

# **Coral Buildups in Mesophotic, Siliciclastic Prodelta Settings (Late Eocene, Southern Pyrenees, Spain): An As Yet Unexplored Play?\***

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## **Abstract**

Cenozoic zooxanthellate corals are commonly considered to form framework-dominated buildups in shallow, well illuminated (euphotic) and oligotrophic conditions. In contrast, detailed outcrop study and facies-component analysis show that Eocene non-framework coral buildups also developed in turbid, poorly illuminated (mesophotic) and relatively nutrient-rich conditions. The study area is located in the South-Central Pyrenean Zone (Jaca Basin). Here, middle to upper Eocene prodelta clay/marl succession passes up-section into prograding delta-front sandstones and, subsequently, into continental sandstones and conglomerates. Coral-rich lithosomes occur in the upper part of the clay/marls succession and are completely encased in clay.

Within coral buildups, facies consist of: 1) coral boundstone with different coral growth fabrics (platestone and domestone, and subordinate pillarstone and mixstone) and abundant red algae, in a mud-dominated matrix; 2) well sorted fine-grained or poorly sorted coarse-grained skeletal packstones with abundant coral fragments, red algae, bryozoans, benthonic foraminifers and rare planktonic foraminifers, locally rich in larger benthic foraminifers and siliciclastic sand; 3) red-algae-rich coral rudstone with pack-wackestone matrix; 4) bryozoan floatstone in a mud-dominated matrix. These carbonate lithofacies pass laterally and vertically into 4) thinly laminated clay to marls with interbedded sandstone beds.

Coral boundstone and associated packstone and rudstone wedges form single bioherms and discrete biostromes (1-8 m thick) that stack into larger carbonate buildups, commonly 20-30-m thick, with some up to 50-m thick. Facies associations, textures, and photo-

dependent components indicate these buildups to have grown in the mesophotic (lithofacies 1, 2 and 3) and aphotic (lithofacies 4) zones and in low energy conditions below fair-weather wave base, where they were only occasionally hit by exceptional storms. Dominance of corals and bryozoans (plankton catchers) over sponges and molluscs (plankton pumpers) indicates predominance of phyto- and zooplankton over picoplankton, which suggest mesotrophic conditions.

Our results highlight the contrast with present-day “classic” reef models and suggest that by the late Eocene reef coral assemblages were able to thrive in low-light, low-energy, turbid and nutrient-rich conditions. The location of these coral buildups, encased in prodelta clays, can be regarded as a new, unexplored, potential play.

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# Coral Buildups in Mesophotic, Siliciclastic Prodelta Settings (late Eocene, Southern Pyrenees, Spain): an as yet unexplored play?

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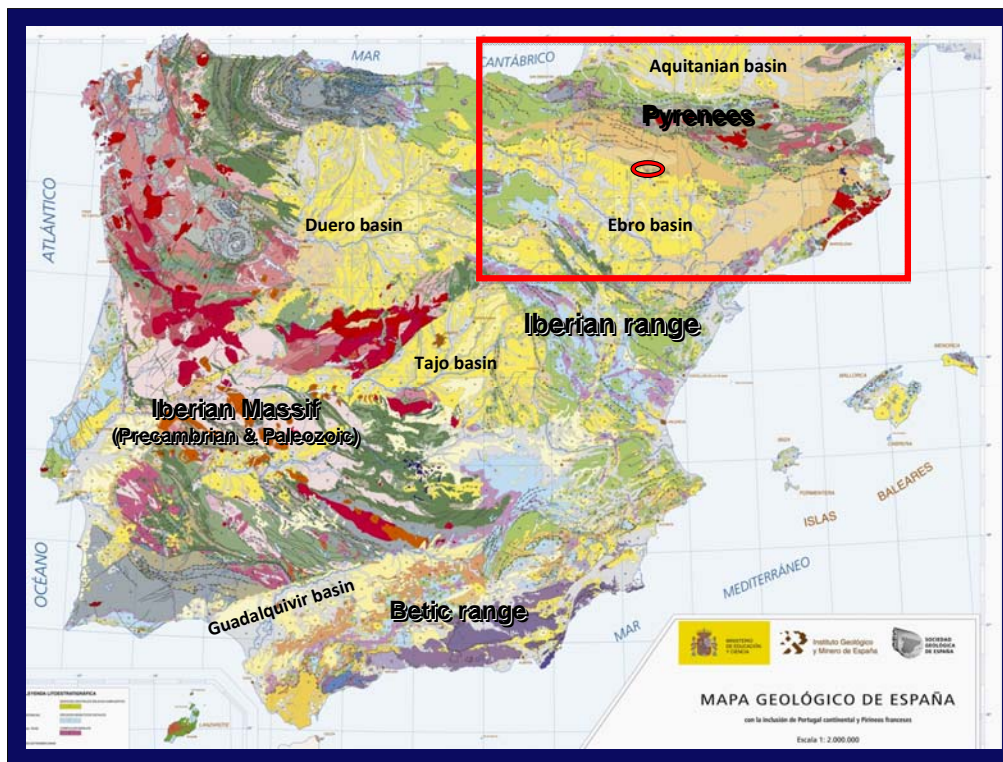
Scleractinian-dominated bioconstructions incased in terrigenous successions are common in the geological record. Nevertheless, there is a generalized inclination to view corals and siliciclastics as mutually exclusive (Sanders & Baron-Szabo, 2005)

