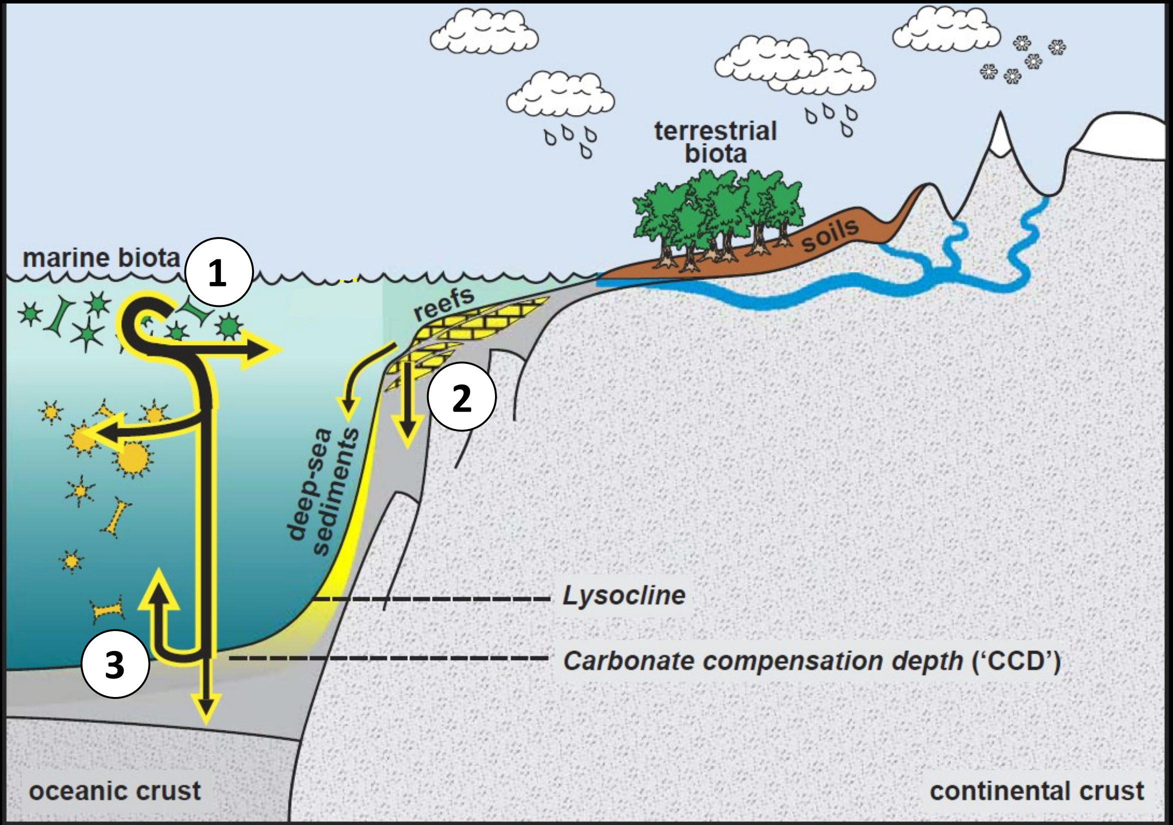
Deep water carbonates

The pelagic fraction of deep water carbonates deposits in the open sea and comprises primarily skeletal fragments of planktonic organisms. A significant volume of carbonate deposits in the deep waters, however can be represented by resedimented material in the form of calciturbidites.

Below: from Ridgwell and Zeebe, modified: (1) pelagic carbonate precipitation; (2) shallow water carbonate depostion; (3) deep water carbonate deposition.

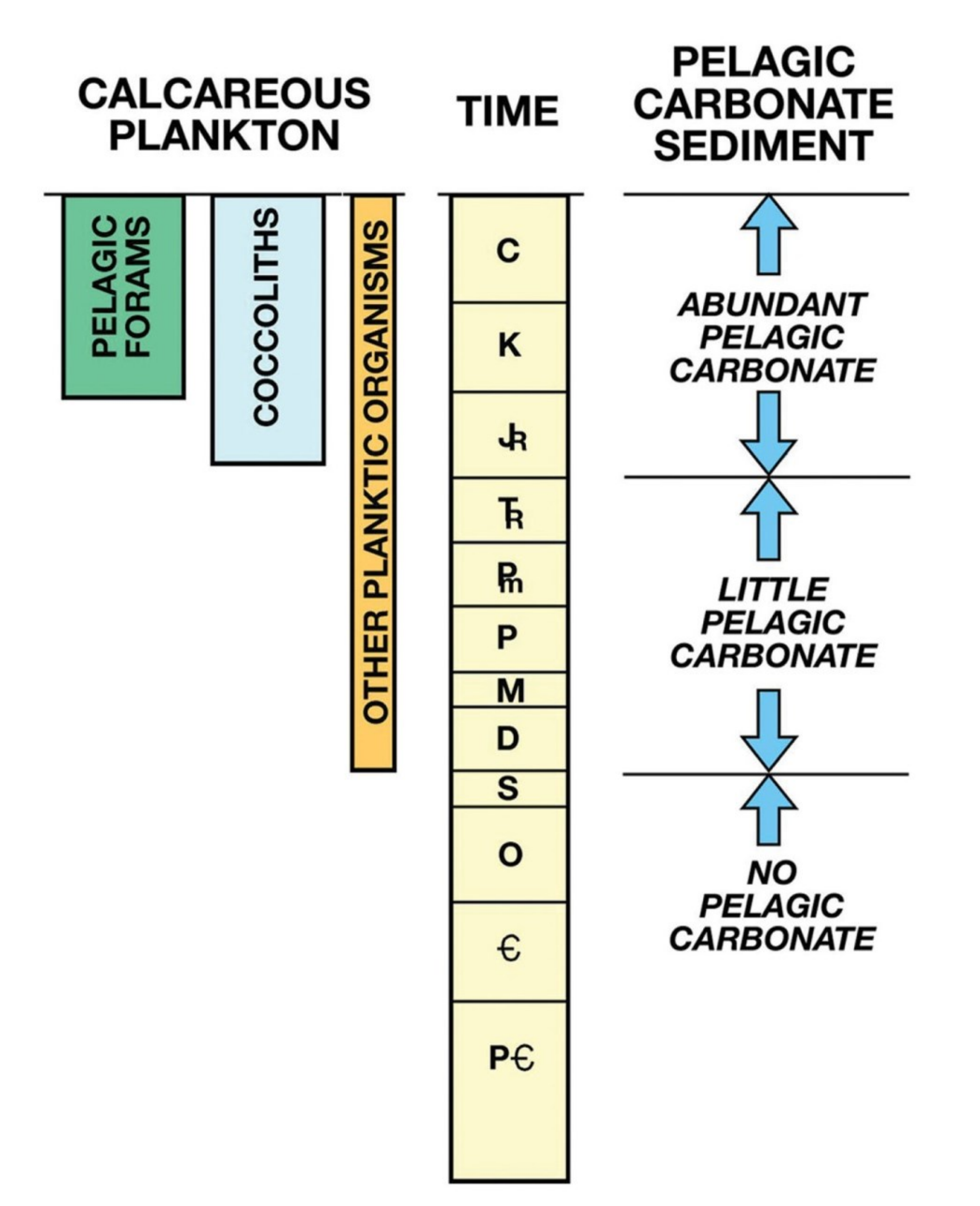


Left: a false colour satellite image showing a coccolitophore bloom in the waters of the English Channel, south of Cornwall.
Right: a SEM image of a coccolithophore

Deep water carbonates

Pelagic sedimentation has not been always abundant in the oceans.

The advent of calcareous nannoplankton is a major event in the history of pelagic sedimentation that occurred sometimes in the Early Jurassic. Earlier, other calcifying planktic organisms existed, but did not accumulate in large volumes.



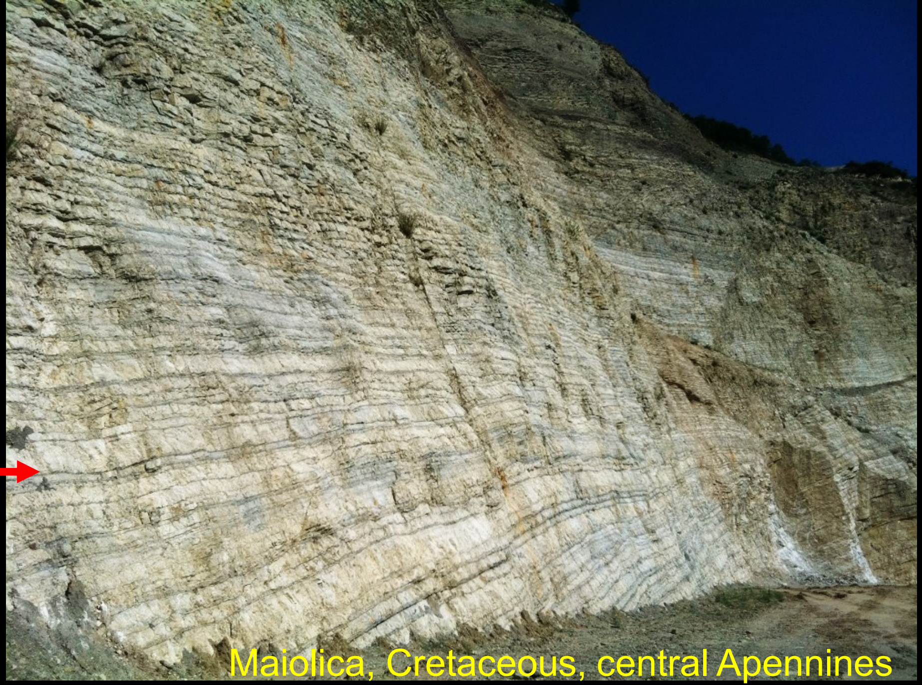
From James and Jones, 2015. Relative abundance of pleagic carbonate sediment through time. Pelagic carbonate became a major part of carbonate deposition in the oceans after the diffusion of coccolithophores and pleagic foraminifera since the Jurassic.

Deep water carbonates

Two types of deep-water sediments

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

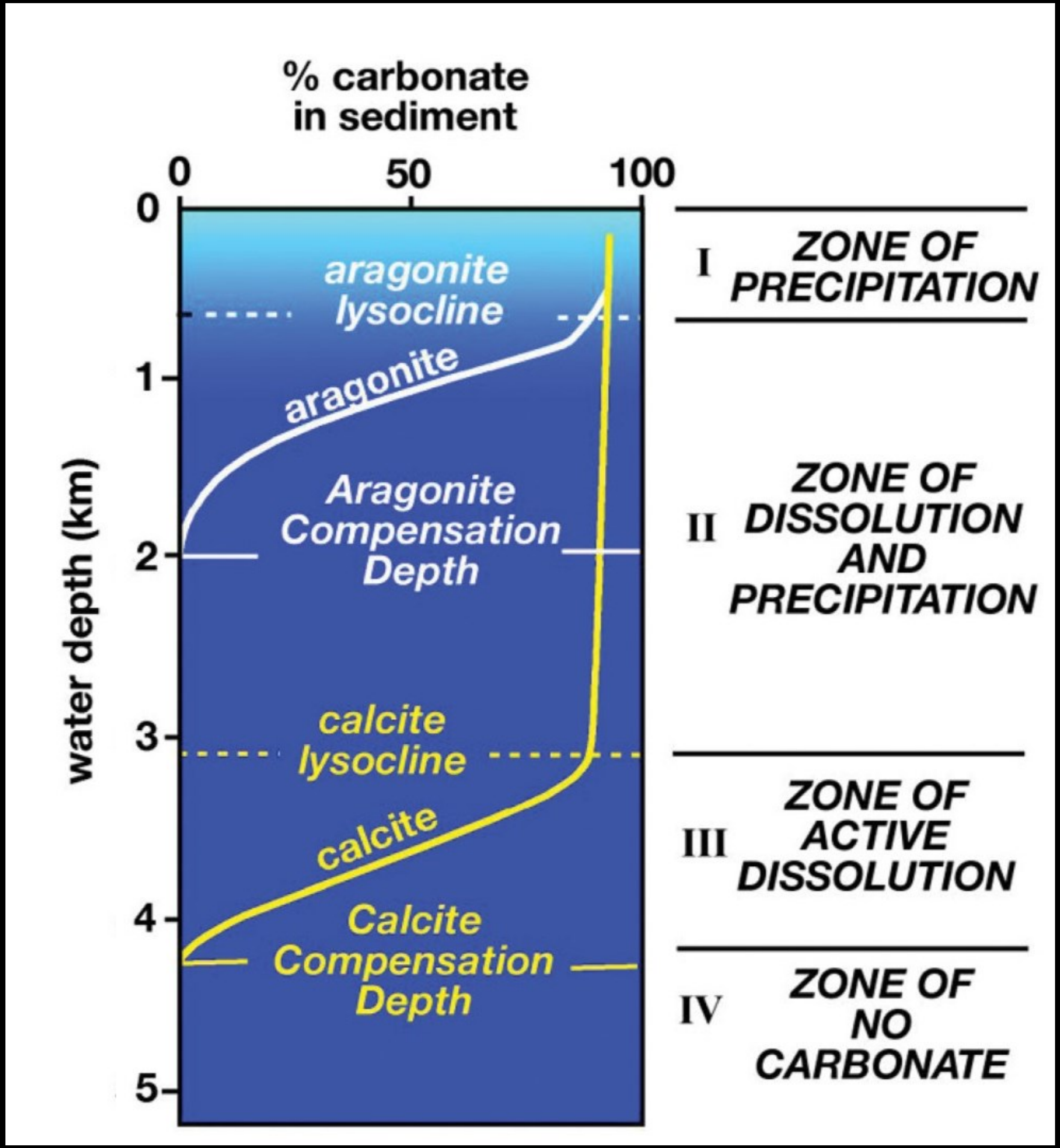
- **Hemipelagic**: mostly pelagic sediment, that includes, however, a component supplied from adjacent emerged lands or neritic platforms.


