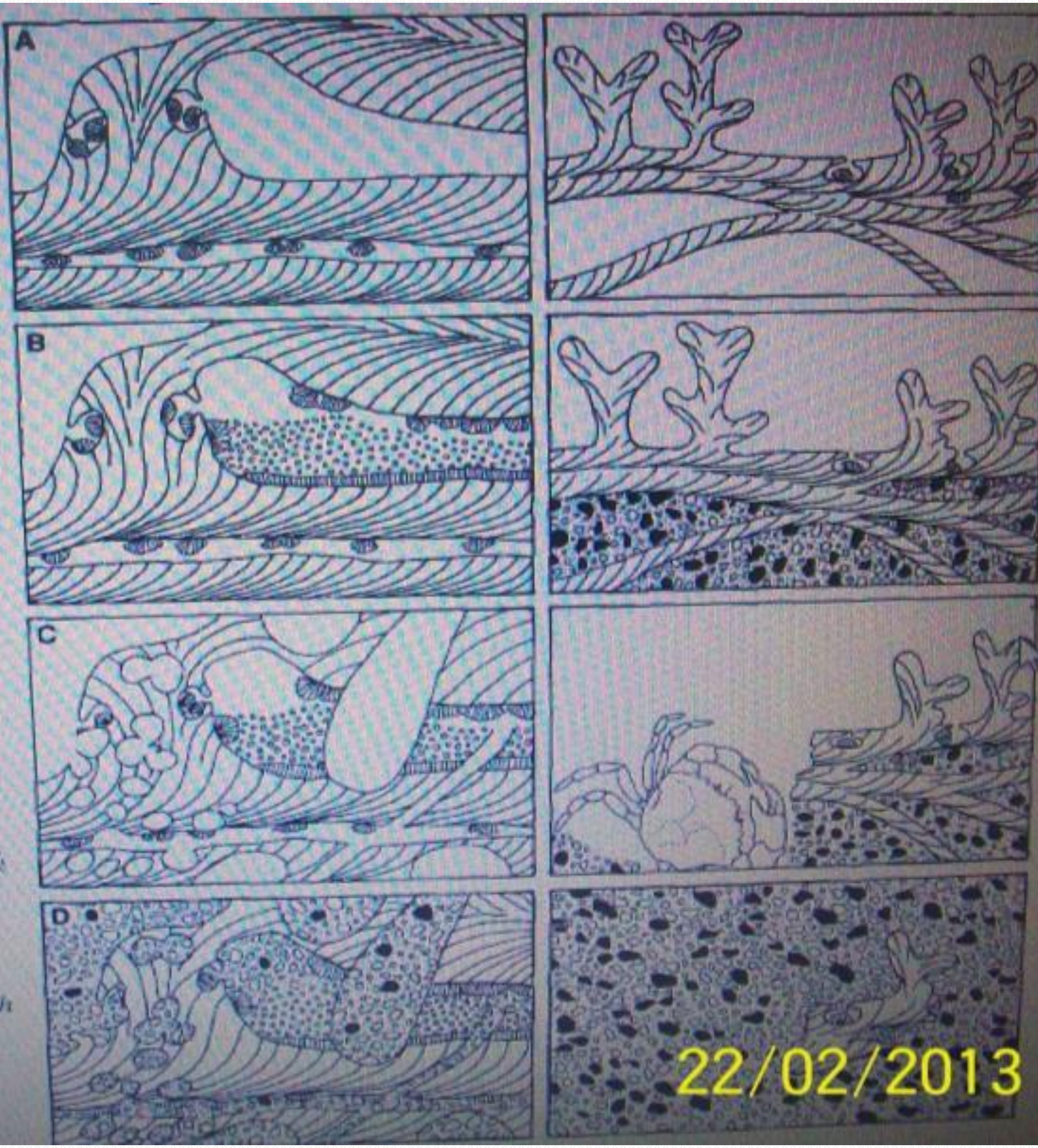


Fig. 4.92 *Contrasting roles of reef processes in high-energy frame-built crustose coralline algal reefs and lower-energy reef mounds. (A) Construction phase: in high-energy reefs a rigid framework is formed by fused thalli. In the moderate-energy reefs the framework is more delicate. In both examples minor intraskeletal cements may occur in conceptacles. (B) Cementation: this is more widespread in the higher-energy reef where a greater seawater flux occurs and where cavities are kept open. In the moderate-energy framework the growth cavities may be filled by fine-grained sediment. (C) Bioerosion: in the rigid high-energy framework borers will be the main agents of bioerosion. In the lower-energy reefs crustacean burrowing destroys the delicate framework. (D) Sedimentation: with further sedimentation the high energy reef will develop a grainstone matrix with* in situ *framework, while the moderate-energy framework is destroyed and incorporated into a coralline algal wackestone—*

Controls on the Reef Morphology

- **Biological Control**

- **Scleractinian zooxanthellate corals adapted to nutrient-deficient environment i.e. nutrient excess can reduce or kill off coral growth.**

- **Increased nutrient concentrations (phosphates and nitrates) stimulate plankton growth, which reduces water transparency, and both coral and calcareous algal growth**

- **In addition, high nutrient excess can stimulate the growth of non-calcareous algae and other organisms. i.e. both competition and bioerosion will increase, reducing reef growth.**

- **Nutrient supply can be affected by oceanographic changes, induced by climatic, eustatic and tectonic factors**

- Under optimal conditions scleractinian growth can be very rapid and 100 m 1000 yr-1 is possible

- However, reef growth is slower because optimal conditions are not reached or maintained

- Rates of reef growth of 9-15 m 1000 yr-1 have been recorded in the Caribbean, and 7-8 m 1000 yr-1 along the Great Barrier Reef (but with rates as high as 16 m 1000 yr-1 for coral frameworks)

- Different biofacies on reefs also grow at different rates

- Reef growth is typically greatest on the wave influenced windward margins of reefs.

- In the highest energy zones, such as reef crests, crustose coralline algae dominate, but they are slow frame-builders with mean rates of 3.2 m 1000 yr-1 on Caribbean reefs and 2 m along the Great Barrier Reef

Along moderate-energy zones acroporoid corals dominateand these have much higher growth rates

Antecedent Topography

Reefs will preferentially develop on topographic highs because shallow-water corals grow faster than deeper forms and sedimentation will be reduced on higher areas

***The presence of antecedent* topographic features will therefore influence the position and growth of reefs**

***Older reefs:* Many present-day reefs have developed on older reefs as exposed platforms or shelves were flooded during the last sea-level rise.**

Karstic topography: During Pleistocene sea-level low-stands prolonged subaerial exposure created karstic surfaces on many platforms and shelves and with later sea-level rises reef growth occurred on these karstic highs

Erosional terraces: Pleistocene low-stands were associated with wave erosion and terraces along many
coastal zones. The terraces were later colonized by reef organisms

Siliciclastic/volcanic topographic features: New reef growth has taken place on depositional relief such as the Pleistocene river terraces of Belize

However, as pointed out by James & Macintyre, many reefs at the present time, and in the geological record, have developed where no obvious topographic highs occurred i.e. Antecedent positive topography is not always a requirement