During the Cenozoic, hermatypic corals are commonly considered to have formed framework-dominated buildups in:

- ◆ Shallow water settings (euphotic zone)
- ◆ Oligotrophic conditions (low nutrients)

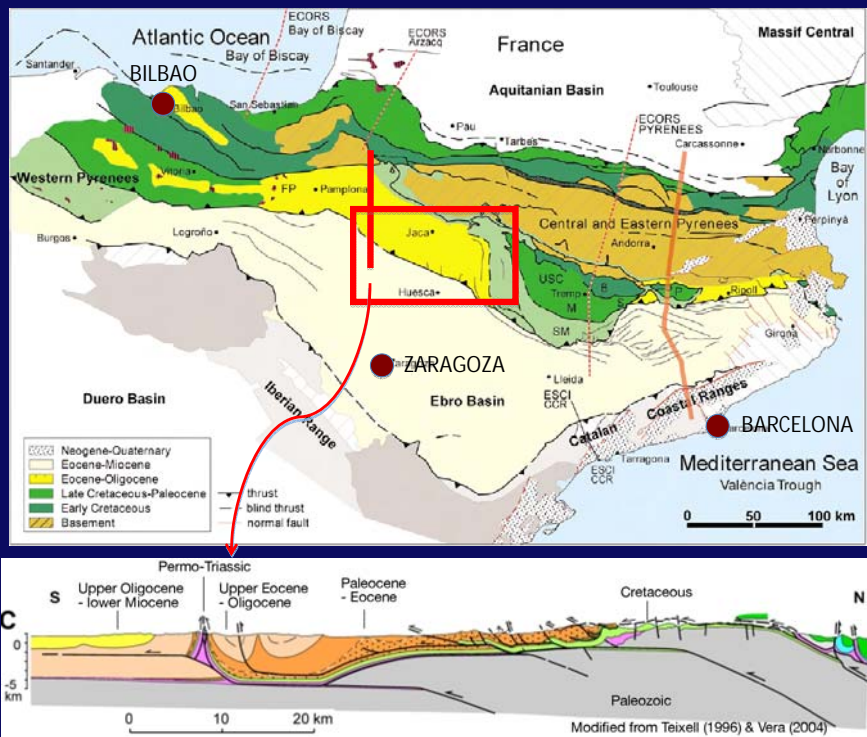
Detailed outcrop study shows Eocene non-framework coral buildups (cluster reefs) to have developed in clay-dominated, mesophotic & mesotrophic conditions





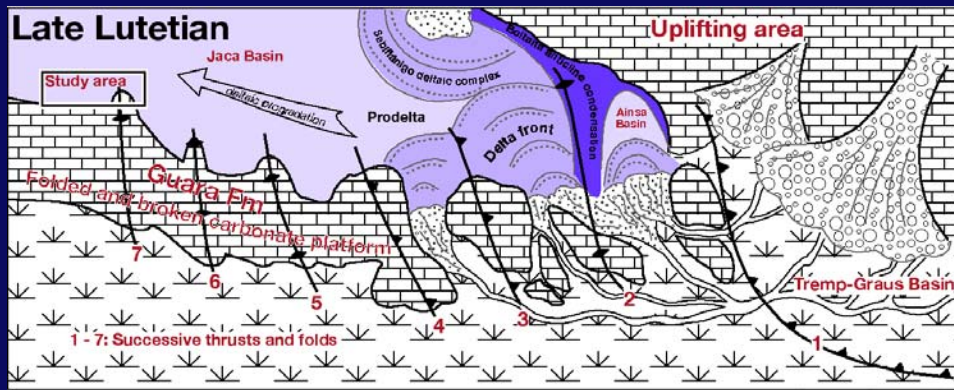
**Presenter's Notes:**

The study area is located in Northern Spain at the edge of the Pyrenees Chain.