Maiolica, Cretaceous, central Apennines


Scisti a Fucoidi, Cretaceous, central Apennines

Deep water carbonates

A major control in pleagic carbonate precipitation is the depth of the Calcite (and Aragonite) Compensation Depths (CCD and ACD). The position of these surfaces varies in space and time and can be influenced by several factors (e.g. fertility of surface waters and degree of understaturation of deeper waters)



From James and Jones, 2015

Deep water carbonates

Some typical attributes of phanerozoic pelagic carbonates:

- Presence of planktic or nektic macrofossil remains.
- Sedimens are fine, well bedded and display great lateral continuity and gradual lateral facies changes.
- Small-scale laminations. Can also display cm- to m-scale sedimentary rhythms
- Nodular facies.
- Condensed successions (thin sediment accumulations deposited over long periods)
- Typical bioturbation assemblages with ichnogenera such as *Chondrites* or *Thalassinoides, Zoophycos.*
- surfaces encrusted by minerals such as glauconite, Mn-Fe oxides, phosphate), hardgrounds.

Deep water carbonates

Deep water carbonates often comprise well-bedded, fine grained, sometimes finely laminated sediments that display great lateral continuity. Beds can be grouped in thicker *bundles.*

The Cretaceous Chalk exposed on white cliffs on the soutern coast of England. From James and Jones, 2015.

The iconic Scala dei Turchi in Sicily is cut in the early Pliocene Trubi Mars formation that is made of an alternation of fine grained pelagic carbonatess and marly layers. The limestone-marl couplets are grouped in thicker bundles. This rhythmic organization is due to Milankovian forcing.
Photograph fromDi Gigi L. Filice - Scala dei Turchi Agrigento Sicilia, CC0, https://commons.wikimedia.org/w/index.php?curid=86019120

Deep water carbonates

Deep water carbonates are often associated with chert in various proportions.
Chert is a sedimentary rock composed on microcristalline silica.
In deep water carbonates chert has biogenic origin and derives from tests and skeletons of diatoms, silicoflagellates and radiolarians

Chert nodules in pleagic limestones.

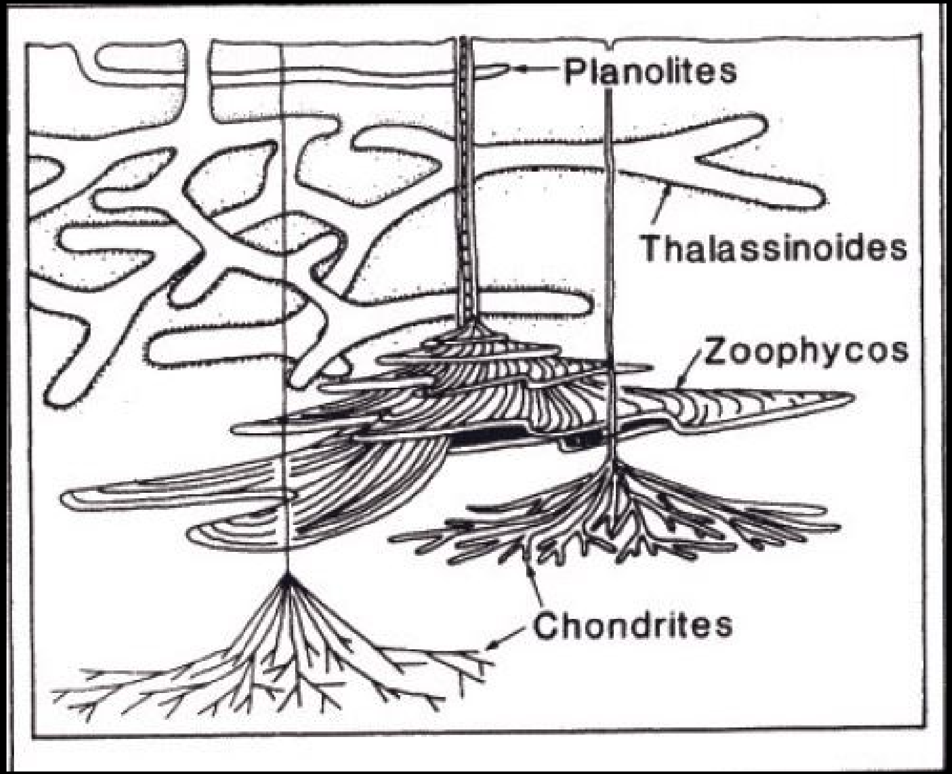
Deep water carbonates

The origin of chert is essentially diagenetic. This type of diagenesis occurres in the early stages of burial. The siliceous sediment is mobilized and replaces carbonate. Compaction may cause the formation of nodules. In some cases, as for instance in the cretaceous chalk, chert is found filling bioturbations

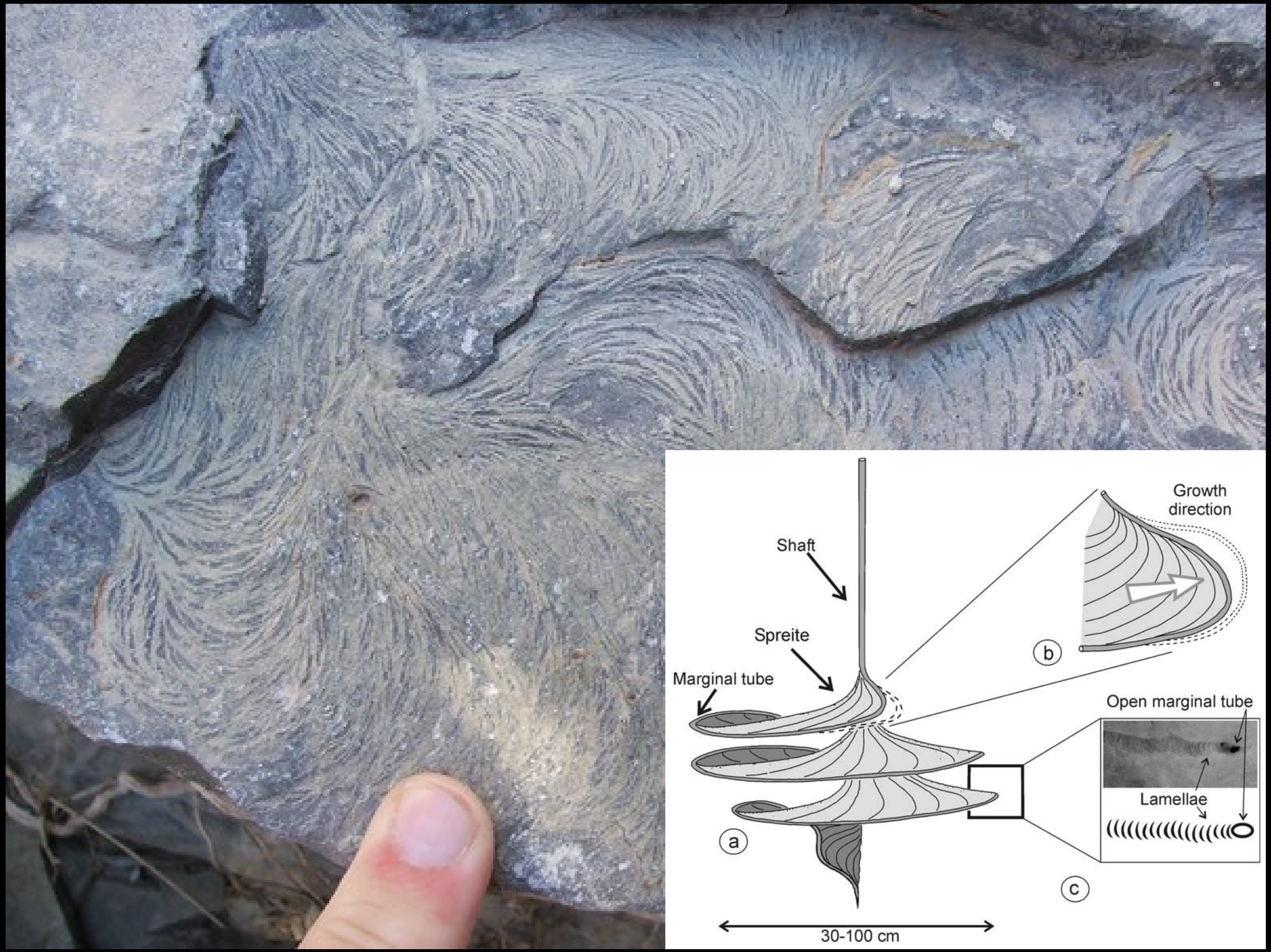
Chert in the chalk exposed along the coast of Etretat (France).

Deep water carbonates

Deep water carbonates can contain several types of ichnofacies. The most typical are perhaps *Thalassinoides*, *Zoophycos* and *Chondrites*.



From Tucker, 1990

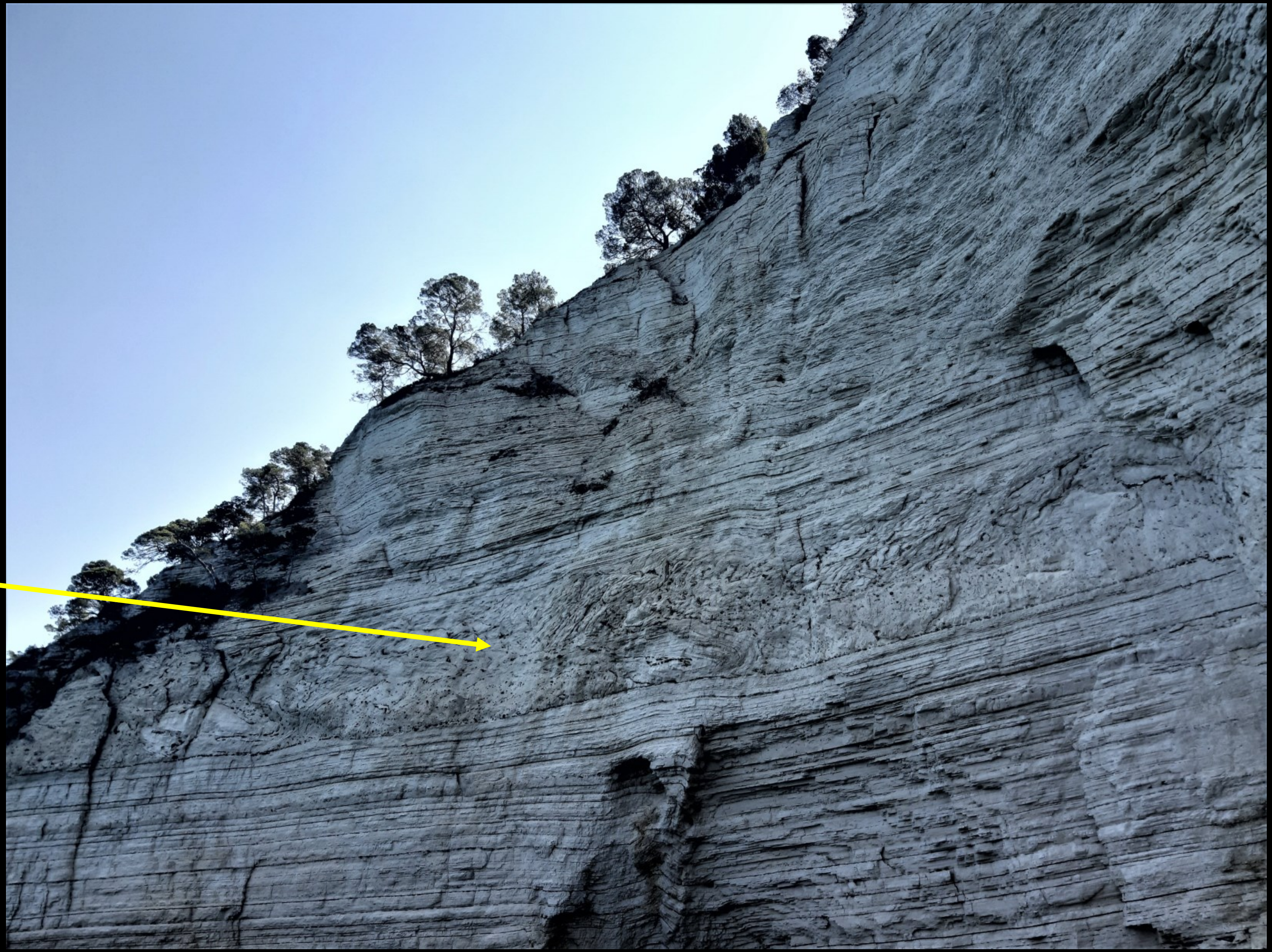


Zoophycos in Mississipian limestone from New Mexico (USA). Inset shows the shape and internal structure of a *Zoophycos* trace fossil.