Sea Level Changes and Reefs

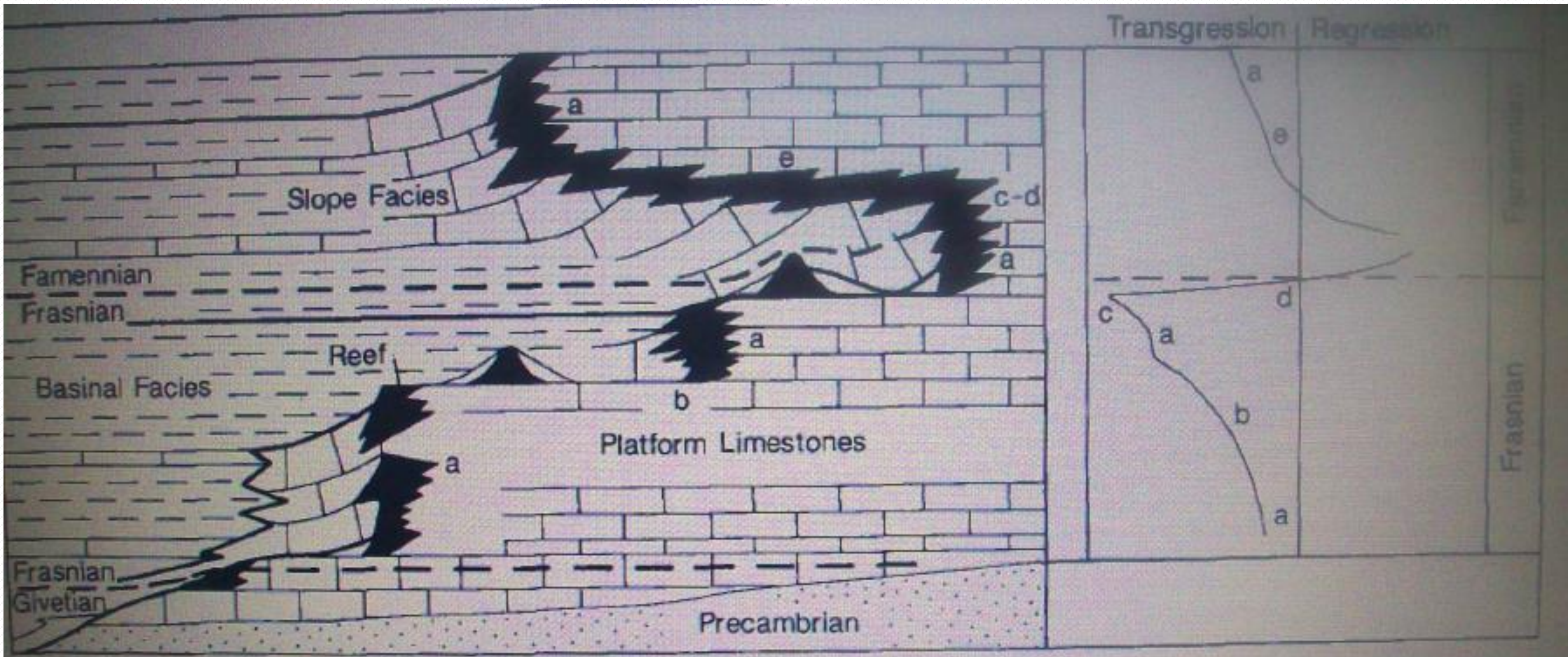
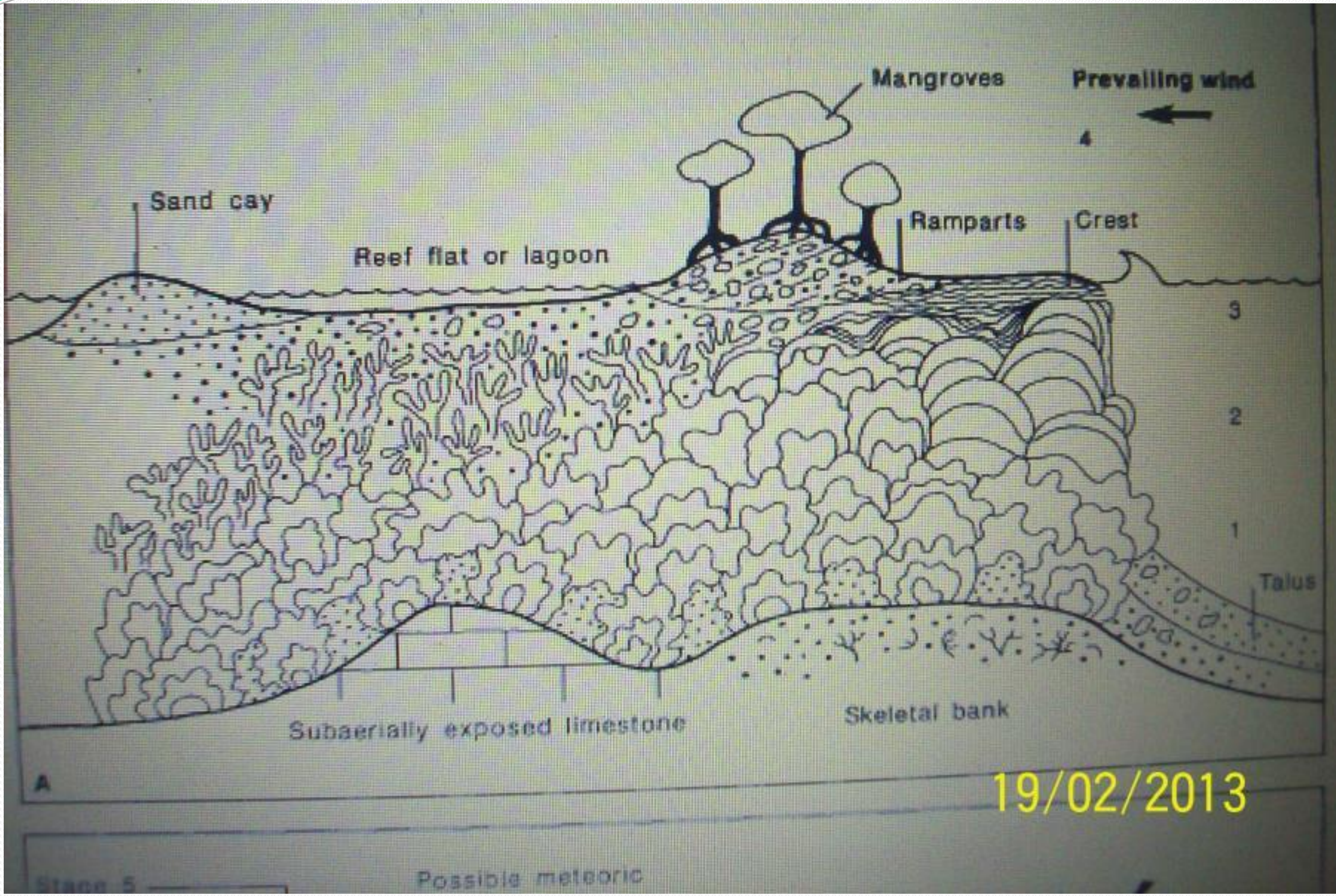
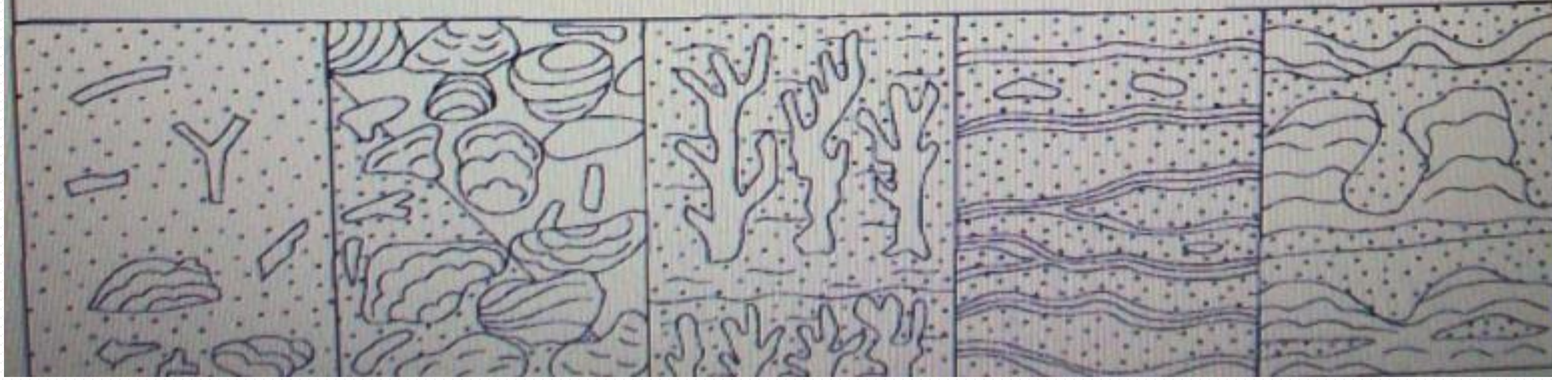


Fig. 4.98 *Schematic cross-section illustrating the development of Devonian reef complexes and associated facies in the Canning Basin of Western Australia, and relative rates of transgressions and regressions during the deposition of the reefs.*


Mangroves
Prevailing wind
4
Sand cay
Ramparts
Crest
Reef flat or lagoon
3
2
1
Talus
Subaerially exposed limestone
Skeletal bank
A
19/02/2013
Stage 5
Possible meteoric

Sediments Textures in a Reef

Allochthonous		Autochthonous		
Original components not organically bound during deposition		Original components organically bound during deposition		
>10% grains>2mm				
Matrix supported	Supported by >2mm component	By organisms which act as baffles	By organisms which encrust and bind	By organisms which build a rigid framework
Floatstone	**Rudstone**	**Bafflestone**	**Bindstone**	**Framestone**



Reef facies

Reef Crest : **The highest zone on the reef is the most exposed part of the reef, and is subjected to wave activity.**

Reef-crest zones in the geological record are typically recognized on the presence of reef rock dominated by laminar, encrusting forms (bindstones and framestones) with low diversity fossil biotas

Crests, because of their position, are prone to exposure and show signs of near-surface or subaerial dIagenesIs than other reef zones

Reef front: **The reef front can be regarded as that part of the reef extending from the highest point on the reef profile (crest) to a point below which little or no skeletal frame-building occur**

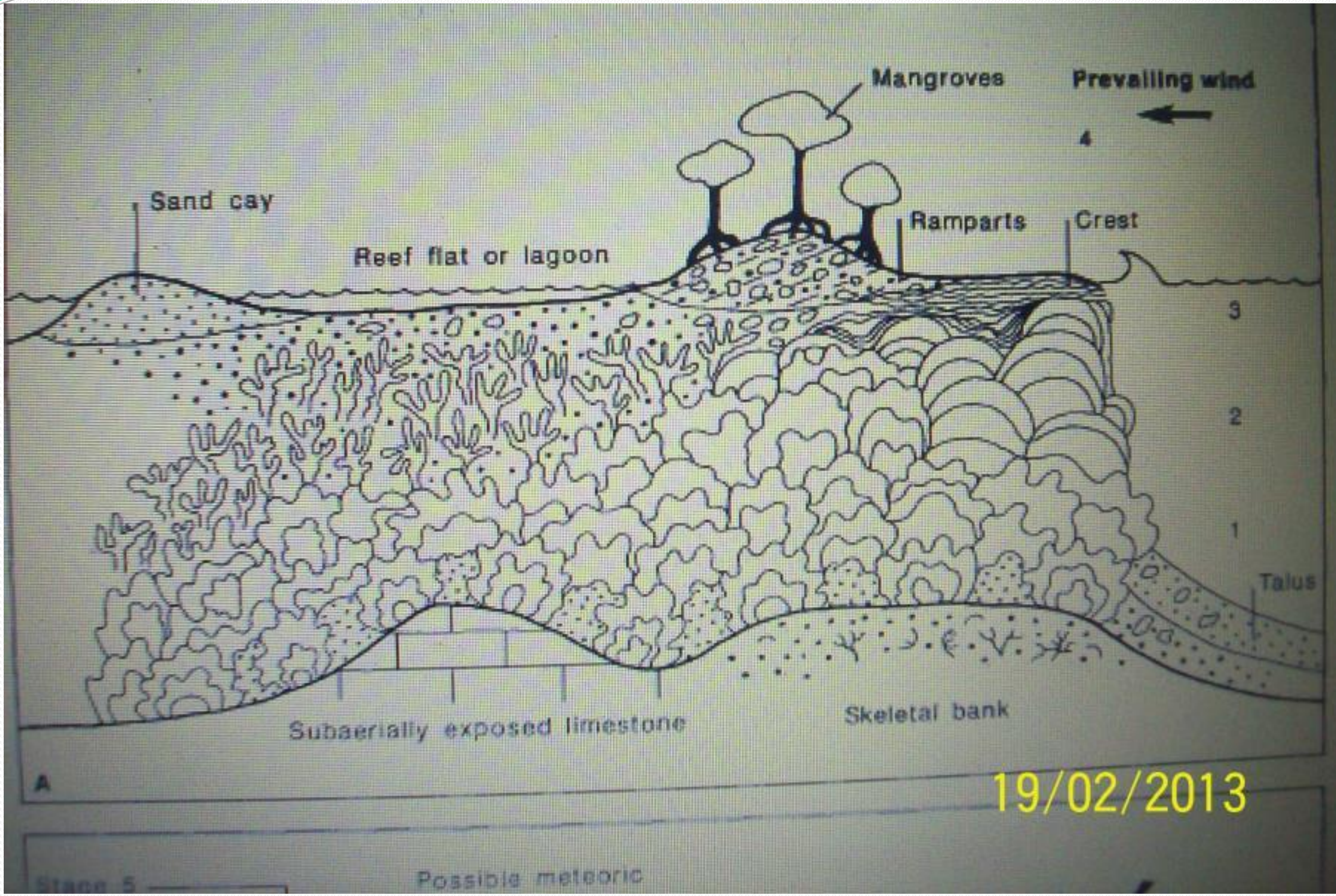
This depth varies according to local conditions but may extend to 70-100 m in modern reefs

As water depth increases down the reef front, energy and light levels decrease with subsequent changes in biotas

The reef rock is dominated by framestones with bafflestones and bindstones.

Fore-reef slope: It is an area, seaward of the reef front, which grades down into the surrounding basin floor.

It is dominated by gravity flow deposits and pelagic-hemipelagic sediments



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Reef Flat: **Behind and partially protected by the reef crest is the reef-flat zone, in which two environments can be recognized: the reef pavement and the sand apron.**

The reef pavement is immediately behind the crest and is afforded some shelter by it.

The pavement zone is variable in width, from a few metres to over 100 m as on the Belize Barrier Reef

The depth is typically only a few metres and the zone may be exposed at low tide. The surface is smooth to undulatory with small coral growths, micro-atolls and an
algal cover.