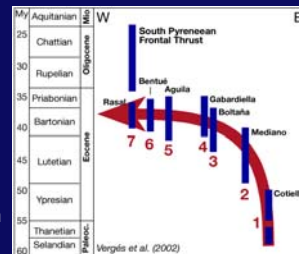
**Presenter's Notes:**

The area is located in the Jaca Basin, a partially, slightly deformed area, belonging to a previous foreland basin of the Pyrenees Chain, successively incorporated into the External Thrust Belt.



Dreyer et al. (1999) & Millan et al. (1994)

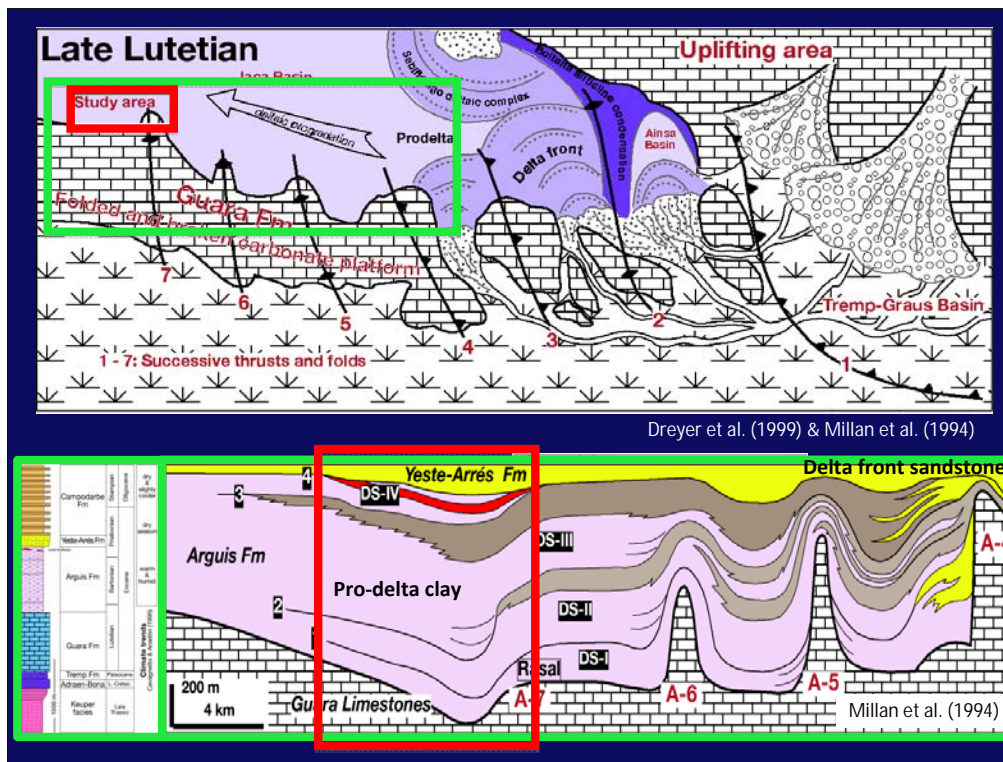
Timing of deformation  
(Vergés et al. (2002))