Deep water carbonates

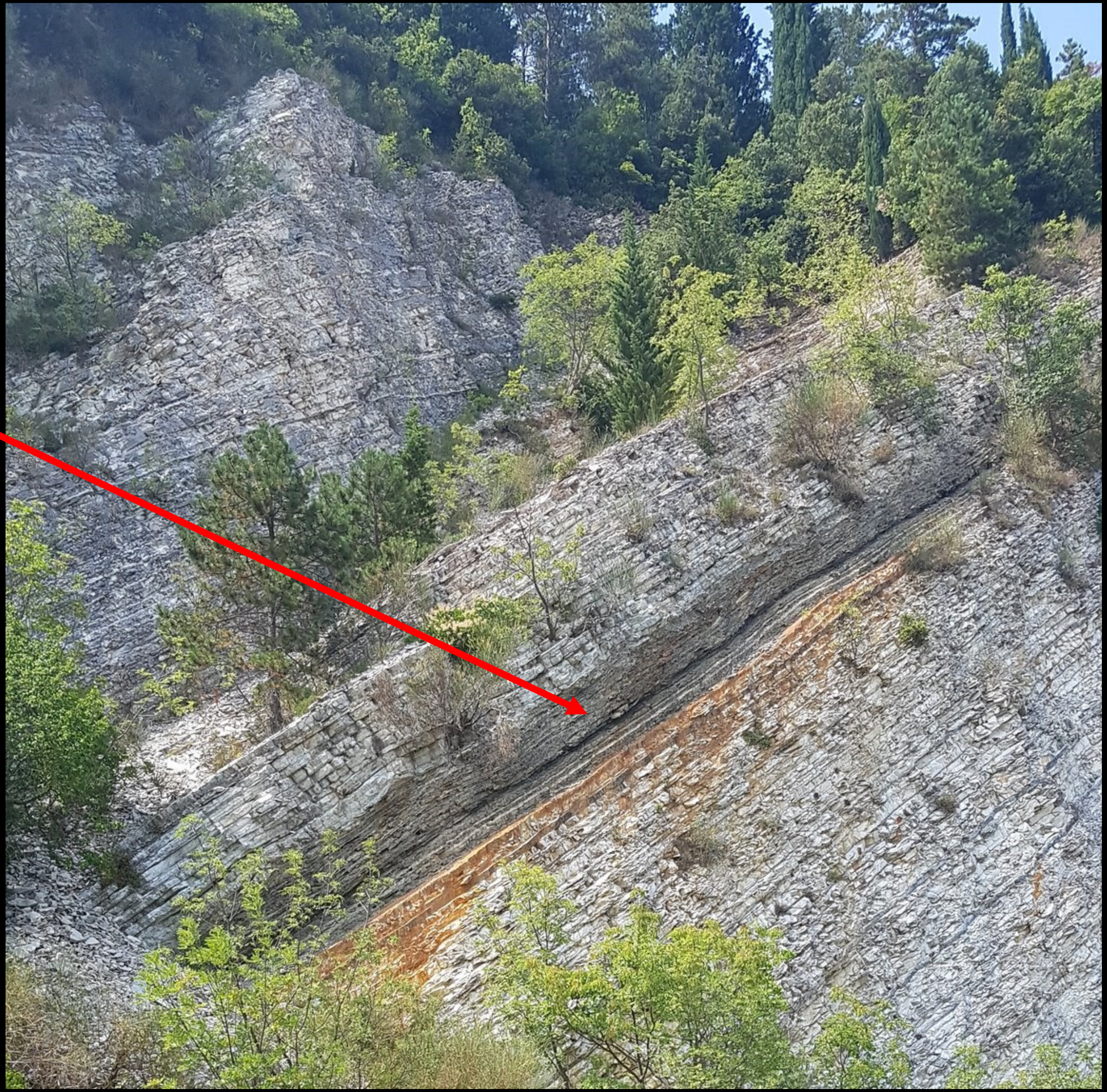
Landslides are not infrequent in deep-water carbonates. They can be triggered by, for instance, earthquakes, and are facilitated by partial lithification and by the exisence of even small gradients.

Slumps are typical of some deep-water carbonate successions. A slump deposit appears as an interval in which layering, earlier nice and regualar, suddenly becomes chaotic or convoluted.



Deep water carbonates

Pelagic carbonates can be also found interbedded or intermixed with non carbonate material (e.g. as in hemipelagic facies).
In some cases, organic rich shales can deposit. Such sediments has for instance deposited during *ocean anoxic events*, times in which the sea floors where characterized by widespread anoxia/disoxia.
In some cases black shales can be followed over very large extensions and found in distant basins.
A famous example in Italy is the Bonarelli Level (Cenomanian Turonian).

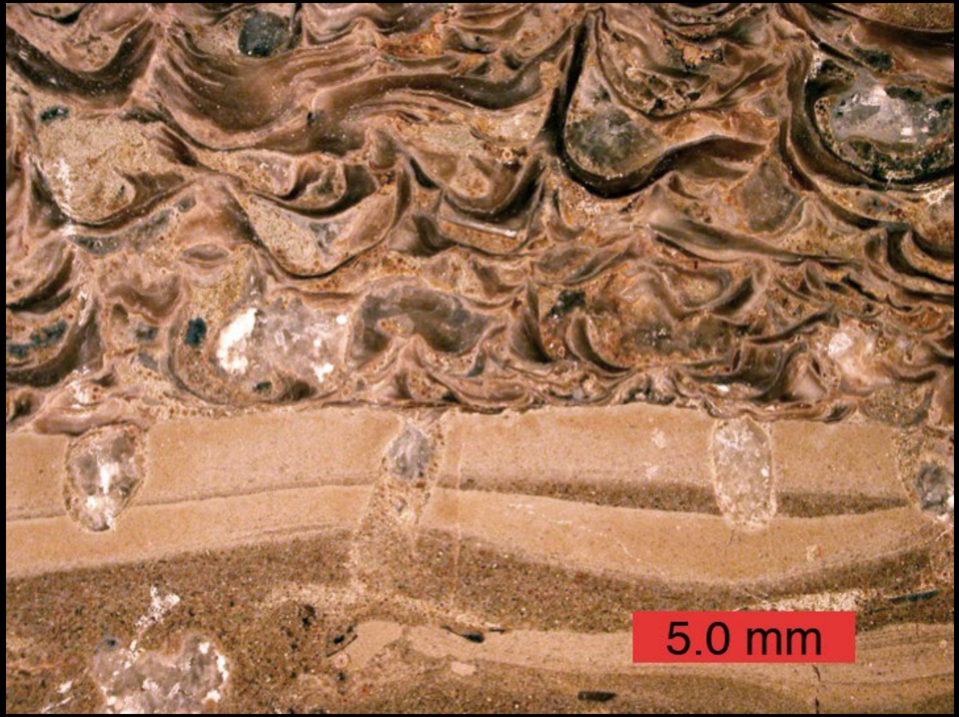


The Bonarelli Lelvel in the Furlo Gorge (central Apennines, Italy)

Deep water carbonates

In the Mesozoic and Cenozoic accumulation rates has been estimated on the order of 30 mm/kyr. For comparison accumulation rates of shallow water carbonates can exceed 1000 mm/kyr.
Furthermore, the seafloor can be sometimes below the CCD or sedimentation can stop.
In these conditions Mn/Fe oxides or particualr minerals such as glauconite can accumulate and hardgrounds can develop.

Thin section of a hardground in deep water carbonates. The fine grained, laminated carbonate below is burrowed and the burrows are infilled by sediment above which is characterized by abundant shells of encrusting oysters. Note that the burrows are not flattened or elongated in a direction parallel to the lamination. This indicates that the sediment below was indurated when it was burrowed or became indurated before compaction

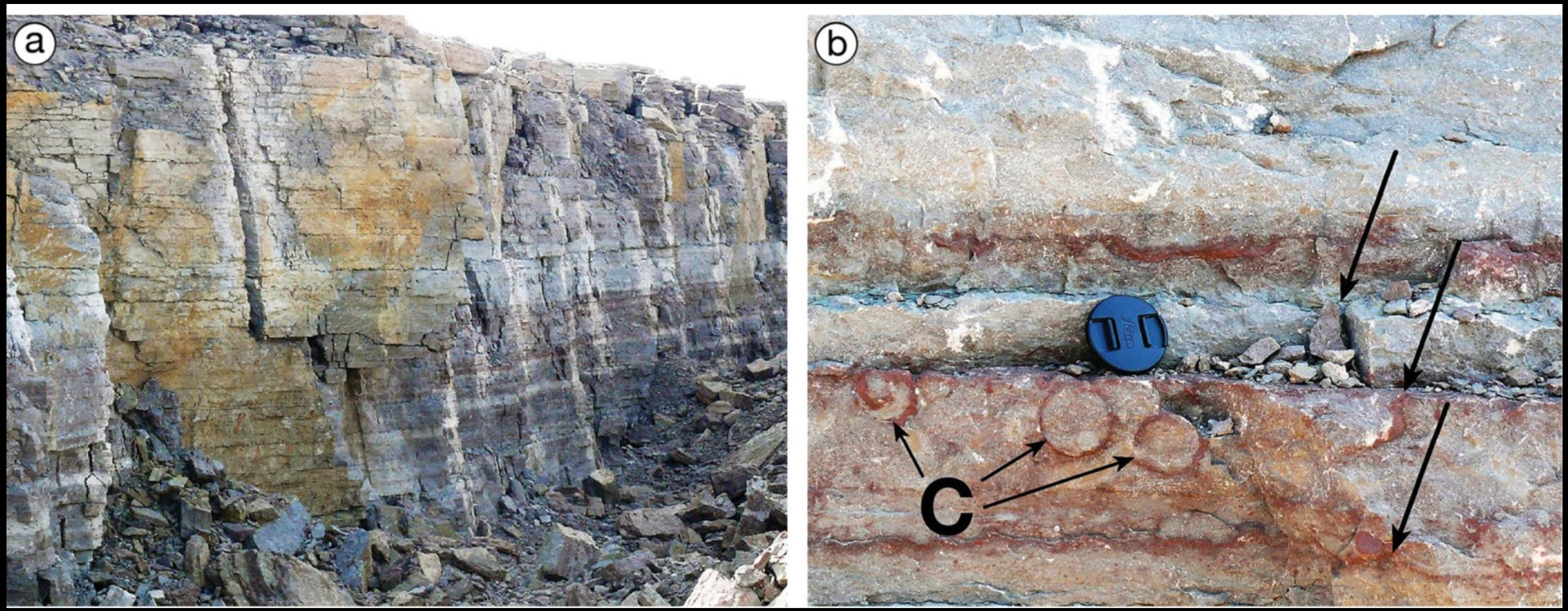


Burrowed hardground surface. The burrows are filled with the sediment that deposited on the hardground

Deep water carbonates

Paleozoic and early Mesozoic carbonate successions, since they deposited prior to the «explosion» of pelagic calcification, are often thin and very condensed.
Nevertheless deep-water carbonates in Paleozoic and early Mesozoic do exist. Their origin is, however, unclear. Possible sources include:

- Disgregation of macrofossils
- Inorganic/abiotic carbonate precipitation in the water column (whitings)
- Transportation from ramps or platform through hyperpycnal and mesopycnal flows.