Commonly, it is rubble strewn with coral and algal debris derived from the reef crest

This material can include large boulder-sized material, and much of the debris is encrusted by crustose coralline algae.

Bioerosion is extensive with some early cementation

Typical reef rock types are bindstones and rudstones, with sparse framestone.

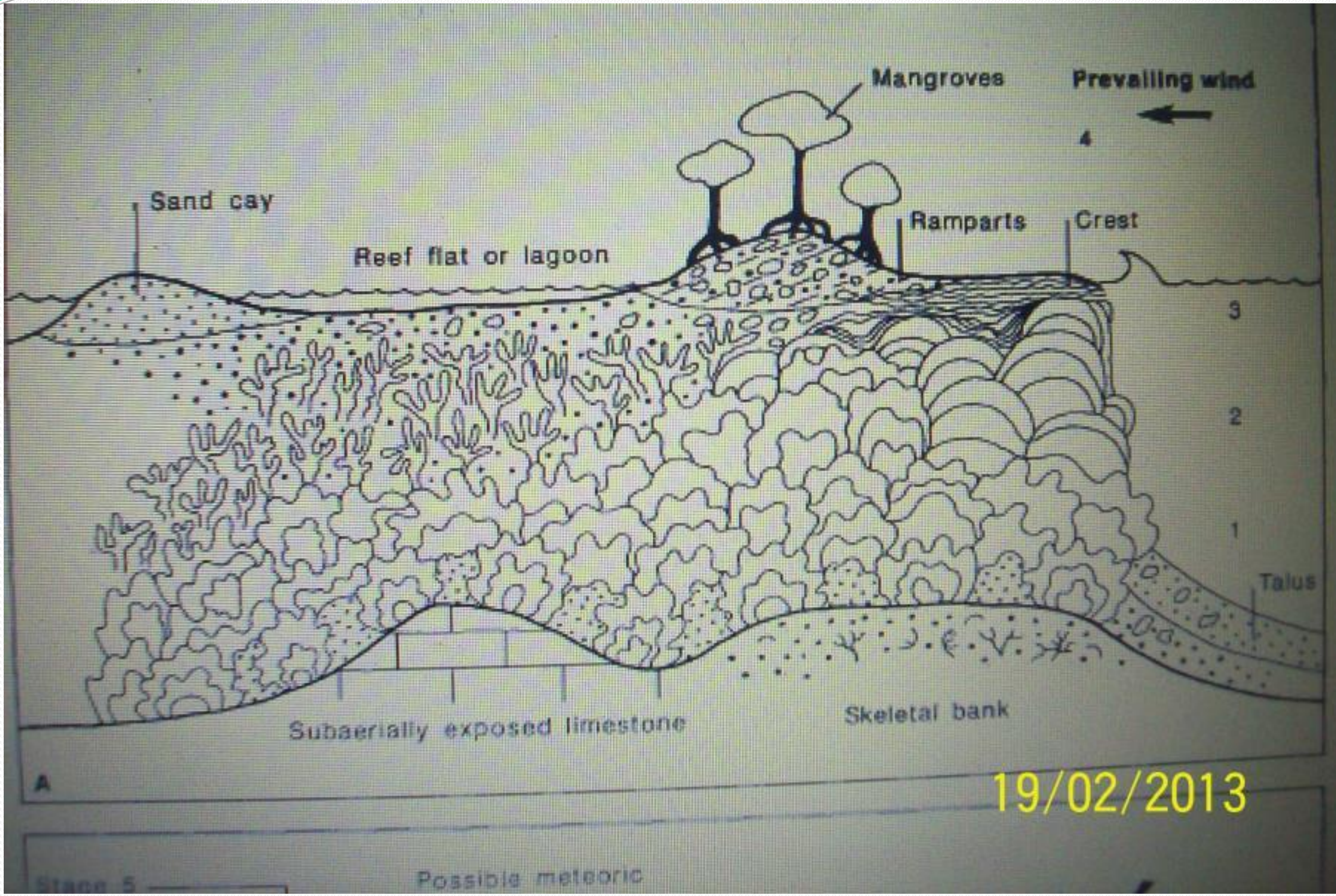
The sand apron: **It extends behind the pavement, and water depths range up to 10 m and may extend for 160 km parallel to the reef trend.**

The aprons vary in width from 100 to 200 m wide

Such sand belts can constitute potential **hydrocarbon reservoirs and are commonly more important than the reef front which undergoes extensive early marine cementation**

- **Rock types will be grainstones and rudstones which will grade into the back-reef, more muddy lagoonal sediments.**

- **Locally and distally the sand apron may be colonized by sea-grasses or algal mats, and will be stabilized, and the resulting sediments will be burrowed muddy sands (packstones-wackestones), reflecting the binding and baffling action of the vegetation.**



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Lagoon: **Not all reefs have lagoons, for if the reef rim is not continuous, more open circulation will occur and the back-reef will have the aspect of an open shelf or bay.**

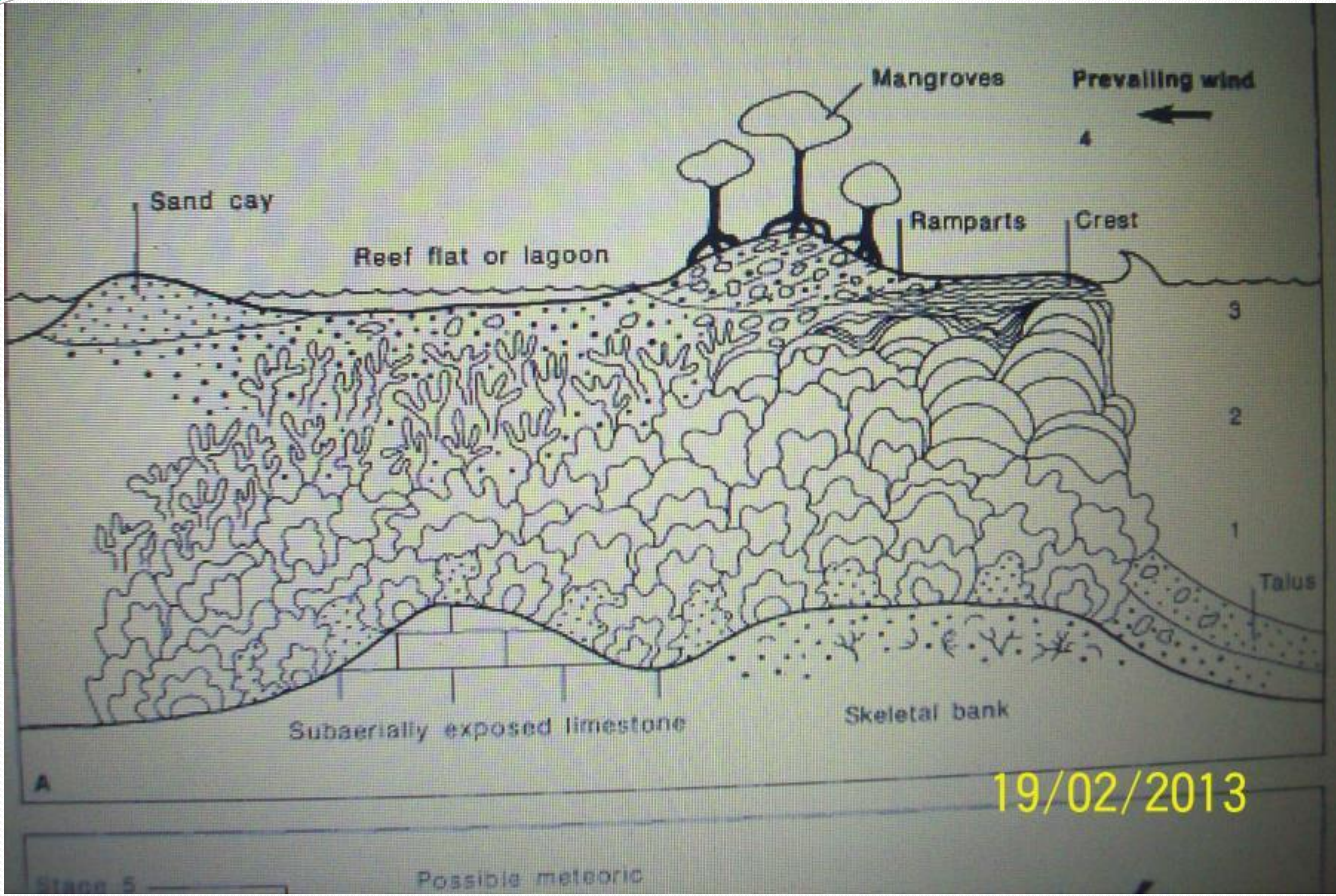
In such settings patch reefs may be separated by inter-reef facies of a more open marine character, rather than protected, lagoonal deposits.

The central region of the Great Barrier Reef provides an example of such a setting

Lagoons may be of a variety of sizes, from relatively small areas developed within atolls to larger zones behind major barrier reefs.

Depth is an important consideration and while many reef lagoons are shallow (under 10 m) some Pacific atoll lagoons are over 70 m deep.

Under such circumstances the lagoonal deposits may be of a deeper-water character



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- The essential characteristics of a reef lagoon, which may be recognizable in ancient reef complexes, are that it is protected and has restricted circulation.

- As a consequence the lower-energy settings may be reflected in finer sediments and a different biota to other reef facies.

- Lagoons act as traps for sediment and the settling of fine sediment deters many sessile organisms.

- Many of the corals have growth forms reflecting the higher sedimentation rates

- Calcareous algae such as *Halimeda and Penicillus are a prominent component of lagoons and* produce copious amounts of carbonate sand and mud.

- Sea-grasses and algae may contribute to the formation of carbonate mud banks (reef mounds) in such protected settings.

- **Further sediment may be contributed from terrigenous sources.**
- **Patch reefs are a common feature of reef lagoons and influence sedimentation.**
- **Great Barrier Reef have two lithofacies i.e. proximal-to-framework and distal-to-framework.**
- **The proximal lithofacies, which are volumetrically minor, are near to the reef rim or to patch reefs within the lagoon.**
- **They consist of coarse, poorly-sorted sediment composed of coral, molluscan and *Halimeda material, from sand to* boulder size.**
- **The distal lithofacies consists of carbonate sands which are heavily bioturbated by callianassid shrimps**

Stages of Reef Growth

Stabilization stage: **This mainly consists of a skeletal accumulation or shoal deposits.**

In the Palaeozoic, the crinoids, perhaps filling a role comparable to the Cainozoic calcareous green algae, were the major contributors to such accumulations.

The typical assemblage consists of sponges, corals, bryozoans and branching red algae. This phase might reasonably be regarded as a reef-mound stage

Colonization stage: **this stage marks the appearance of reef-building metazoans, but diversity is commonly still low.**

Growth forms include branching and encrusting forms, and niche stratification during
the stage increases diversity.

It is generally a short lived phase and so is relatively thin.