### Presenter's Notes:

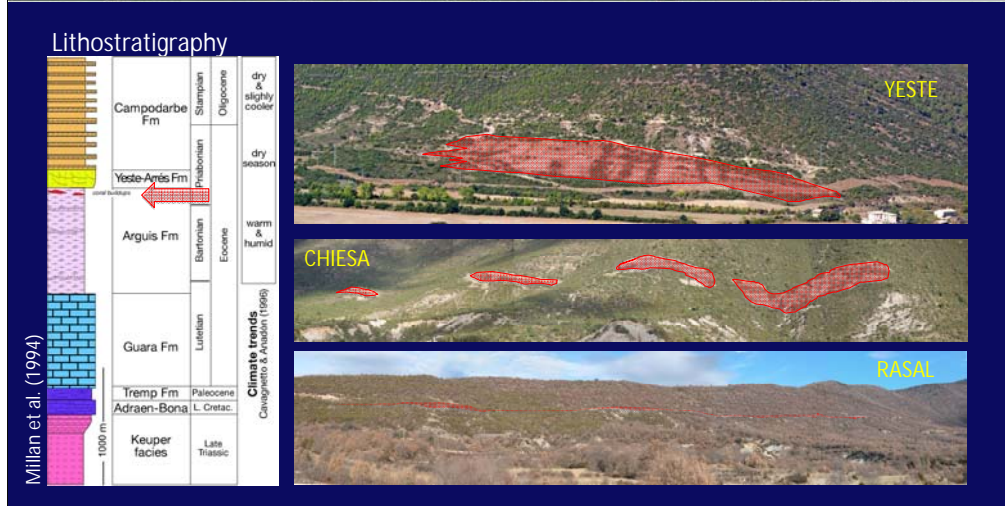
A lateral fold with N-S axis, involved in the contemporaneous deformation of the basin. There was a westward migration of the depocenter. Uplift produced land area that was source area for the development of an extensive delta system, with the main environments being prodelta (in light blue), in which is located the carbonate succession (studied in the area). The westward progradation of the delta system is clearly evident, and the carbonate succession was developed in the upper part of the prodelta clays of the Arguis Formation. The sandy sediments of the delta front (of the Bentue Formation) prograded very rapidly over the previous deposits.





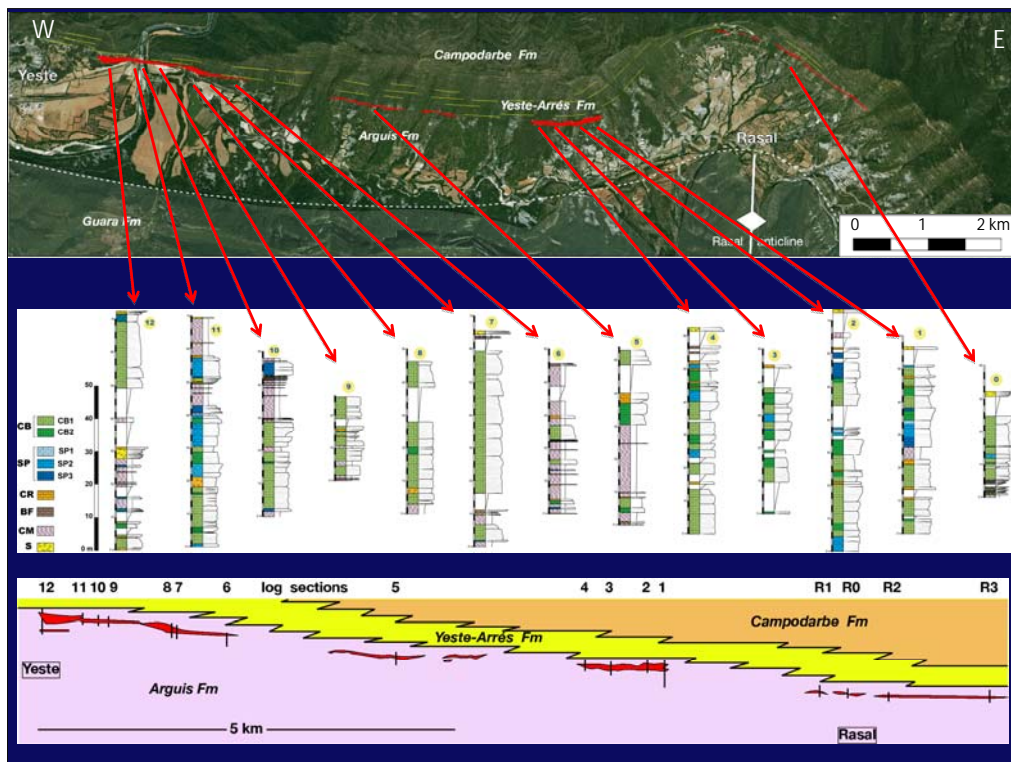
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#### Presenter's Notes:

Stratigraphically the carbonate interval is "located" at the Bartonian-Prämonian boundary. The main outcrops are in three different areas; many stratigraphic sections have been measured.