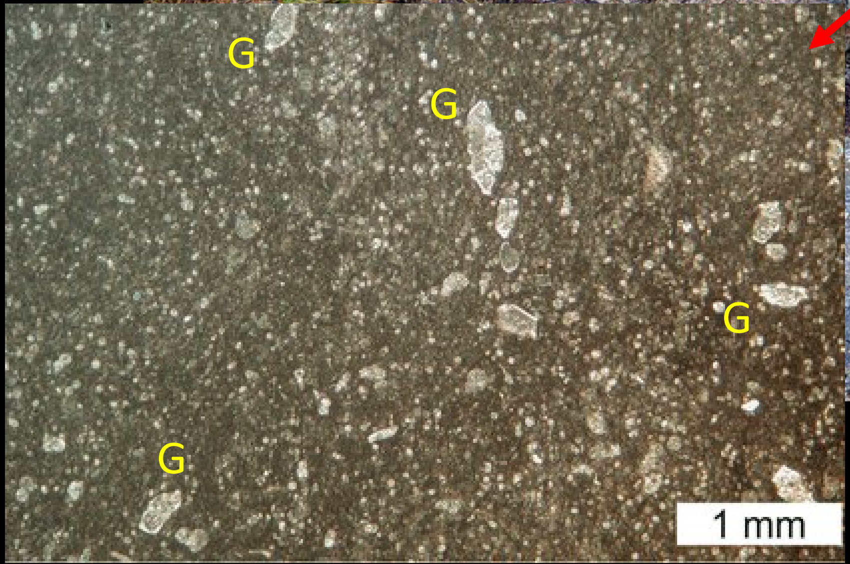


Orhtoceras limestone (Sweden) depositen in a large epicratonic sea that in the Ordovician occupied a large portion of the Baltic Shield.
The succession (a) is very condensed and few tens of meters thick. It is charcaterized by numerous hardgrounds (arrows in b).
Orthoceras shells are marked with letter «C».
From James and Jones, 2015.

Deep water carbonates – Tethyan Mesozoic pelagic sediments

Classic examples of ancient pelagic carbonates are exposed in the Mediterranean region. They accumulated in a variety of depositional settings, but one typical instance that has been studied is when they are associated with shallow water carbonates.

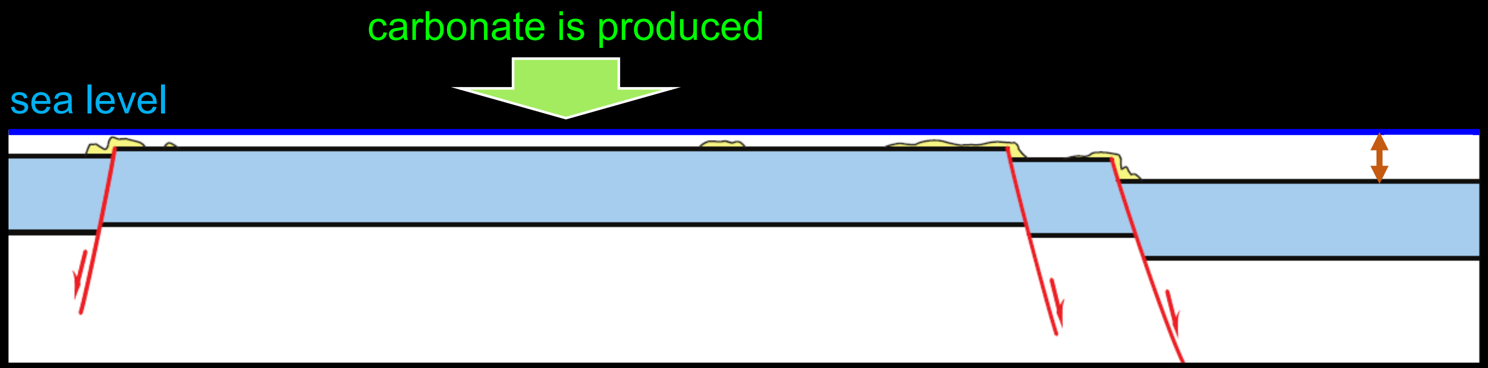
Cretaceous Scaglia Rossa in the Brent de l'Art section (Belluno). The Scaglia Rossa is made of a mainly red micrite with abundant planktonic foraminifera



Thin section of Scaglia Rossa. The facies is a fine grained micrite containing the typical planktonic foraminifer *Globotruncana* (G)

Carbonate platform drowning

We have seen that a carbonate platform s.s. develops when carbonate production is able to keep pace with the local sea level rise.
This is particularly important for T-type platform because the carbonate factory of these platforms is productive in the first tens of meters of water depth.



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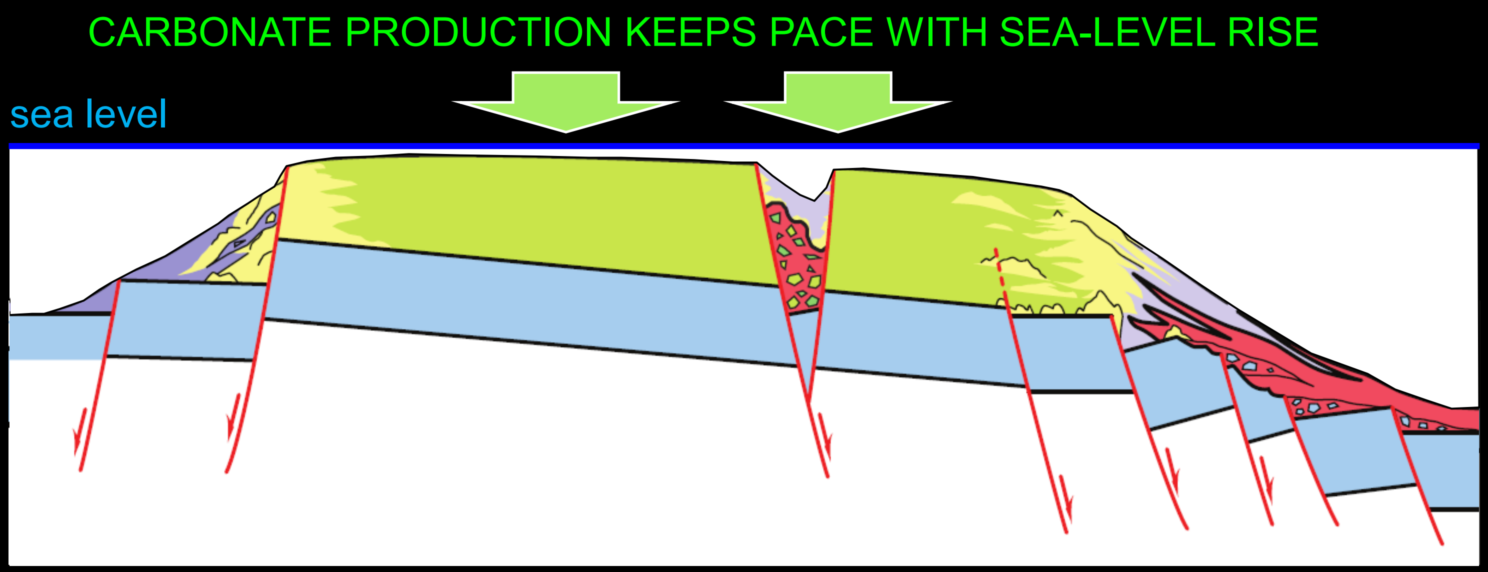

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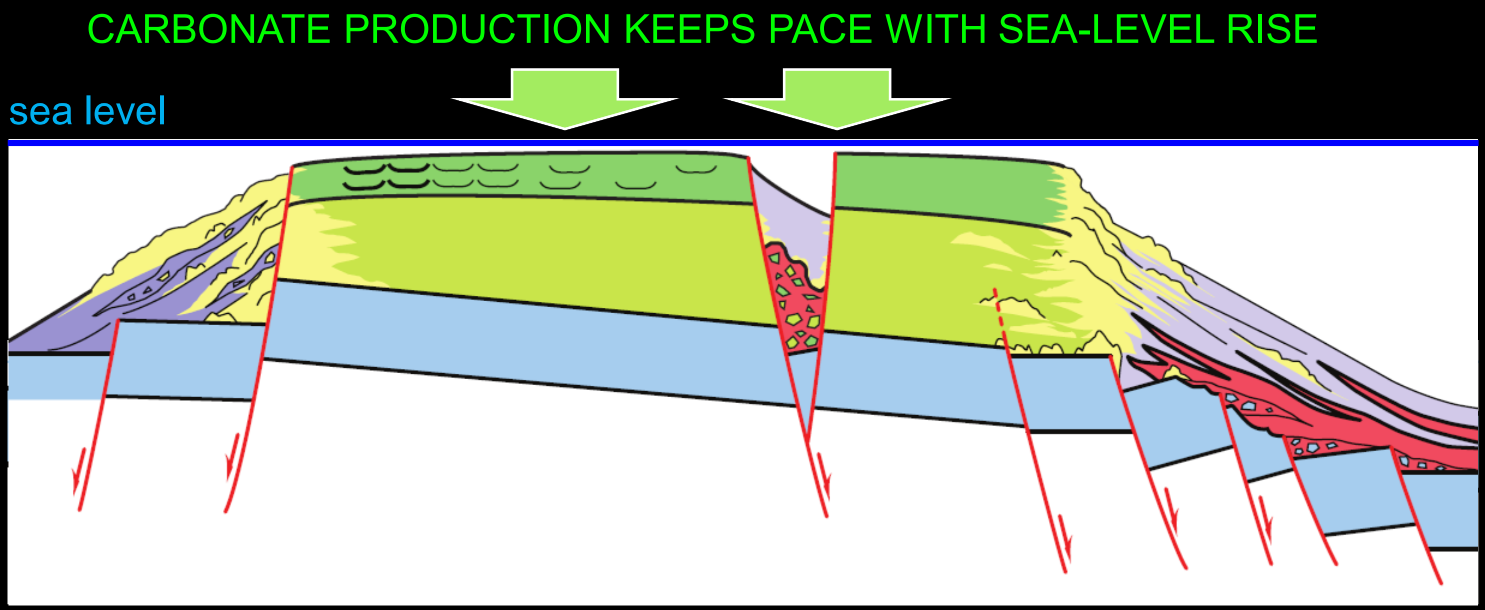