Diversification stage: **Diversity increases and a greater variety of growth forms occur. This stage forms the bulk of the reef.**

Domination (or climax) stage

This stage is characterized by lamellar forms (encrusters) giving a typical bindstone or lamellar framestone cap to the reef.

Stage	Type of limestone	Species diversity	Shape of reef builders
Domination	Bindstone to framestone	Low to moderate	Laminate encrusting
Diversification	Framestone (bindstone) mudstone to wackestone matrix	High	Domal massive lamellar branching encrusting
Colonization	Bafflestone to floatstone (bindstone) with a mud stone to wackestone matrix	Low	Branching lamellar encrusting
Stabilization	Grainstone to rudstone (packstone to wackestone)	Low	Skeletal debris

g. 4.110 *Reef succession within a patch reef core, showing limestone types, relative species diversity and morphology of e reef-builders in each stage. Based on James (1984b).*

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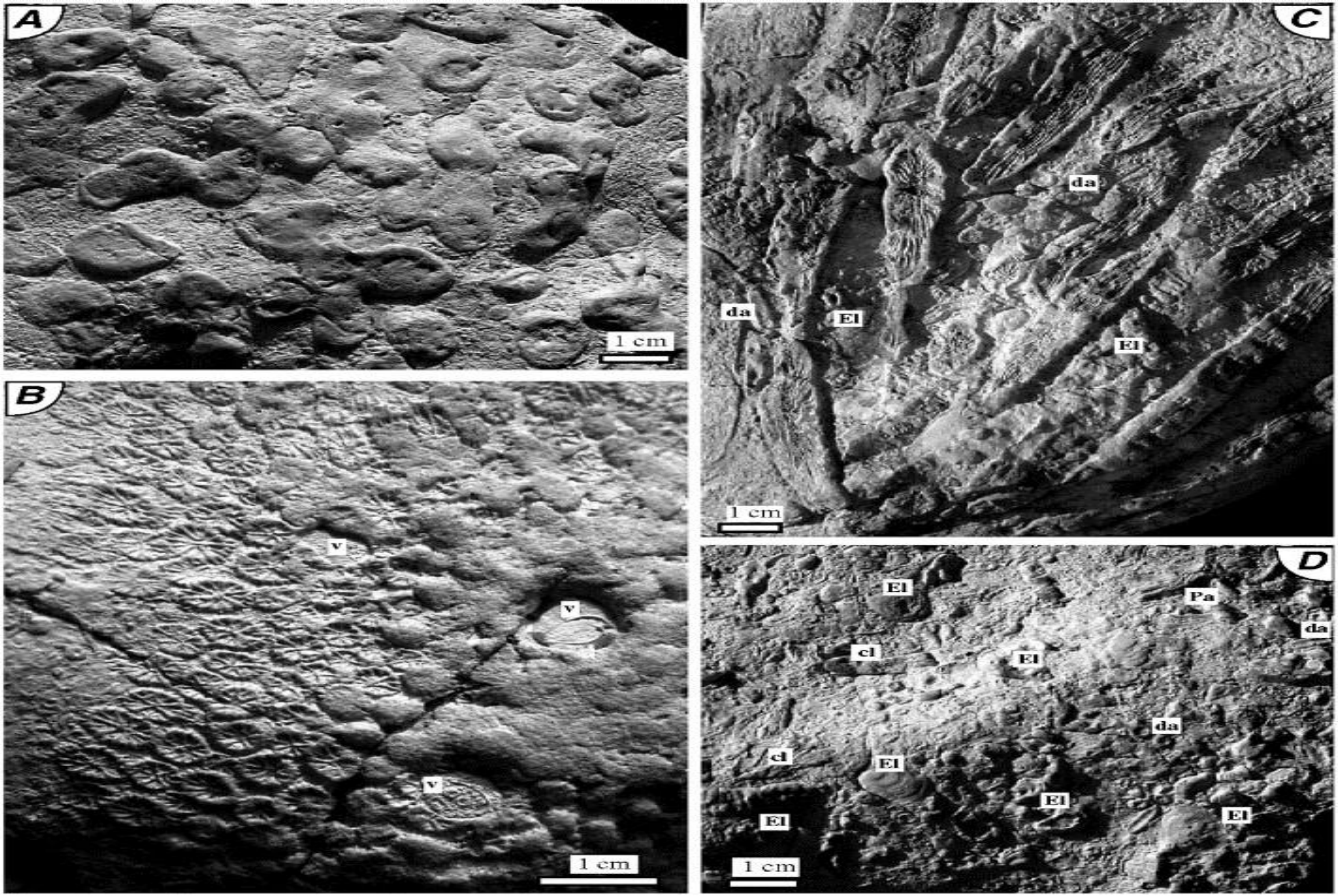
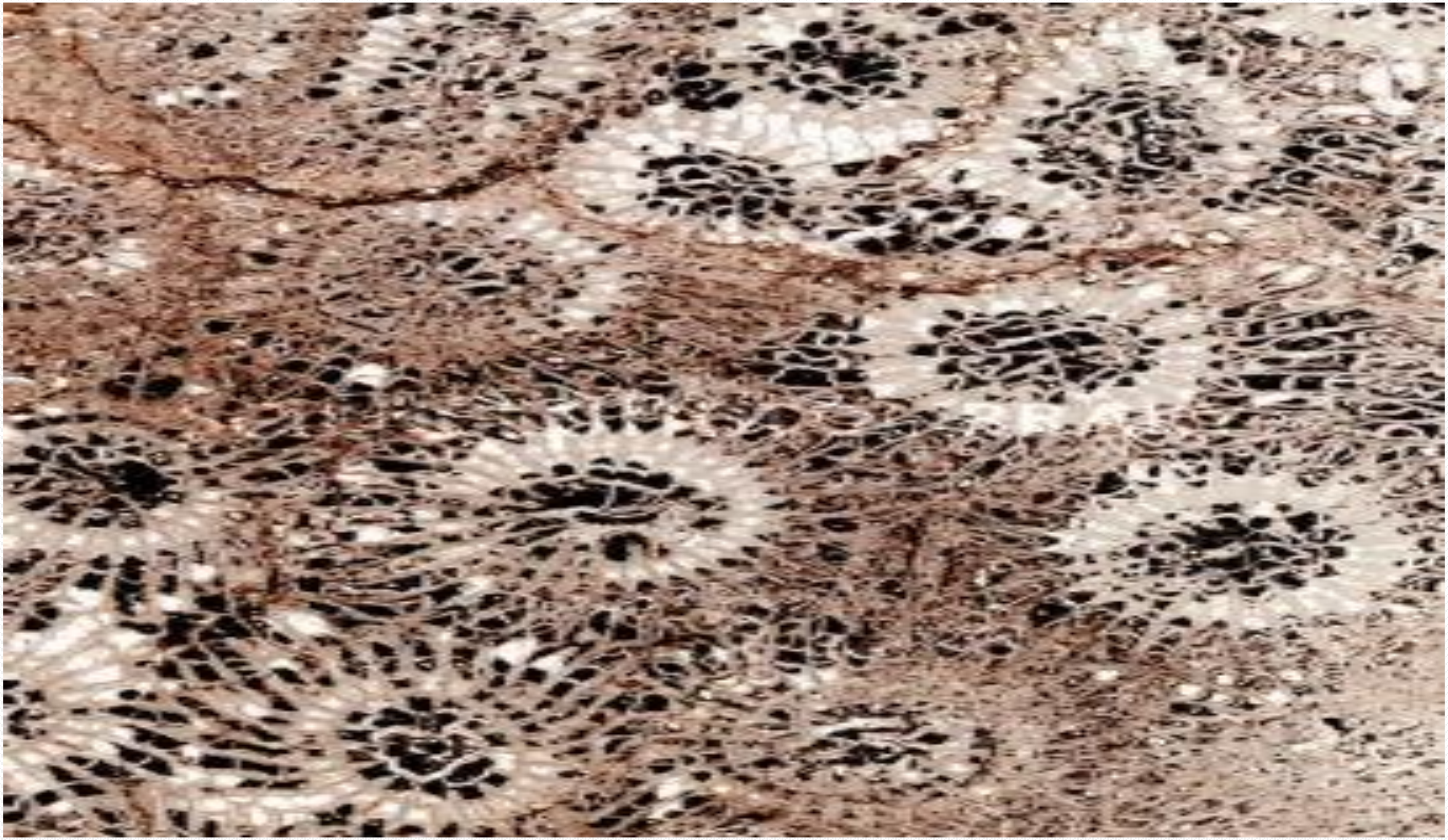
Reef Crest