### ***DfYgYbhfBjBchHg.***

Main carbonate intervals are shown in red; they form discontinuous bodies, as shown in this stratigraphic cross section. Note that this feature formed during the progradation of the delta depositional system. In the stratigraphic logs, coral boundstone is shown in green.

# Facies

CB	CORAL BOUNDSTONE (domestone, platestone, pillarstone & mixstone)	CB1	<i>in situ</i> and in growth position corals, with <u>mudstone-wackestone matrix (fine-grained)</u> , abundant red algae
		CB2	<i>in situ</i> and in growth position corals, with <u>packstone matrix (coarse-grained)</u> , <u>skeletal fragments</u> , and abundant red algae
SP	SKELETAL PACKSTONE (bioclastic calcarenite)	SP1	<u>well to moderate sorted</u> , <u>fine-grained mud-dominated</u> skeletal packstone
		SP2	<u>poorly sorted, coarse-grained (locally floatstone)</u> mud-dominated skeletal packstone
		SP3	<u>poorly sorted</u> packstone, <u>with LBF</u> , locally with terrigenous
CR	CORAL RUDSTONE		coral & red-algae fragments, LBF, bryozoans, bivalves
BF	BRYOZOAN FLOATSTONE		bryozoan & serpulid floatstone with wackestone-packstone matrix
CM	CLAY TO MARLS		laminated or bioturbated
S	SANDSTONES		siliciclastic sandstones



## CB - Coral Boundstone

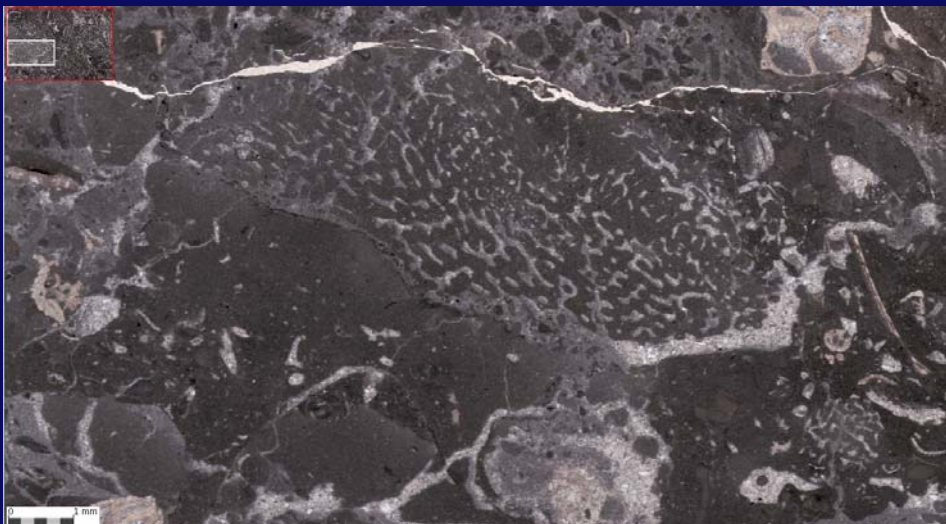


### ***Presenter's Note:***

Characteristic nodular aspect is related to clay and fine-grained matrix between corals.