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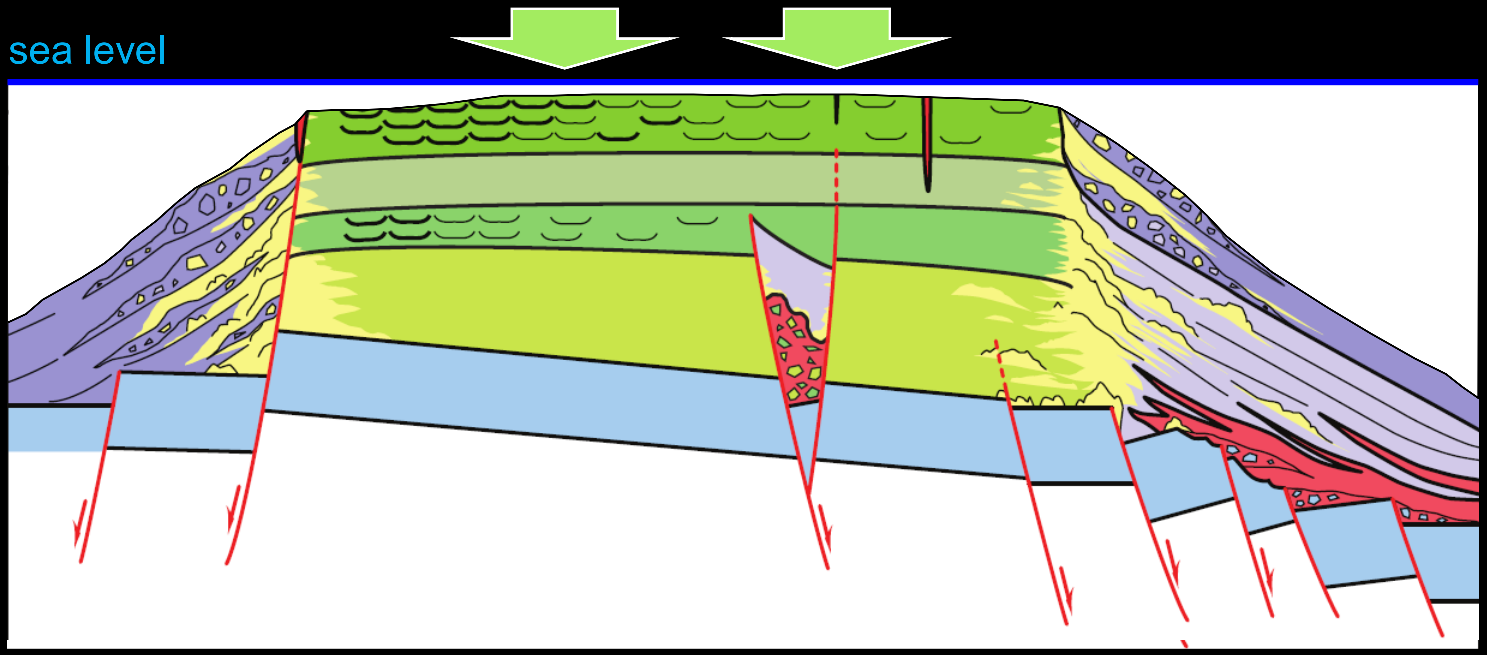
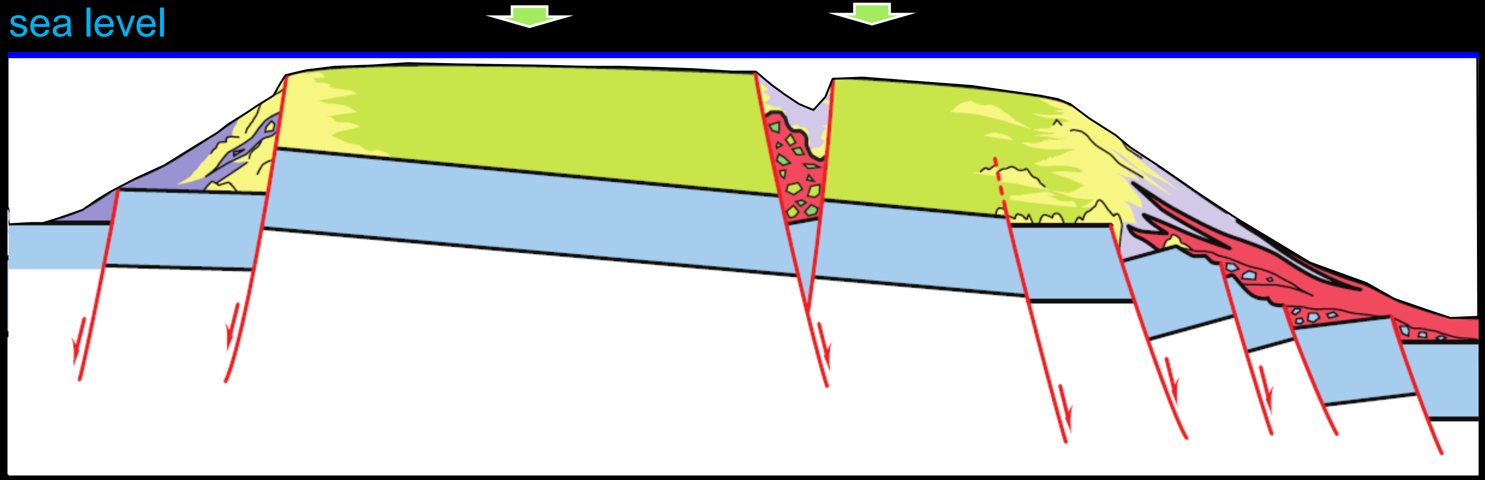


Carbonate platform drowning

But what happens if carbonate production, for some reason, becomes no more able to counter sea-level rise?
In this case the platform starts to sink progressively to highed depths and it may therefore come a point at which carbonate production ceases and the platform drowns.



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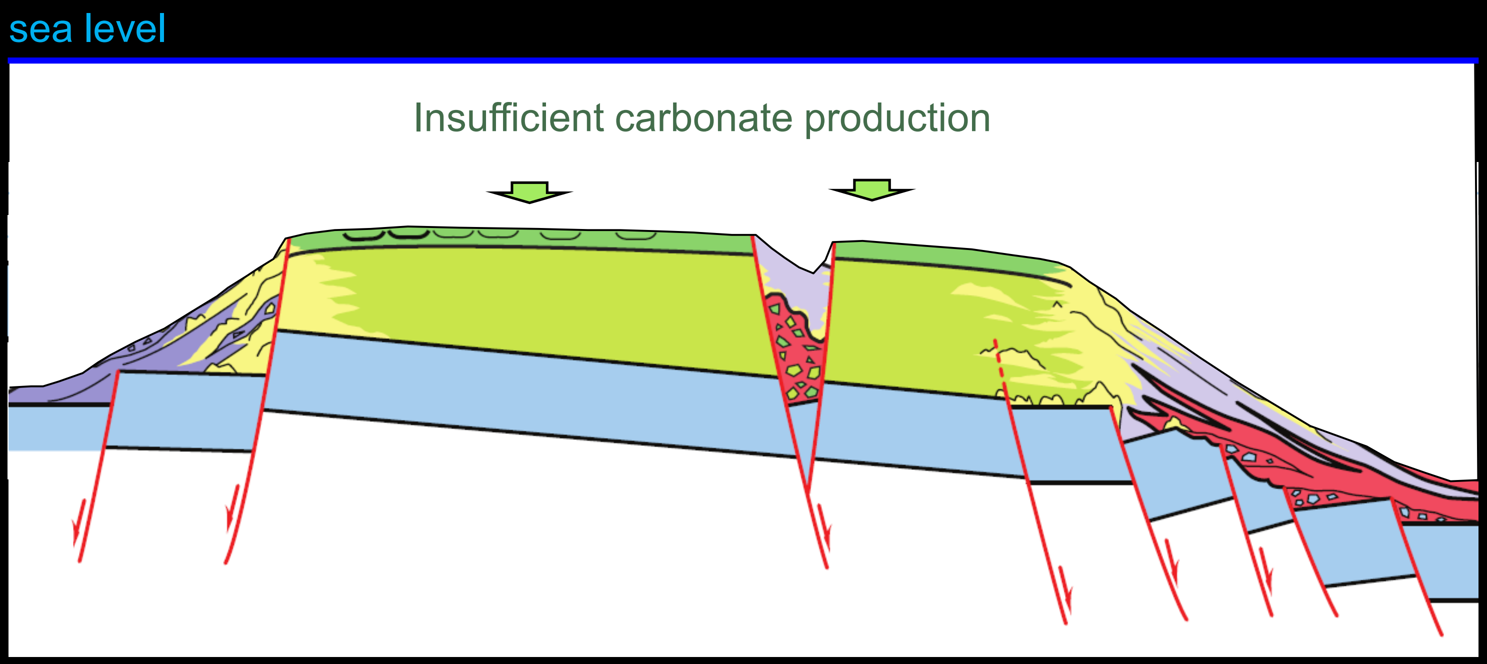

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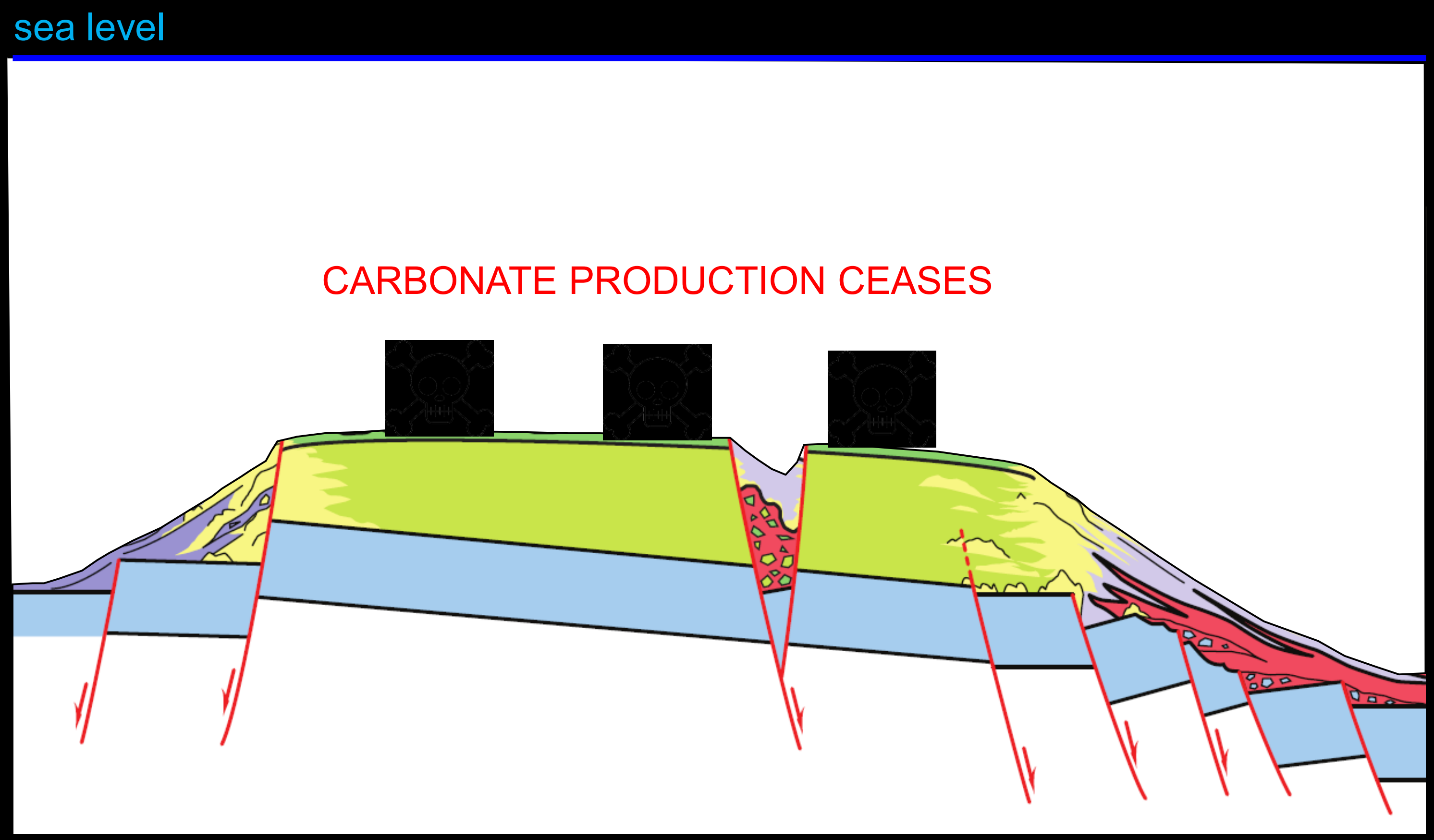
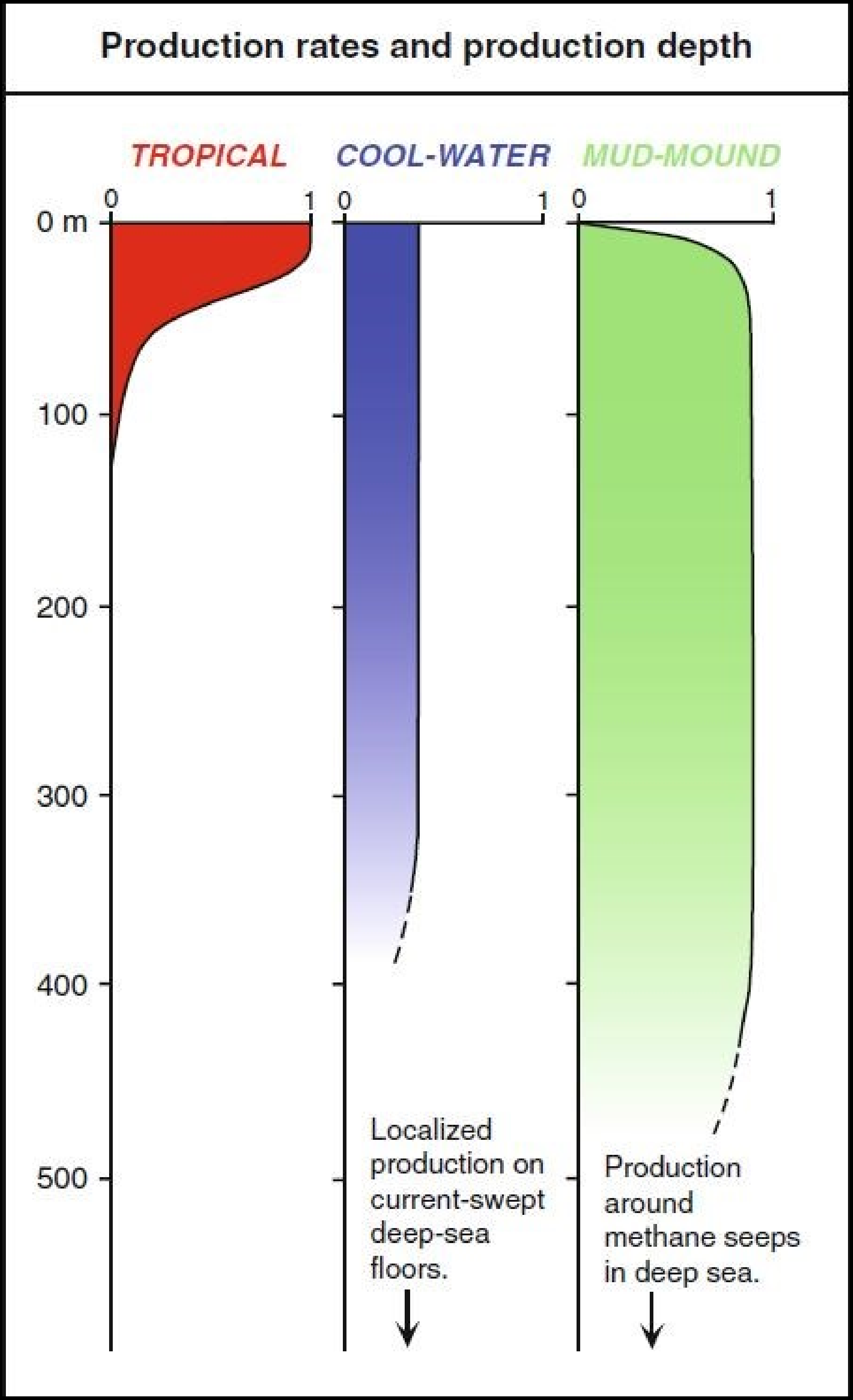


Carbonate platform drowning

Let's recall the carbonate production/depth profile of the three carbonate factories.