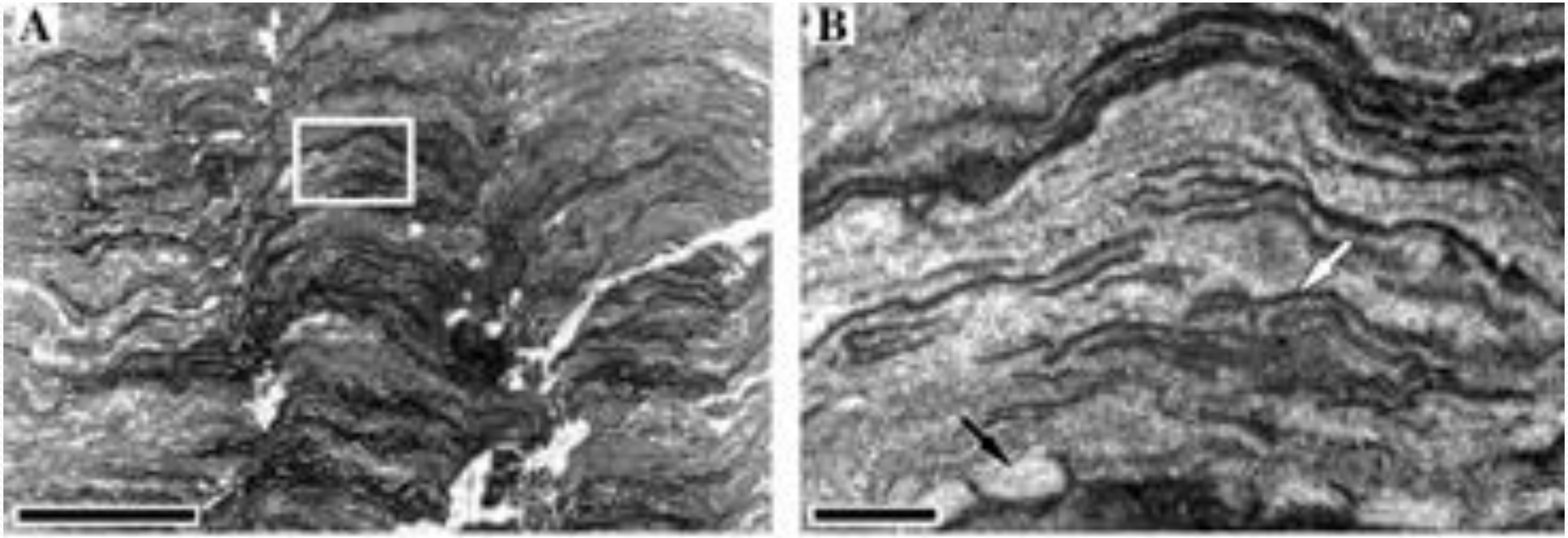


Reef Crest Colonial Corals

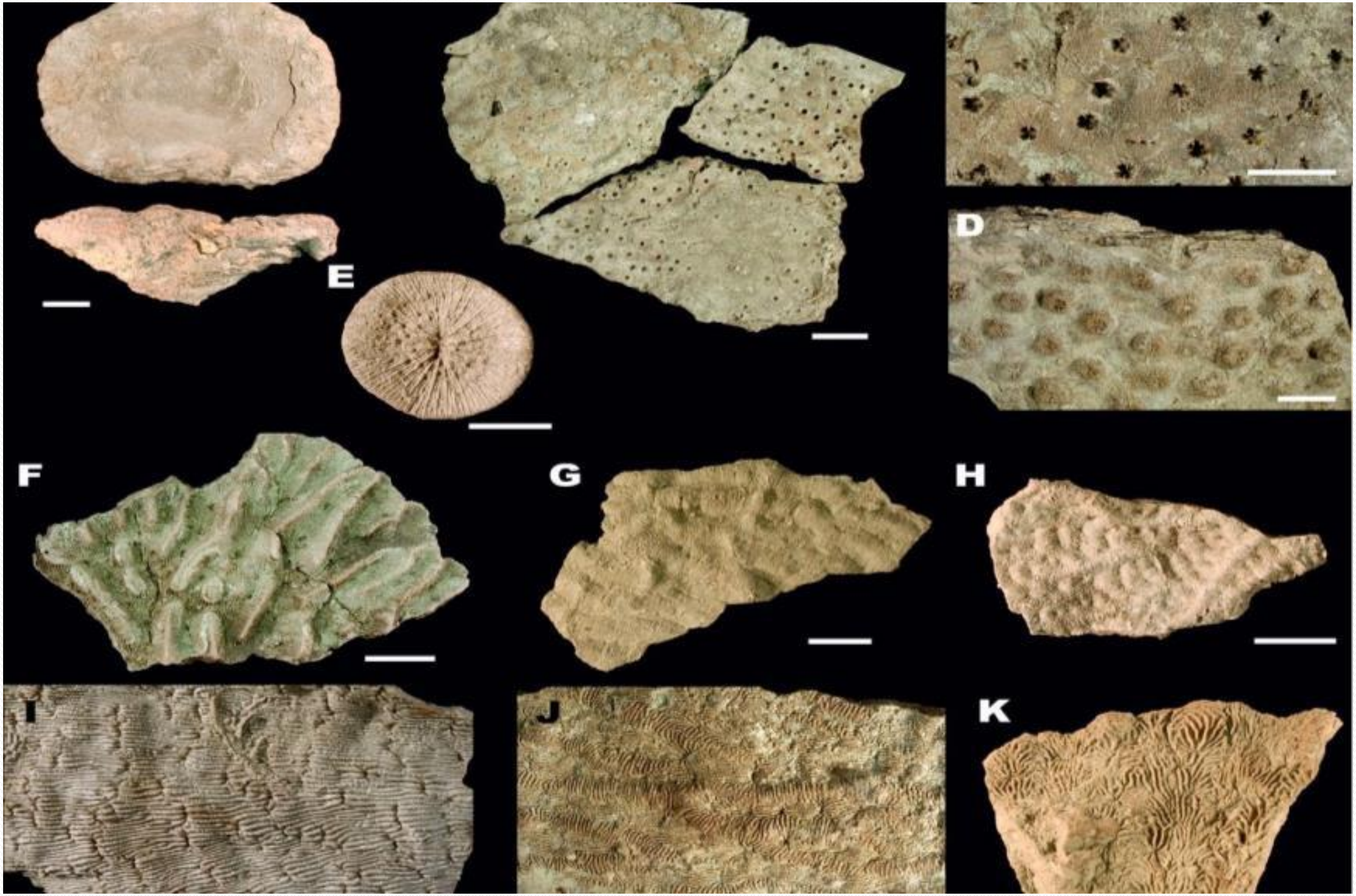


Fore-Reef Breccia

Bindstone in Reef Crest



Scleractinian corals



Halimeda

Calcareous Algae of Lagoon

Deep Marine Systems

Lecture-4

Sediments

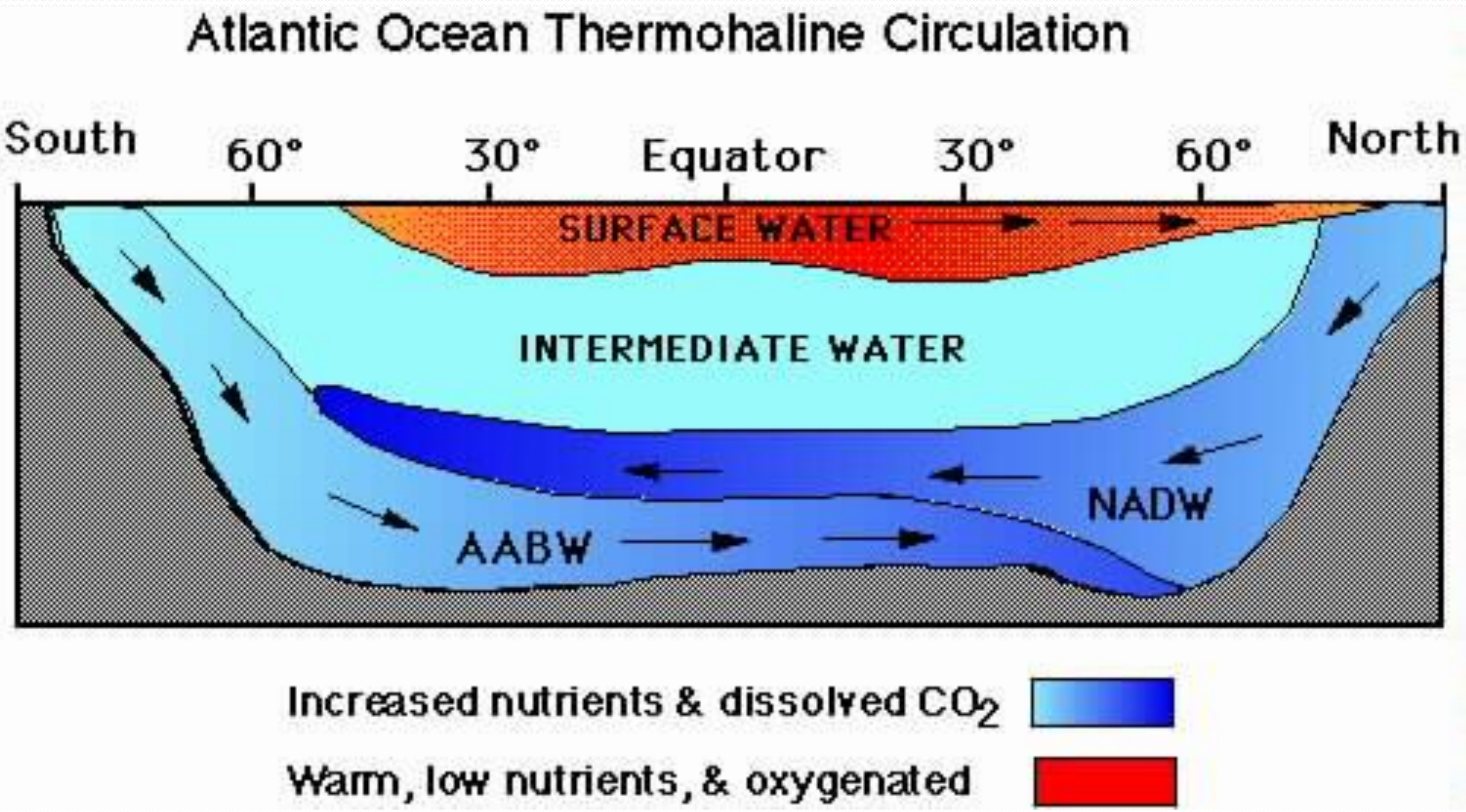
Lithogenous: **From the weathering of preexisting or volcanic activity**

Biogenous: **Skeletal materials by organism is Biogenous**

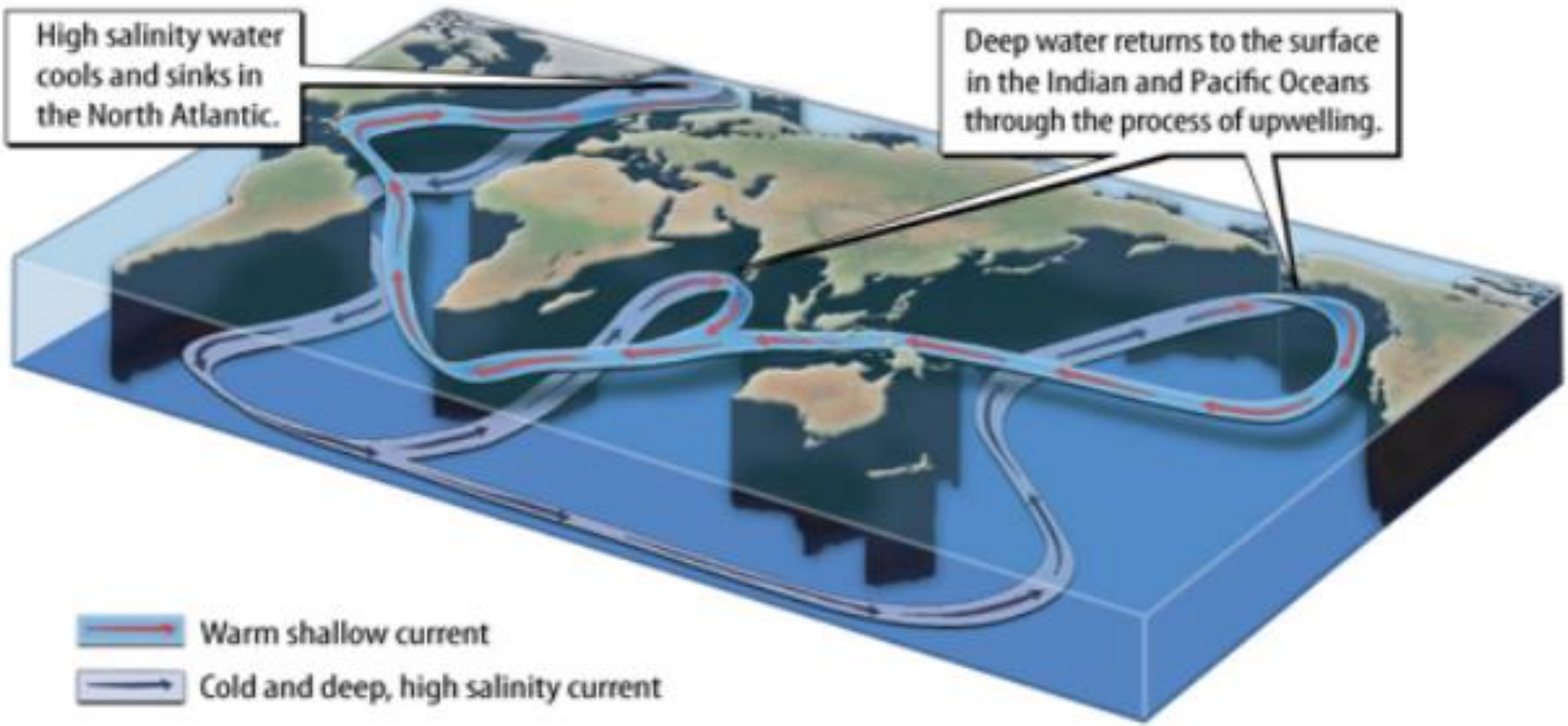
Hydrogenous: **Inorganic precipitates of the sea floor i.e. phosphate, sulfates, oxides, hydroxides, Mn-nodules etc. Altered hydrogenous sediment include zeolites and some clay minerals. Especially smectite which form from volcanic materials.**