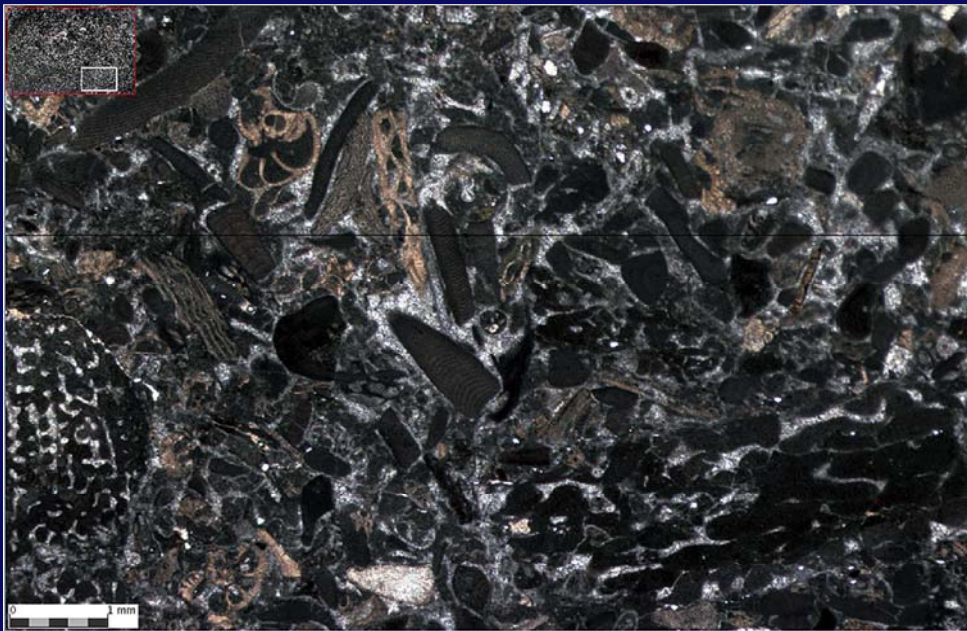


## CB - Coral Boundstone



CB 1 – wackestone matrix

## CB - Coral Boundstone



CB 2 – packstone matrix

## SP - Skeletal packstone



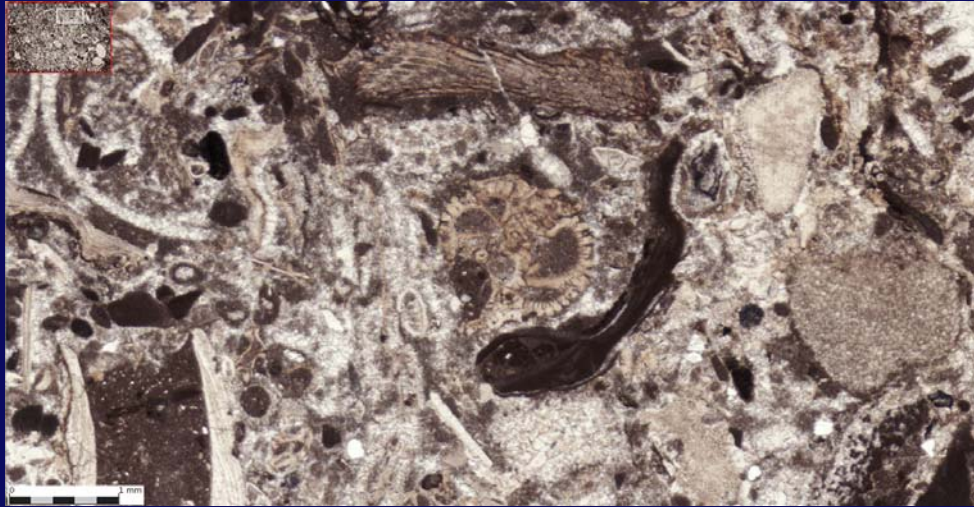
## SP - Skeletal packstone



SP 1 – fine-grained skeletal packstone



## SP - Skeletal packstone



SP 2 – coarse-grained skeletal packstone



## SP - Skeletal packstone

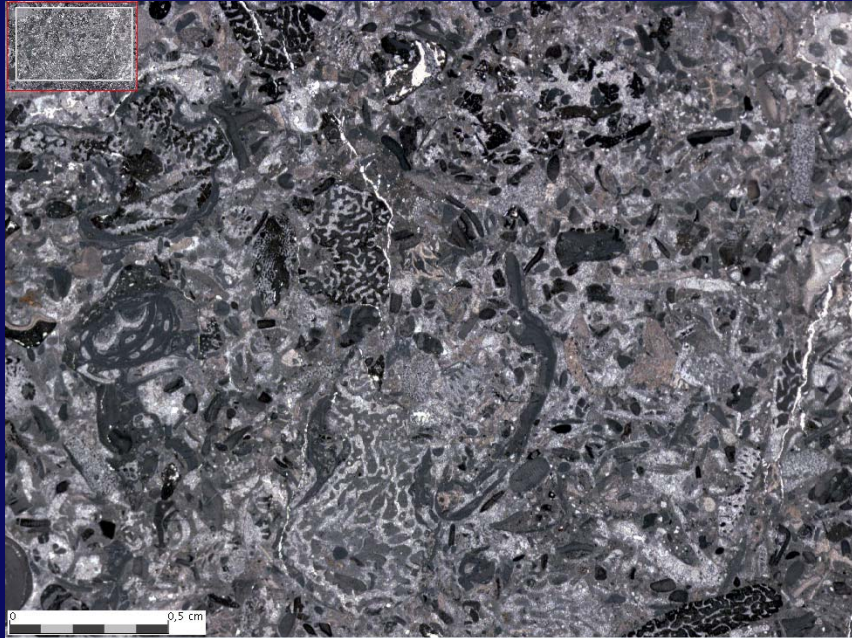


SP 3 – LBF packstone with quartz grains