Which factory is, in your opinion, more vulnerable to sea-level variations?



Schlager, 2003

Carbonate platform drowning

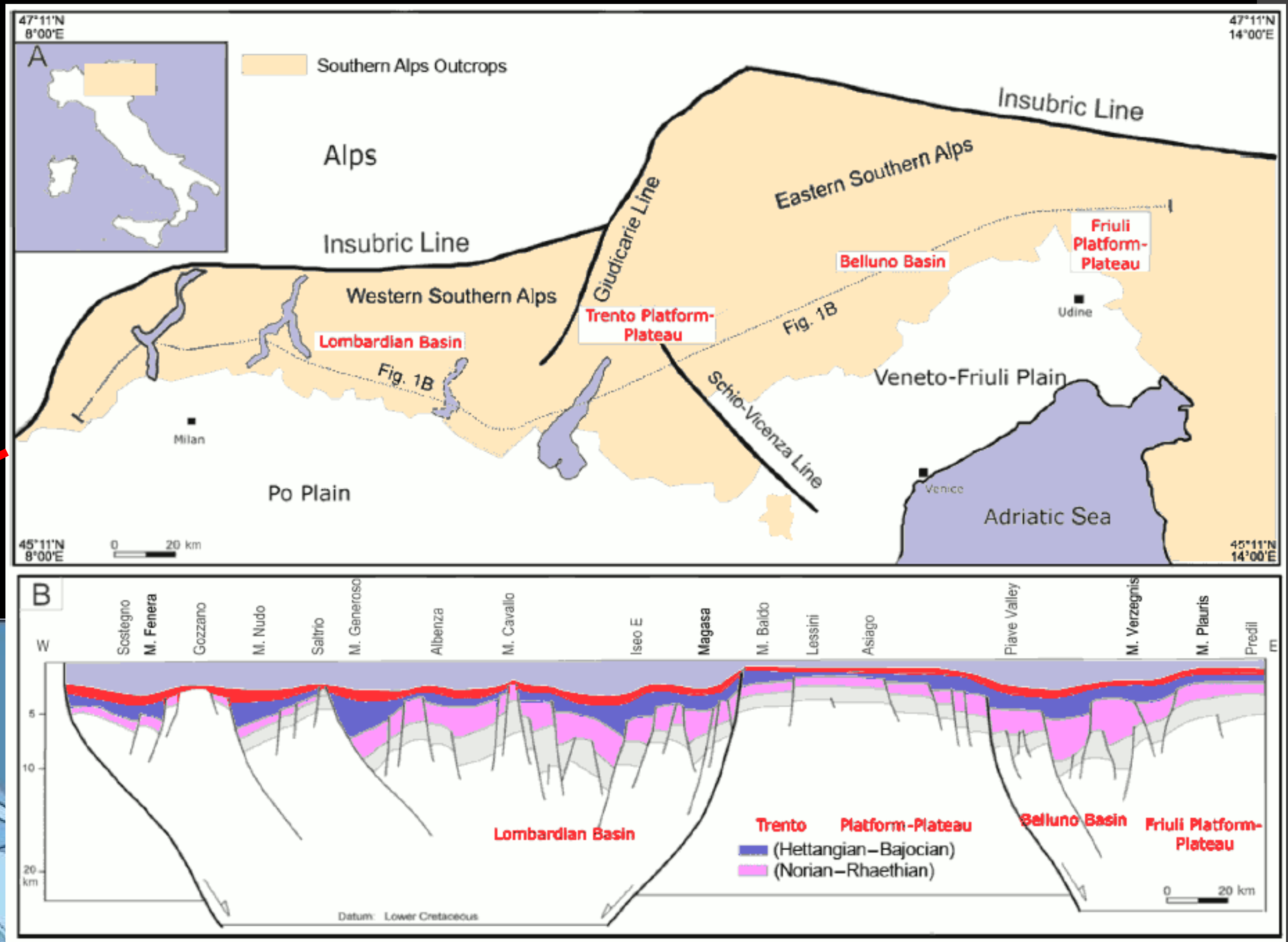
A drowning can be recognized in the geologic record for the presence of a drowning unconformity.

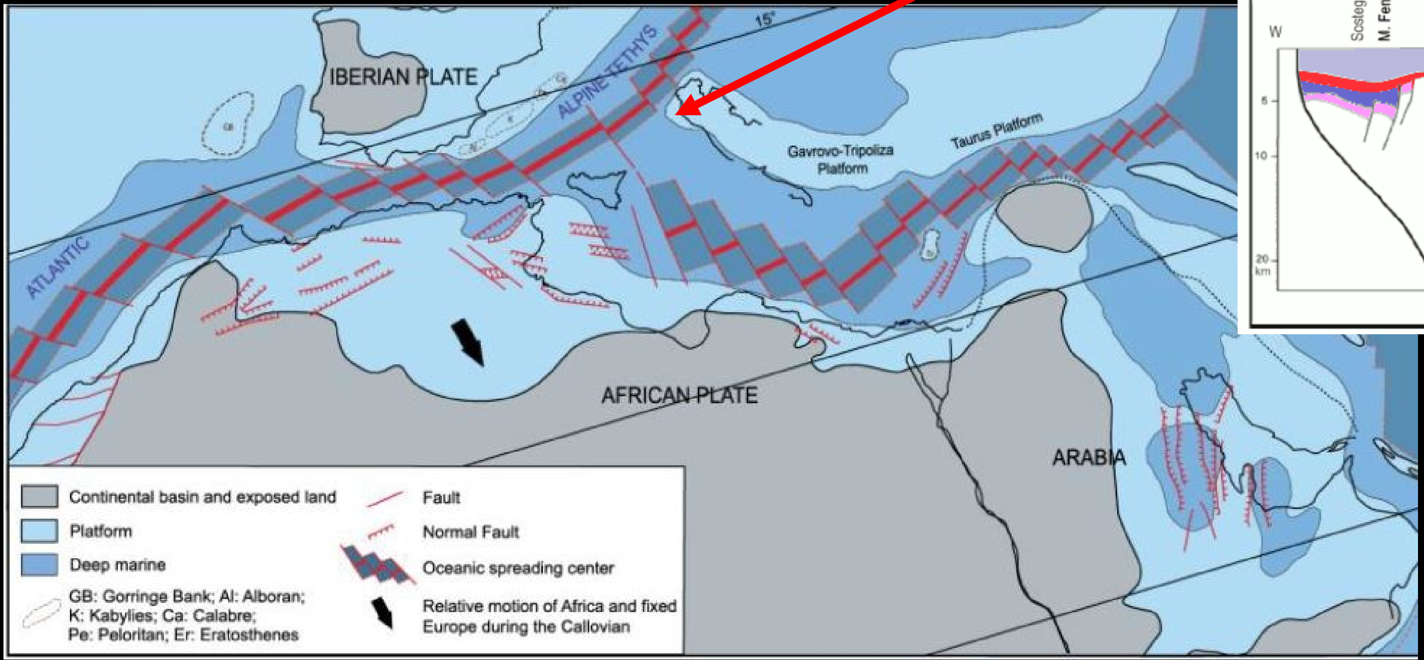
A drowning unconformity mostly consists in the deposition of deep marine facies on top of shallow marine limestones.

Drowning of the Trento Platform as seen in the Brenta Dolomites (Italy).
http://win.geo360.it/pano145_L.htm

Deep water carbonates – Tethyan Mesozoic pelagic sediments

After a long period characterized by shallow water carbonate sedimentation, the area occupied by the Southern Alps was involved in the rifting phase that brought to the break up of the Pangea mega-continent and the to the opening of the Tethys ocean.

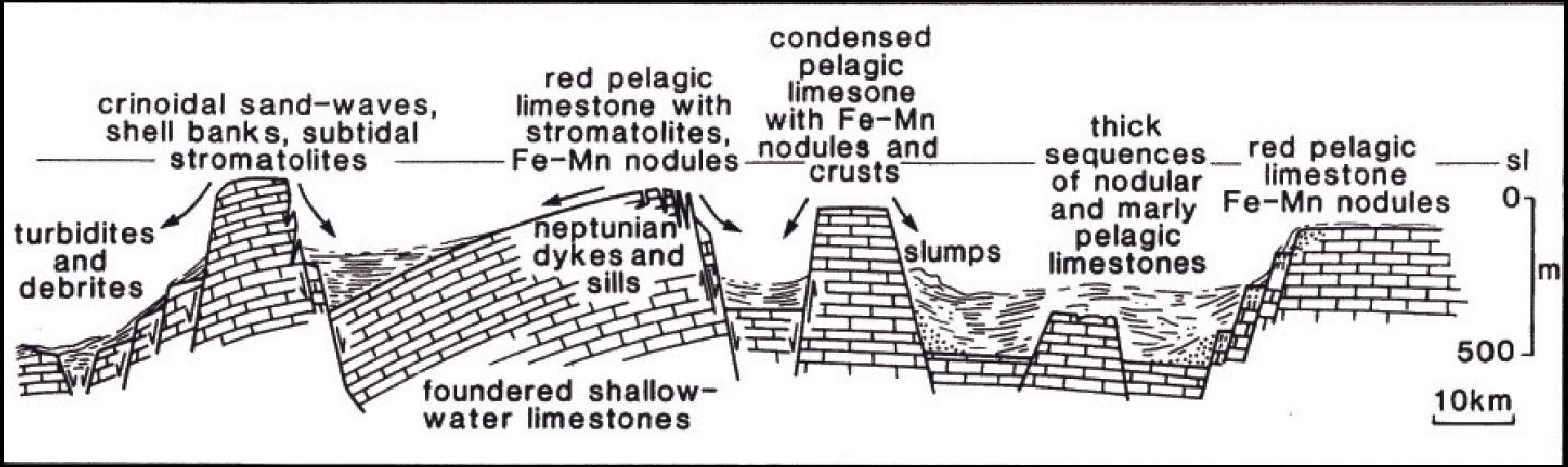




Above, A crustal cross section desumed from the Mesozoic rocks exposed in the Southern Alps. From Masetti et al., 2011, modified.
Left. Middle Jurassic paleogeographic reconstruction of the Mediterranean region showing the ongoing rifting and oening of the Atlantic and Alpine Tethys.
From Frizon et al. 2011.