Cosmogenous: **Extraterrestrial sediments**

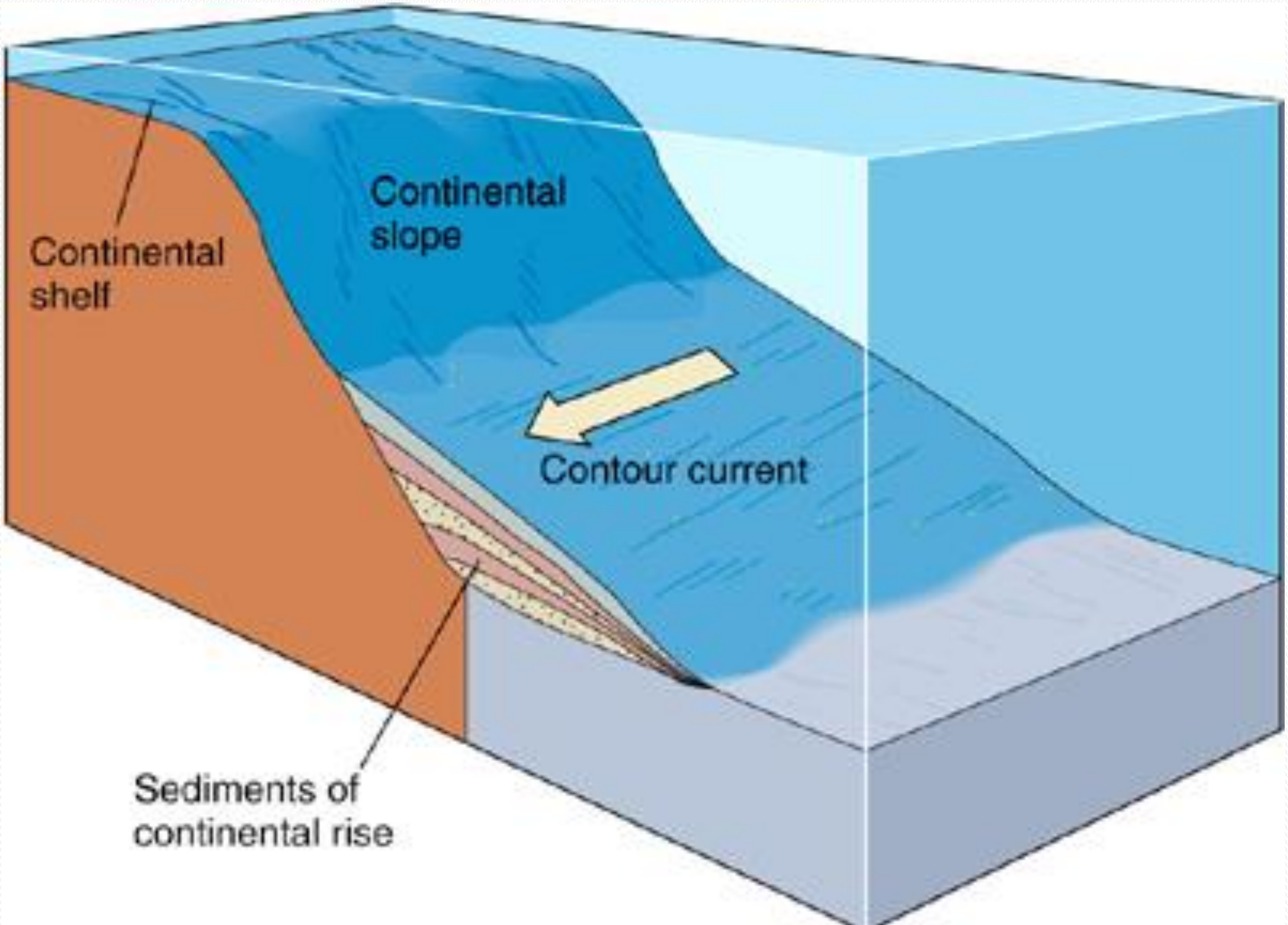
Water Masses in Ocean



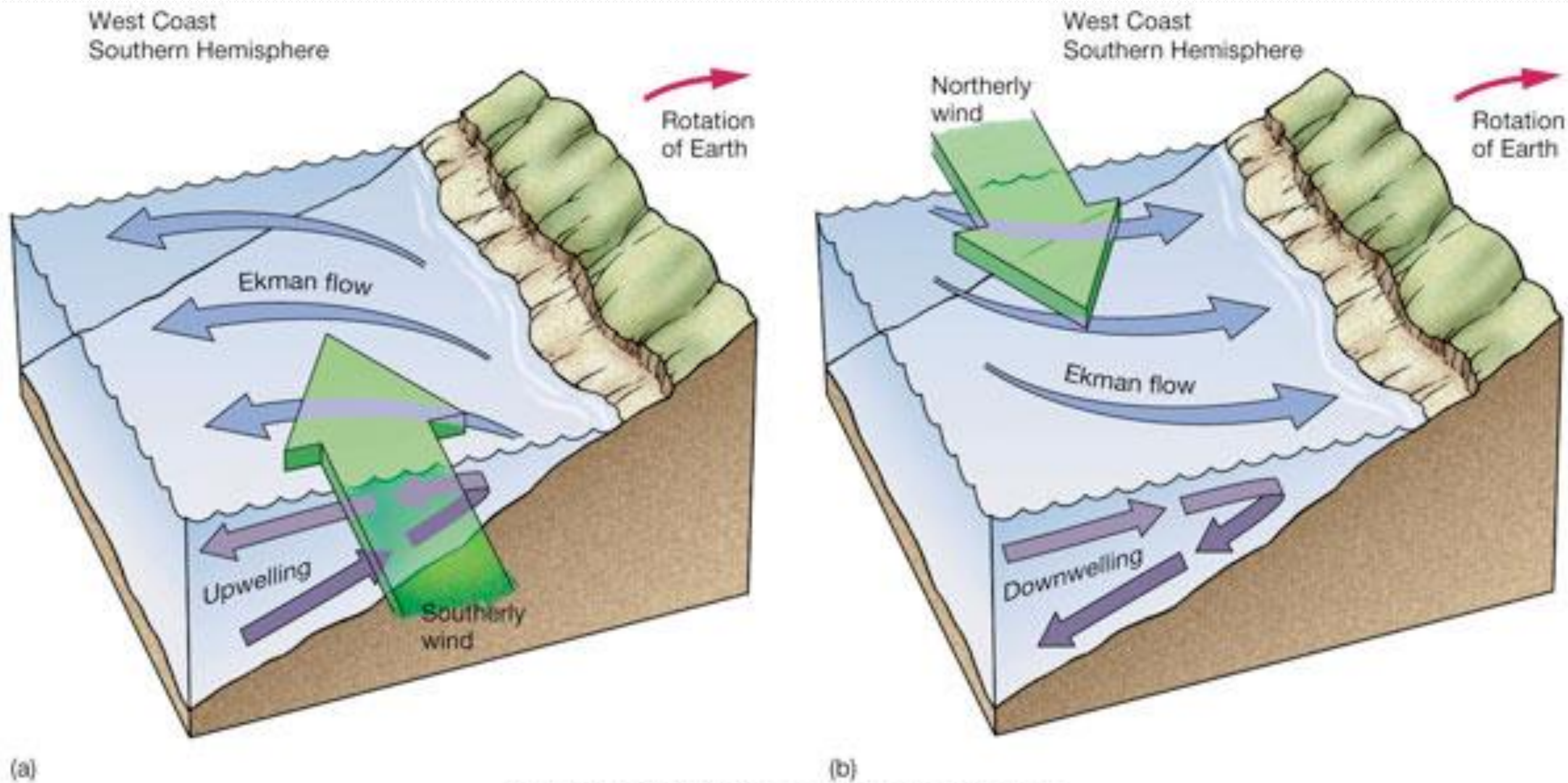
Thermohaline Circulation



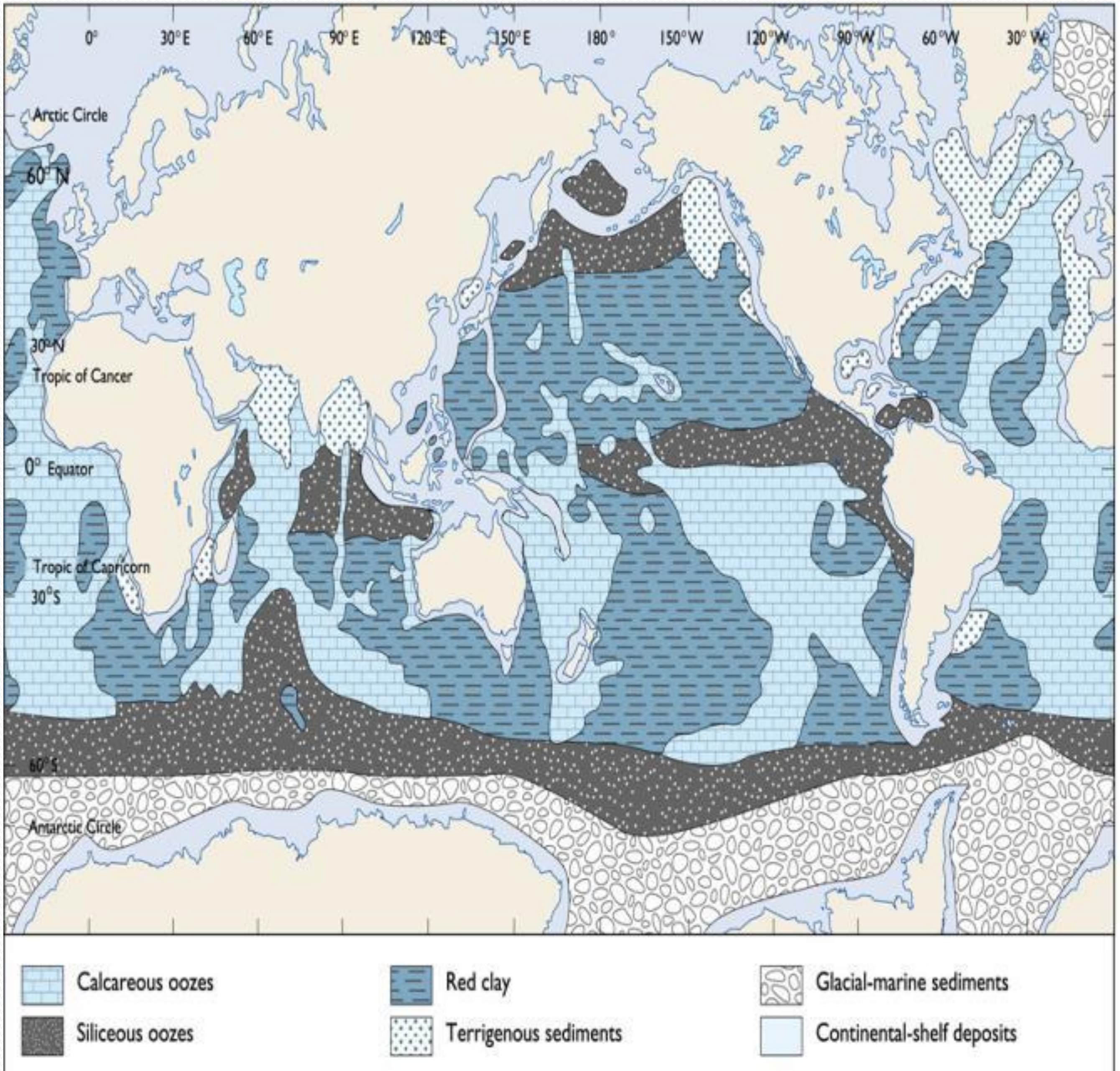
Contour Current and distribution of Sediments