## CR – Coral rudstone



## CR – Coral rudstone

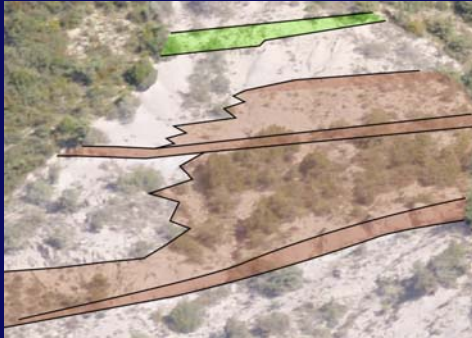


CR – matrix: coral and red algae packstone

***Presenter's Note:***

Rudstone matrix consists of unsorted packstone with abundant coral and red algae fragments.

## BF - Bryozoan floatstone



### ***Presenter's Note:***

Bryozoan-floatstone lithosomes are encased in blue clay/marls.



## BF - Bryozoan floatstone





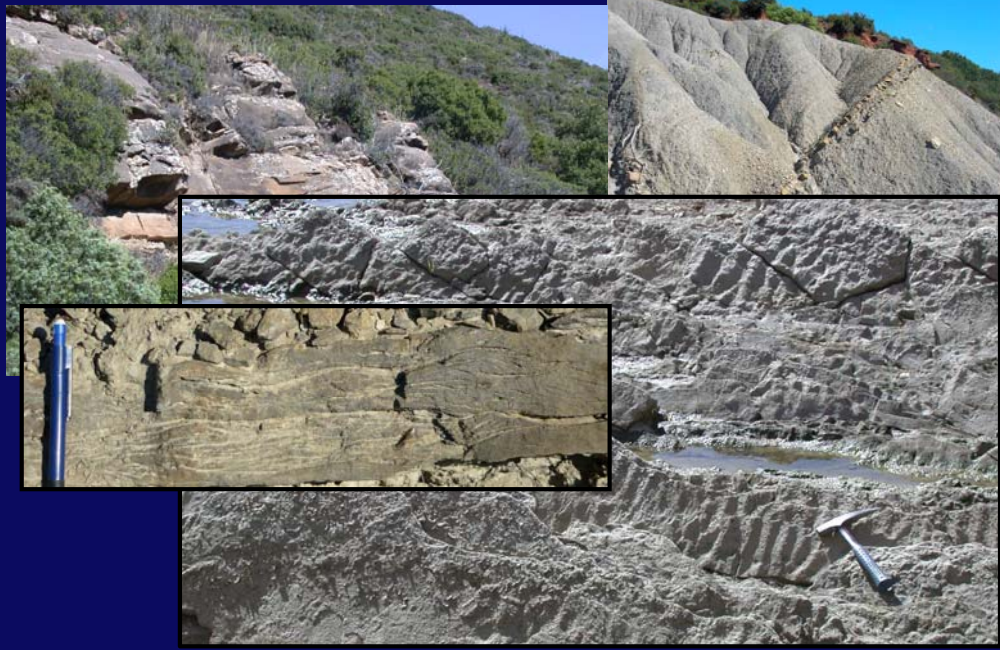
**S**—Sandstones and **CM** - clay/marls