Deep water carbonates – Tethyan Mesozoic pelagic sediments

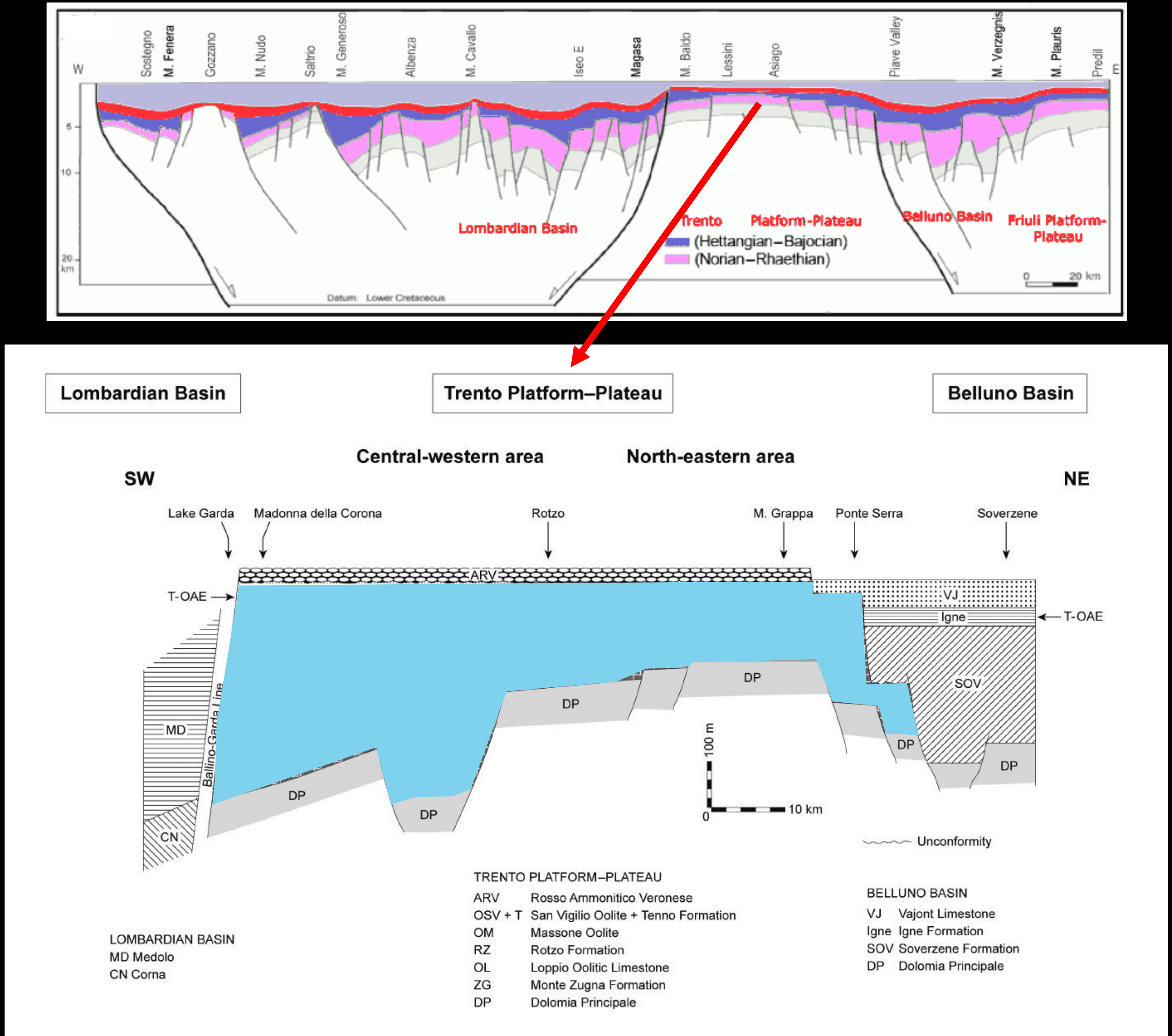
Mesozoic Tethyan pelagic sediments deposited in a variety of depostitional settings. But a peculiarity is that they are often associated with (and display several types of geometric relationships with) shallow water carbonates. This is due to the fact that they deposited in the context of the Early Jurassic rifting phase that brought to the dismembering of many carbonate platforms in the area.



Bernoulli and Jenkyns, 1974

Deep water carbonates – Tethyan Mesozoic pelagic sediments

Rifting brought first to the formation of a series of horsts and grabens.
The Trento Platform was one of these horsts and was bounded to the west by the Lombardian Basin and to the east by the Belluno Basin.
The shallow water carbonate succession of the Trento Platform is known as “Calcari Grigi”

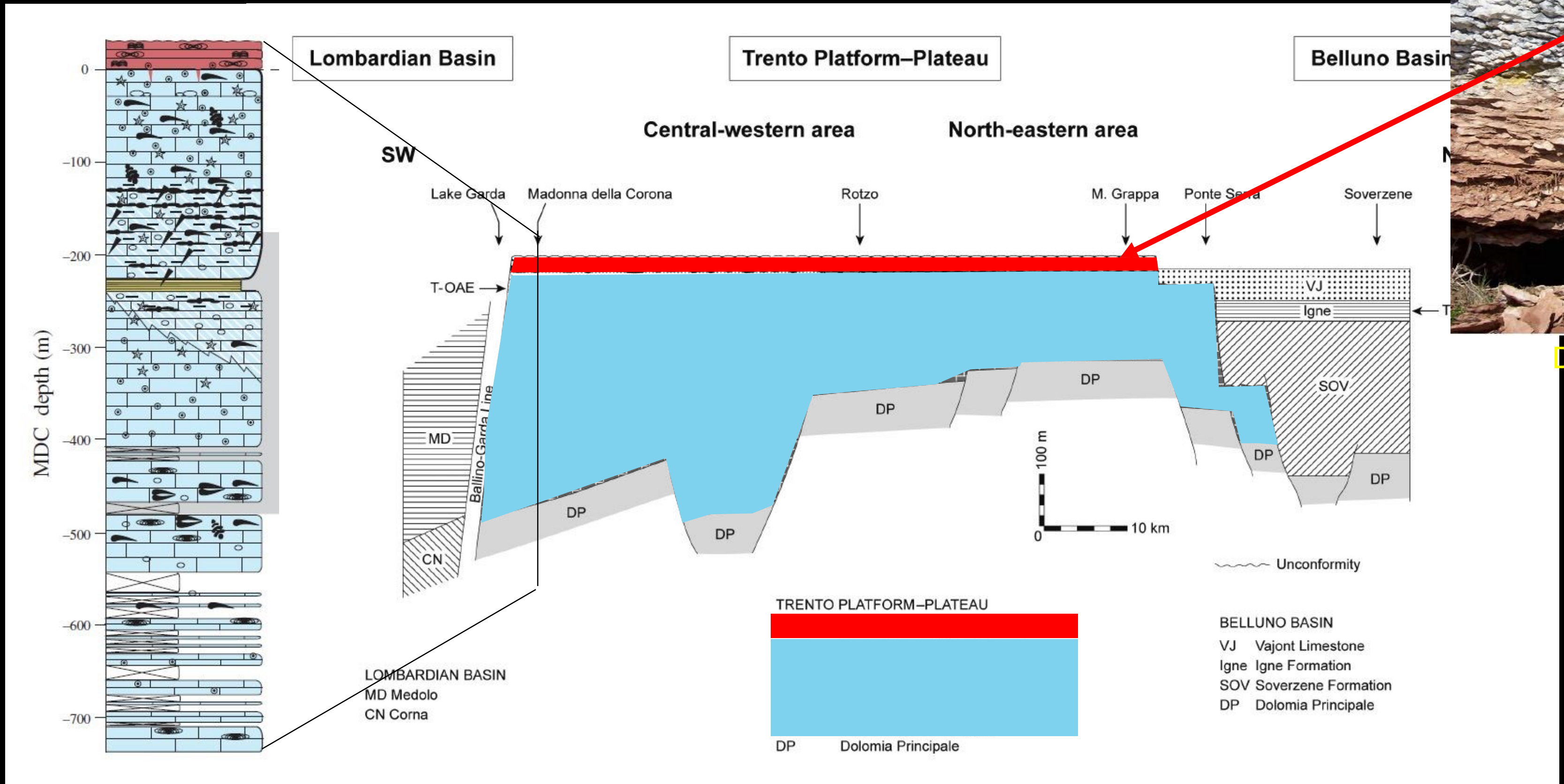


The Early Jurassic shallow water units of the Trento Platform (blue). From Masetti et al., 2011, modified

Some facies of the Calcari Grigi deposited on the Trento Platform.

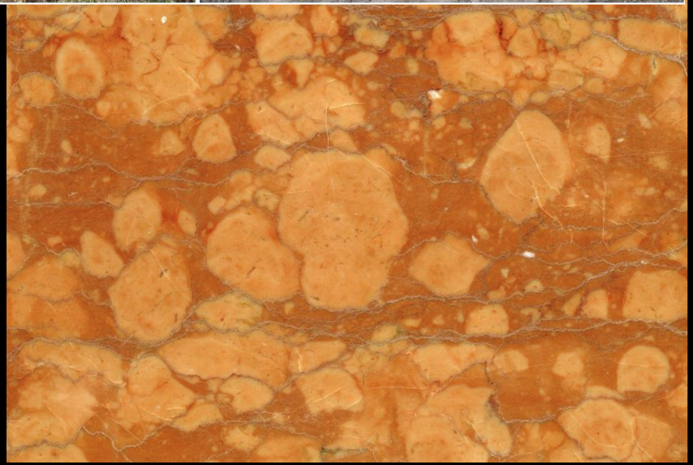
Deep water carbonates – Tethyan Mesozoic pelagic sediments

The Trento Platform in the Aalenian (Middle Jurassic) drowned as testified by the depositon of the pelagic facies of the Rosso Ammonitico Veronese on top of shallow water limestones



The Rosso Ammonitco Veronese (red) is made of pelagic carbonates and lies with a drowning unconformity on top of the shallow water carbonate succession of the Calcari Grigi (blue). From Masetti et al., 2011, modified. The stratigraphic column on the left (Madonna della Corona section) is from Woodfine et al., 2008.