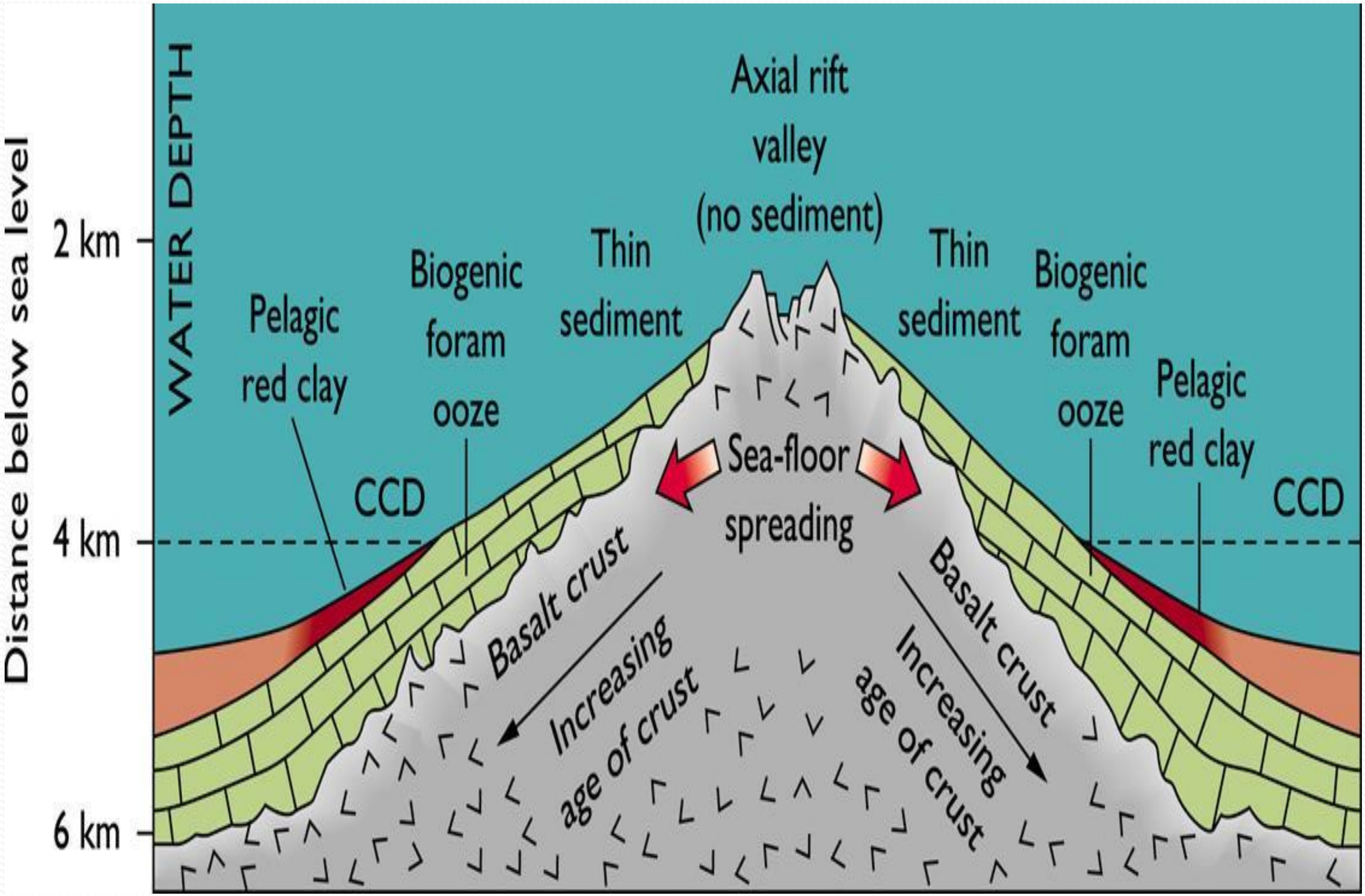
Ekman Transport and Phosphorites



Distribution of Deep Marine Sediments



Distribution of Sediments on Deep Marine Sea Mount



Gravity Deposits

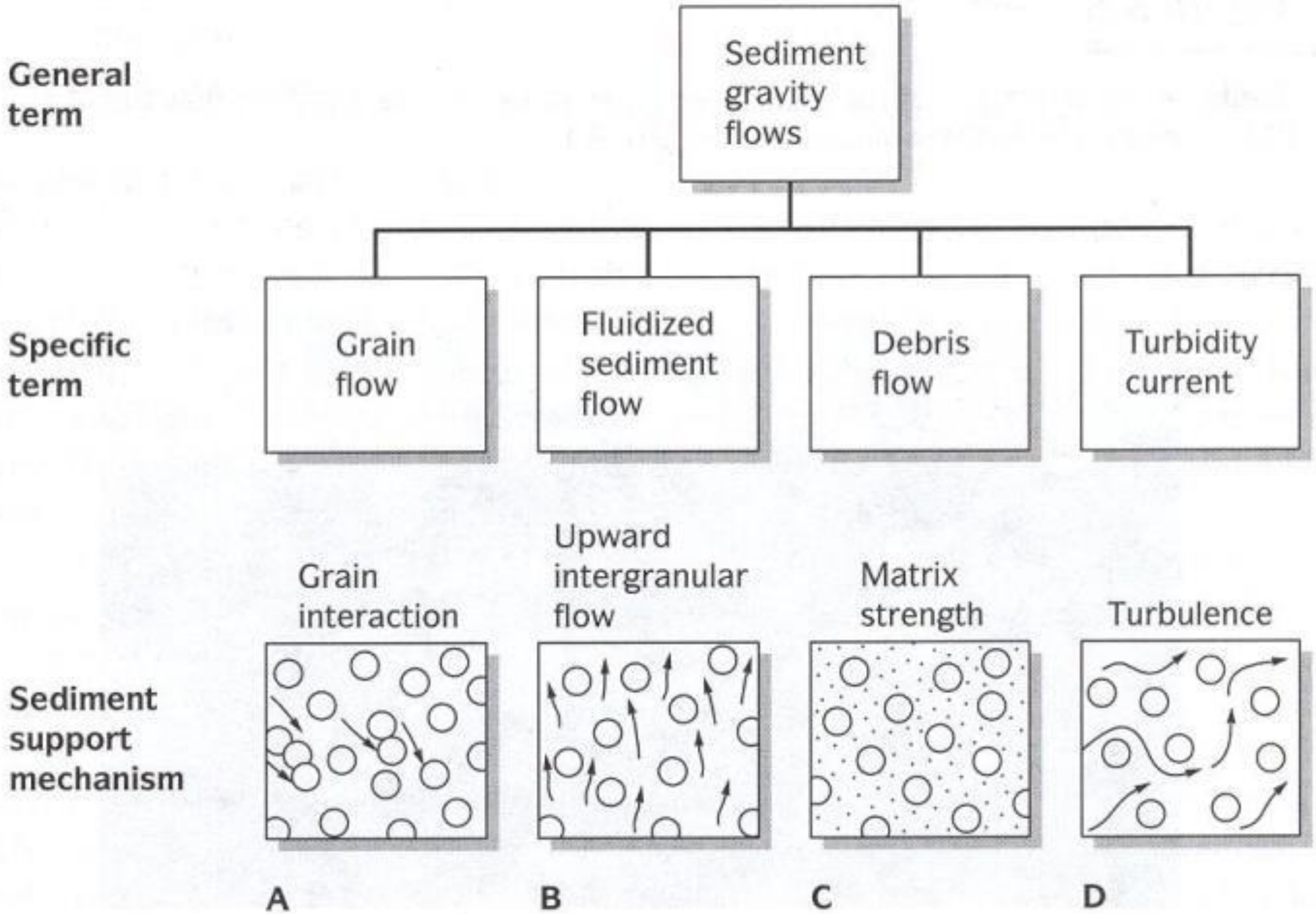
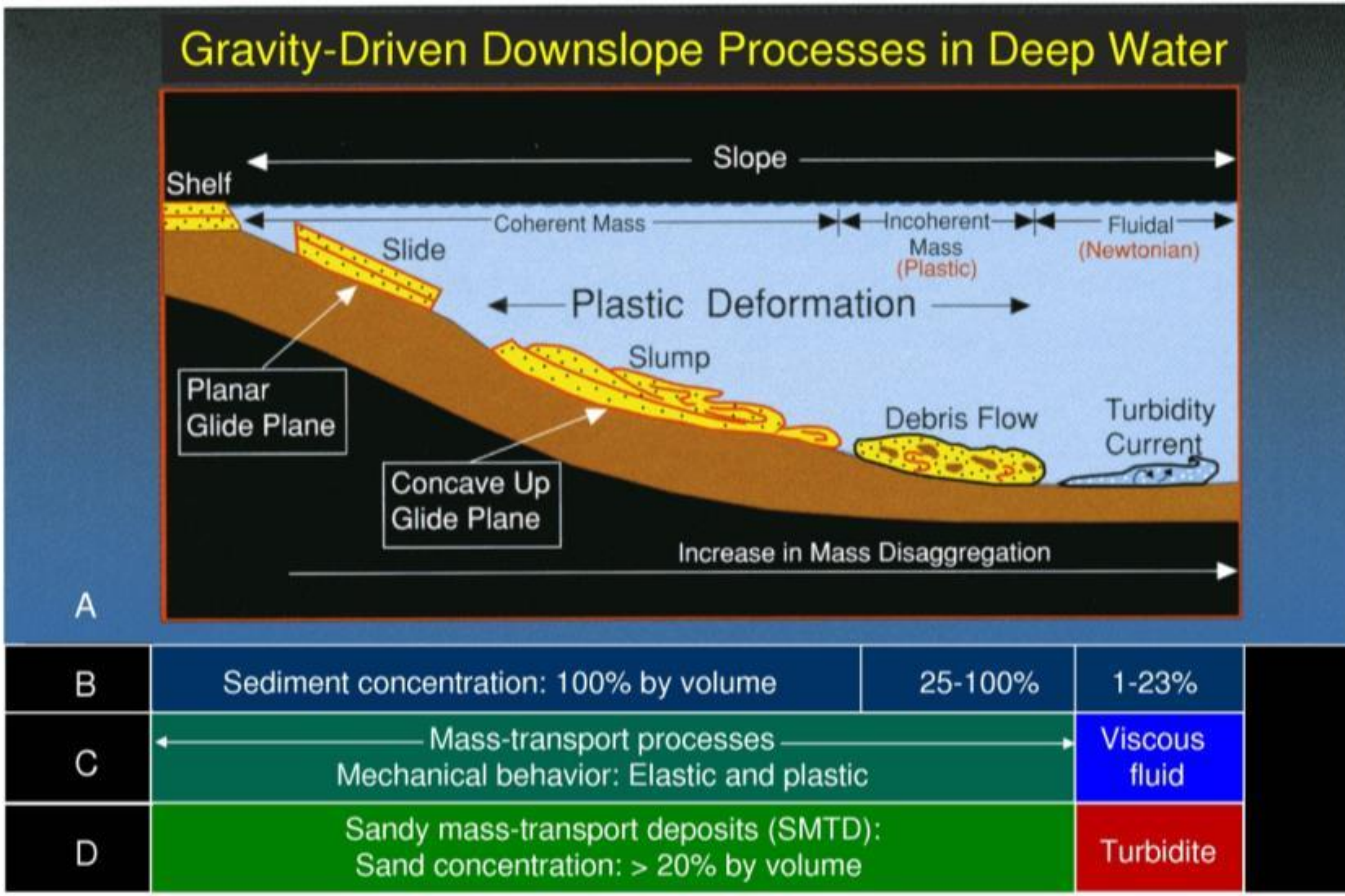