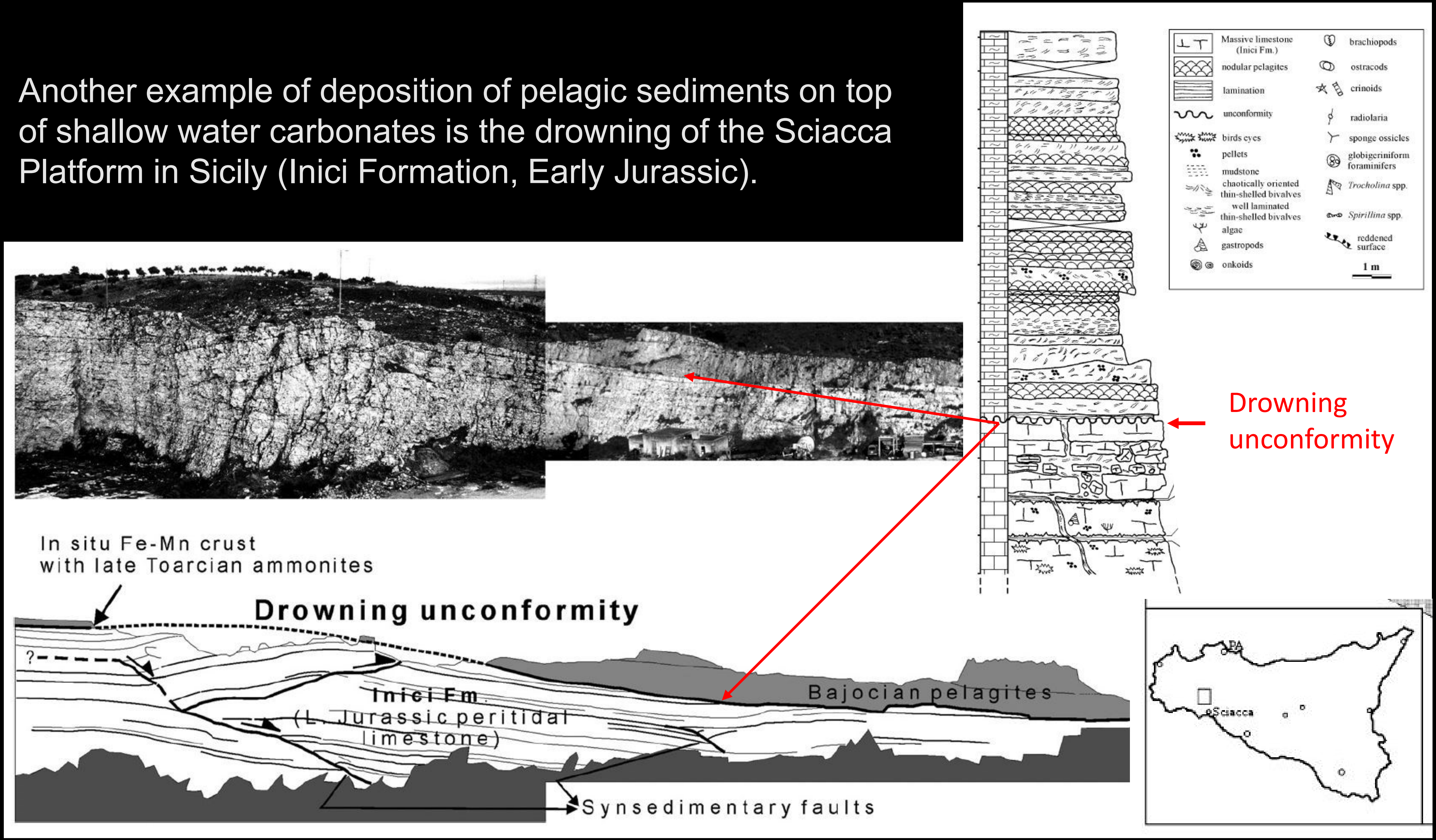
Da Wikipedia.it, public domain image



https://www.flickr.com/photos/jsjgeology/14802172801

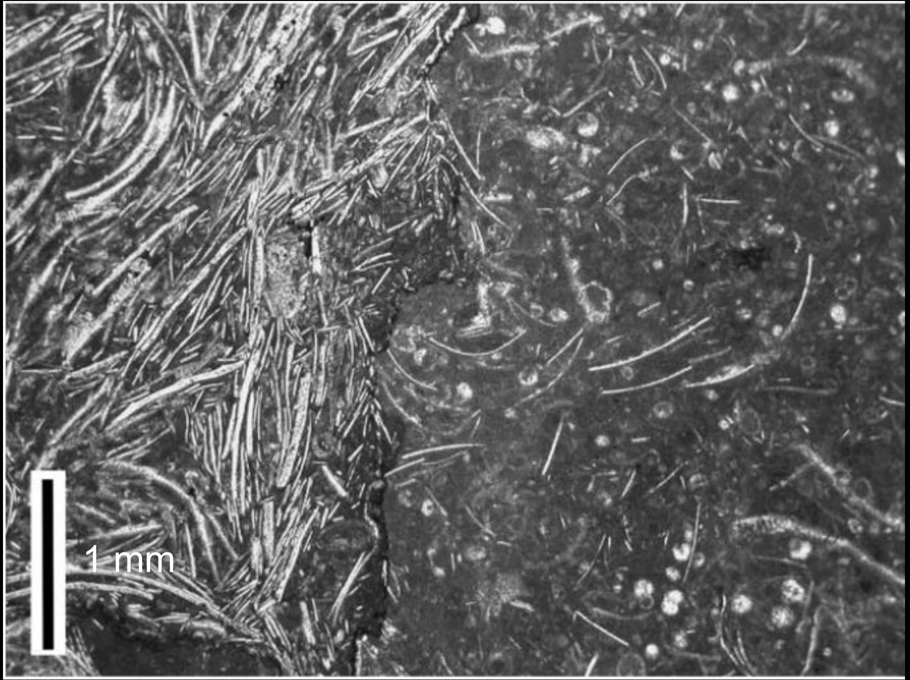
Deep water carbonates – Tethyan Mesozoic pelagic sediments

Another example of deposition of pelagic sediments on top of shallow water carbonates is the drowning of the Sciacca Platform in Sicily (Inici Formation, Early Jurassic).



Deep water carbonates – Tethyan Mesozoic pelagic sediments

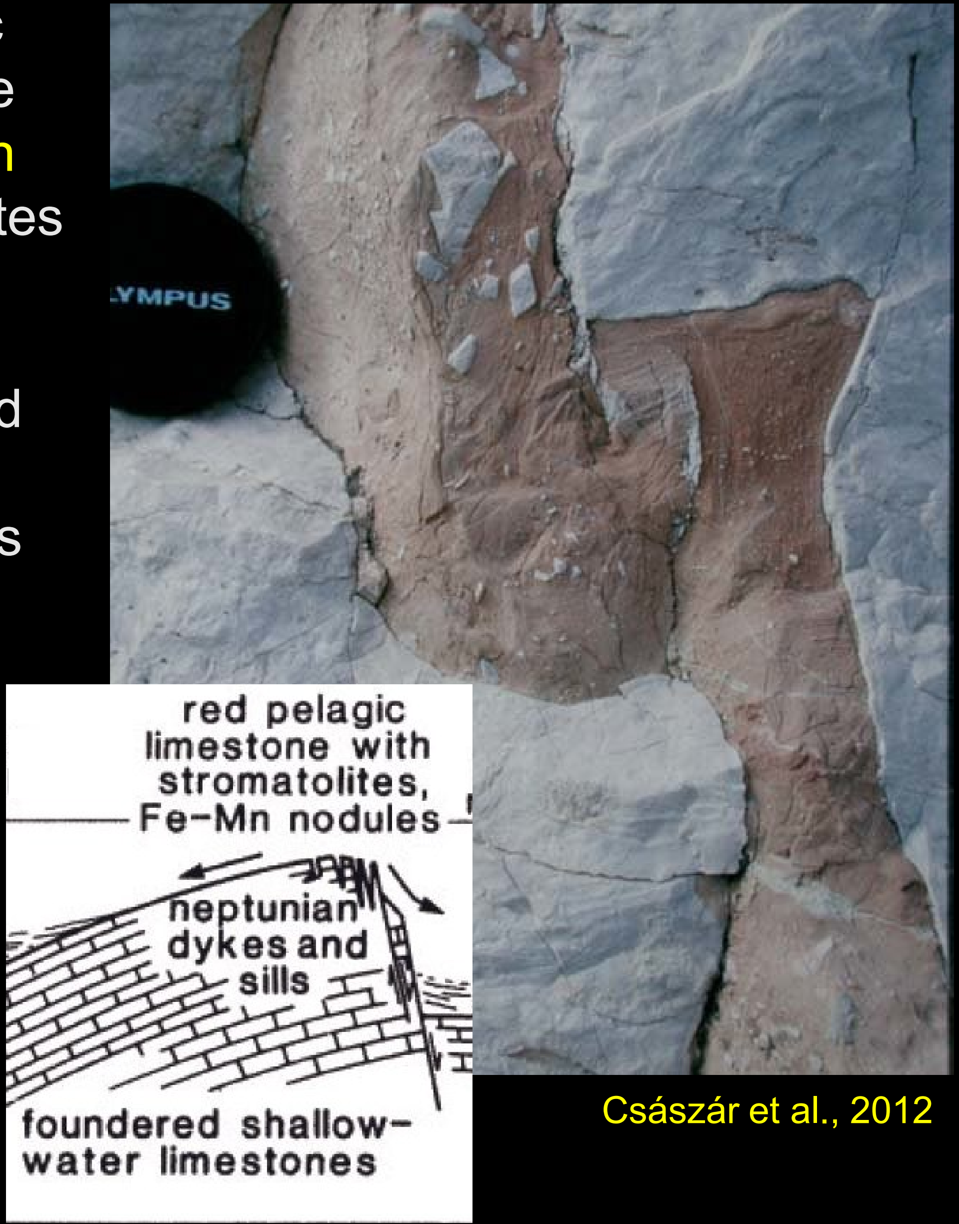
The name Ammonitico Rosso comprises several red nodular limestone that are found in the Tethyan region on top of drowned carbonate platforms. The age of these units can be variable.
Typically the Ammonitico Rosso facies is very condensed. Hardgrounds are often present and fossils such ammonoids show signs of strong dissolution.



Ammonitico Rosso displayis a typical nodular facies. Ammonoids are generally poorly preserved.
To the left a microphotograph of a thin section of Ammonitico Rosso (from Martire et al., 2006). The upper part of the photgraph is a nodule and is made of a wakestone rich in protoglobigerinids, radiolarians and thin shelled bivalves. Below the matrix between nodules is made of a compacted packstone full of thin-shelled bivalves. The depht of deposition of these limestone has been subject of much debate. The absence of extreme paucity of benthic fossils suggests depths exceeding 50-100 m but possible down to several kilometers.

Deep water carbonates – Tethyan Mesozoic pelagic sediments

Another possible variety of pelagic sediments associated to carbonate platforms are infillings of neptunian dikes. Neptunian dikes in carbonates appear as fractures with straight, parallel boundaries filled with fine carbonate sediment (often red) and sometimes fragments of the surrounding platform deposits. This sediment is made of pelagic carbonates. Neptunian dikes can form on platforms when they are subject to extensional tectonics.

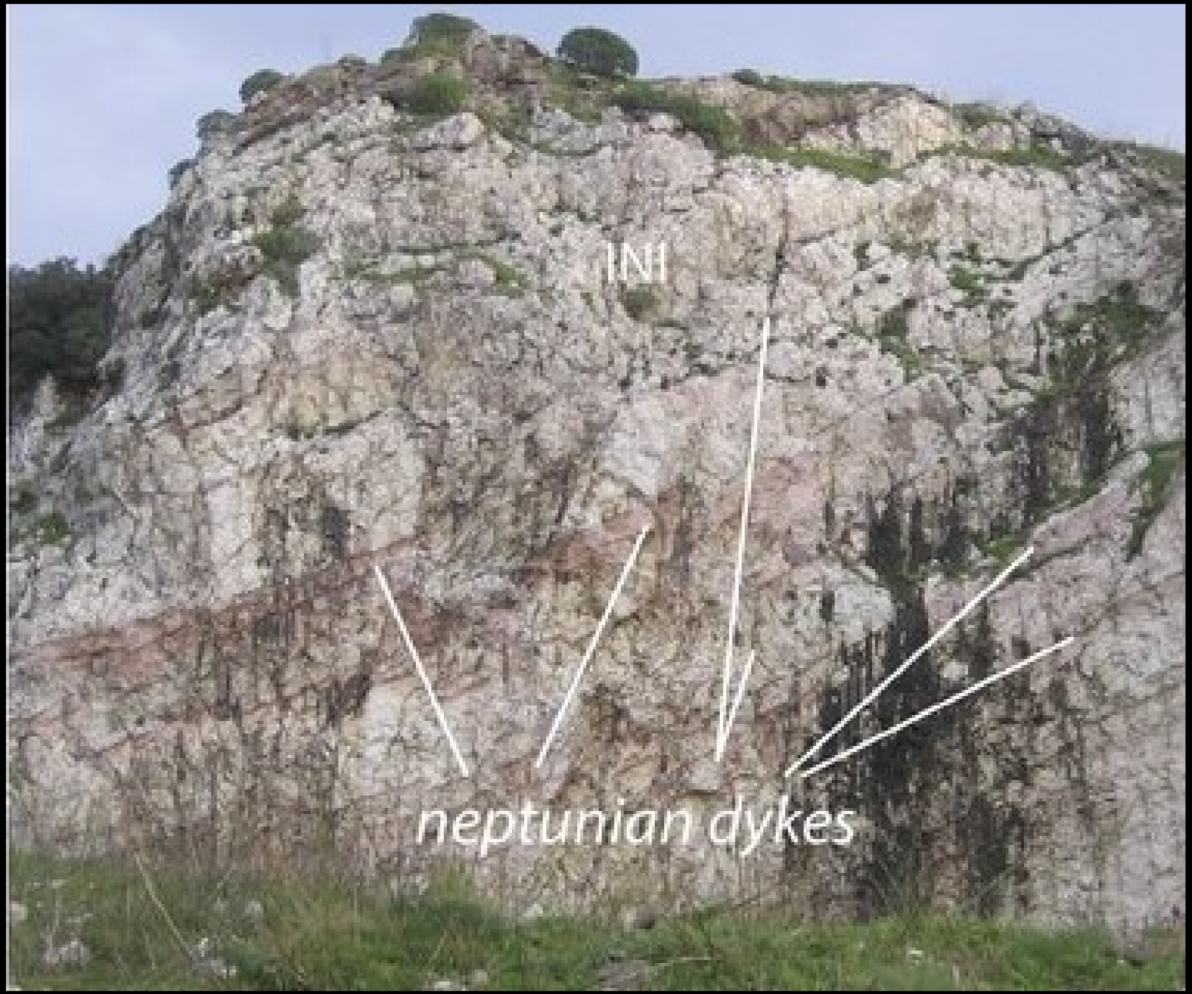


Császár et al., 2012

Photo couresy Nereo Preto

Neptunian dikes in carbonate platforms, unlike karst cavities, display straight, parallel boundaries (right). Infill is often made of a fine grained pelagic carbonate. In some case the infill is made of the pelagic unit that covers a drowned platform.

Deep water carbonates



Another example of neptunian dikes in the Early Jirassic Inici Formation (Sicily).

Take home messages for today

- Deep water carbonates deposit in the open sea and today are mainly made of skeletal fragments of planktonic organism
- The pelagic fraction of deep water carbonate sedimentation was nearly absent in the Paleozoic and became volumetrically important from the Early Jurassic
- Whereas volumes of pelagic carbonates were small prior to the mid Mesozoic, thick deep water carbonate successions deposited in periplatform basins.
- Deep water carbonates are normally well bedded and finely laminated. Benthic forms are rare or absent. Planktic organism (e.g. ammonoids) can be present.
- Sedimentation rates of pelagic carbonates are normally slower (on the order of 10mm/kyr) than those of shallow water carbonates. Condensed successions are frequent. Hardgrounds can be present.
- Mesozoic pelagic carbonates of the Tethyan (Mediterranean) region are often associated with platform carbonates. A notable case are carbonate platform drownings.
- A typical pelagic carbonate facies associated to carbonate platform drownings is the middle Jurassic Ammonitico Rosso.