Figure 3.5

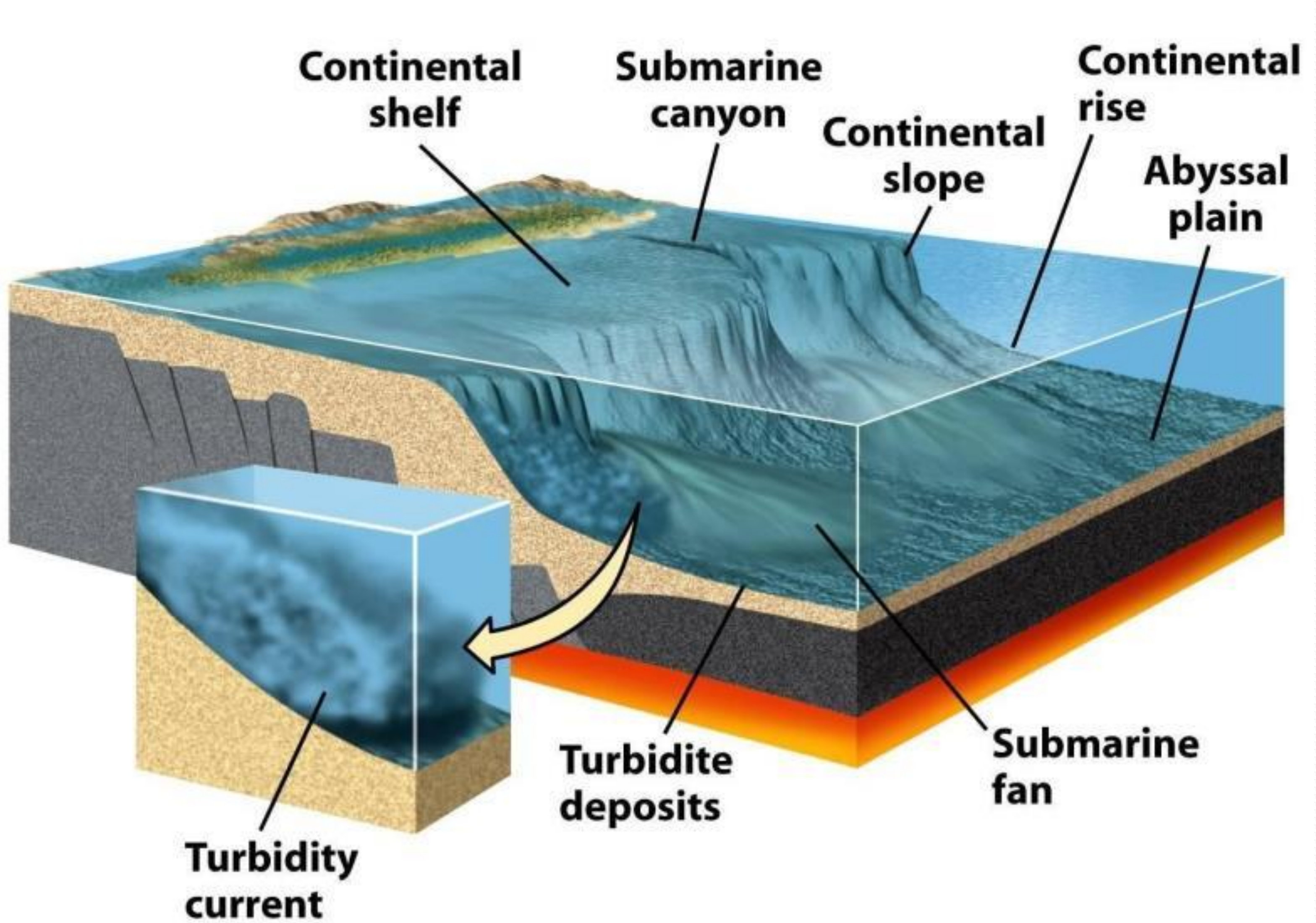
Classification of the four major types of sedimentary gravity flows, showing the interactions between fluids and grains that keep sediment moving during transport.

Debris Flow

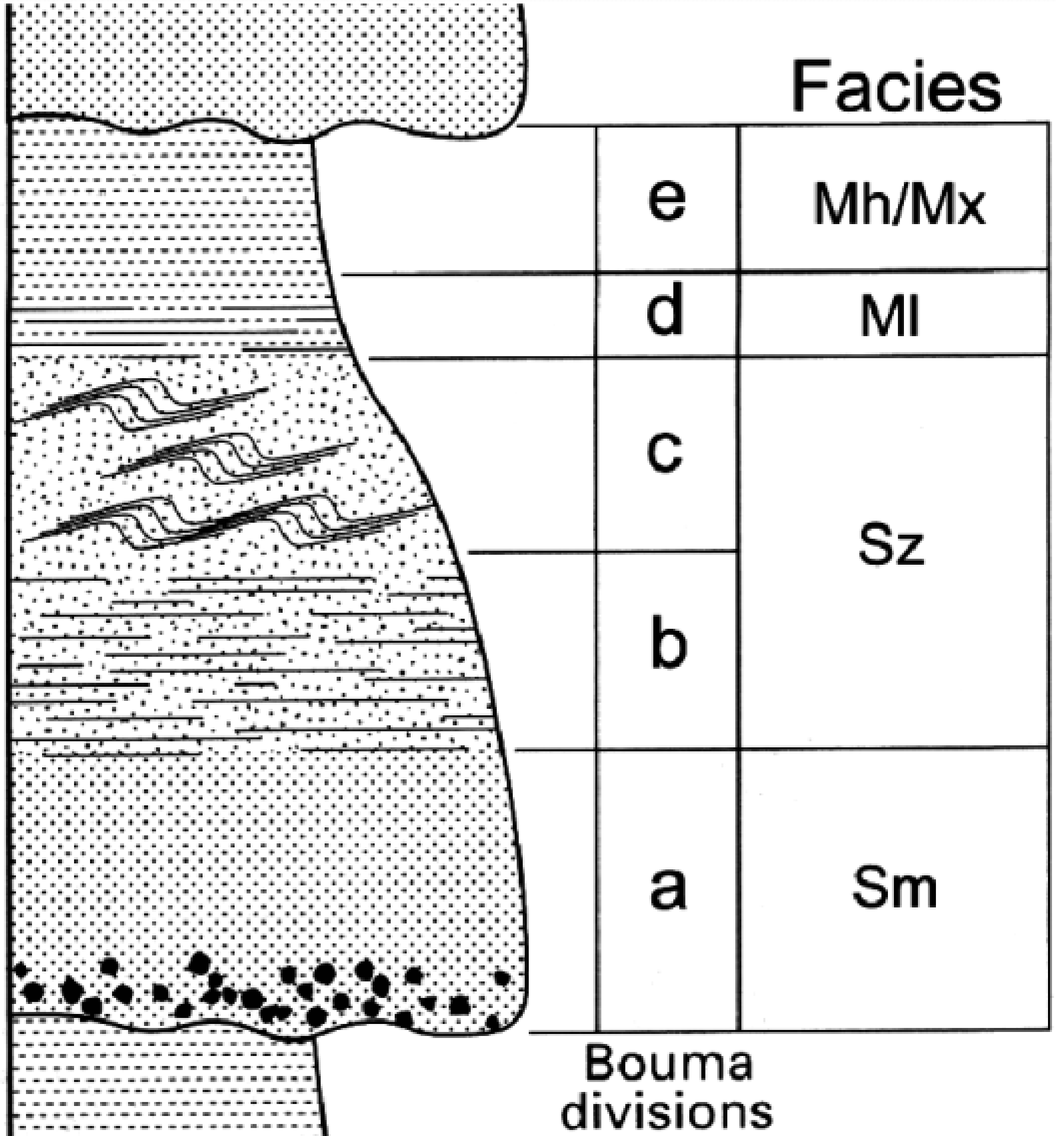

Gravity-Driven Downslope Processes in Deep Water
Slope
Shelf
Coherent Mass
Incoherent Mass (Plastic)
Fluidal (Newtonian)
Slide
Plastic Deformation
Slump
Planar Glide Plane
Concave Up Glide Plane
Debris Flow
Turbidity Current
Increase in Mass Disaggregation
A
B
Sediment concentration: 100% by volume
25-100%
1-23%
C
Mass-transport processes
Mechanical behavior: Elastic and plastic
Viscous fluid
D
Sandy mass-transport deposits (SMTD):
Sand concentration: > 20% by volume
Turbidite

Syn-sedimentary Deformation in Gravity Deposits

Submarine Fans and Turbidity Currents



Turbidites and Bouma Sequence



Stratigraphic Column of Deep Marine Sediments