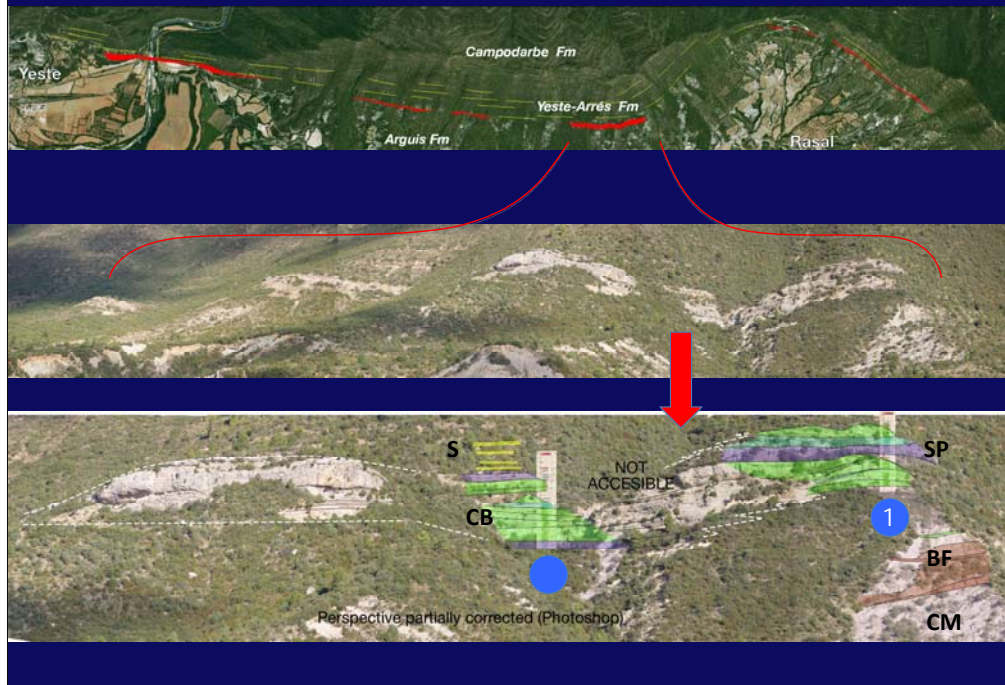
## S – Sandstones and CM - clay/marls



**S** – Sandstones and **CM** - clay/marls



# Buildup architecture

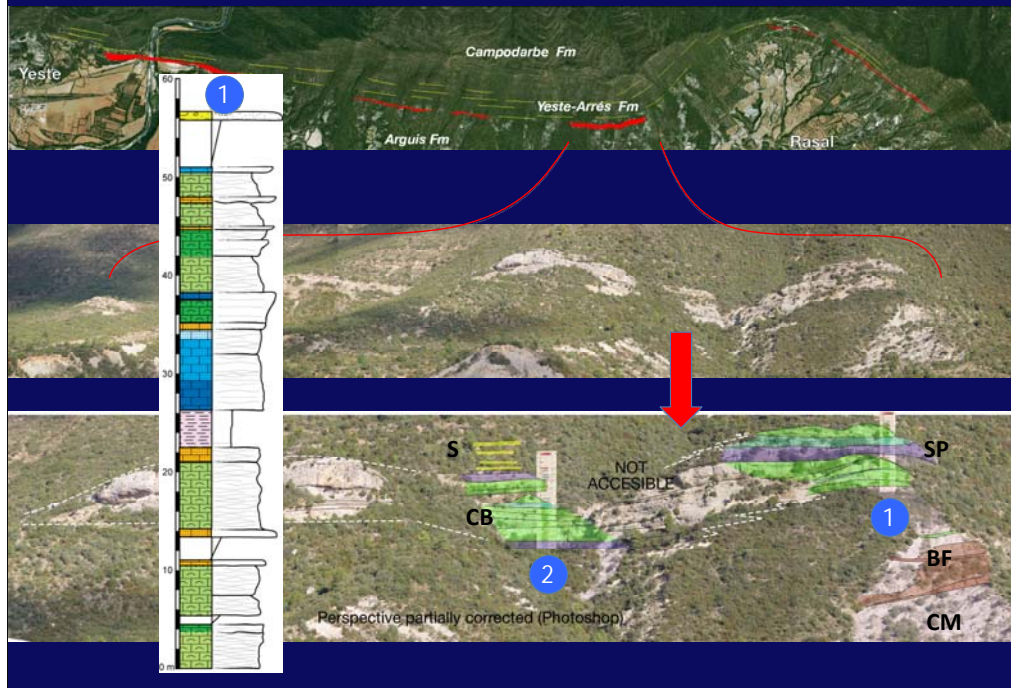


## ***Presenter's Note:***

Architecture of a large, complex buildup near Rasal. Perspective deformation has been partially corrected, and the accessible parts have only been mapped. Note the lateral heterogeneities that prevent lateral correlation of log sections.

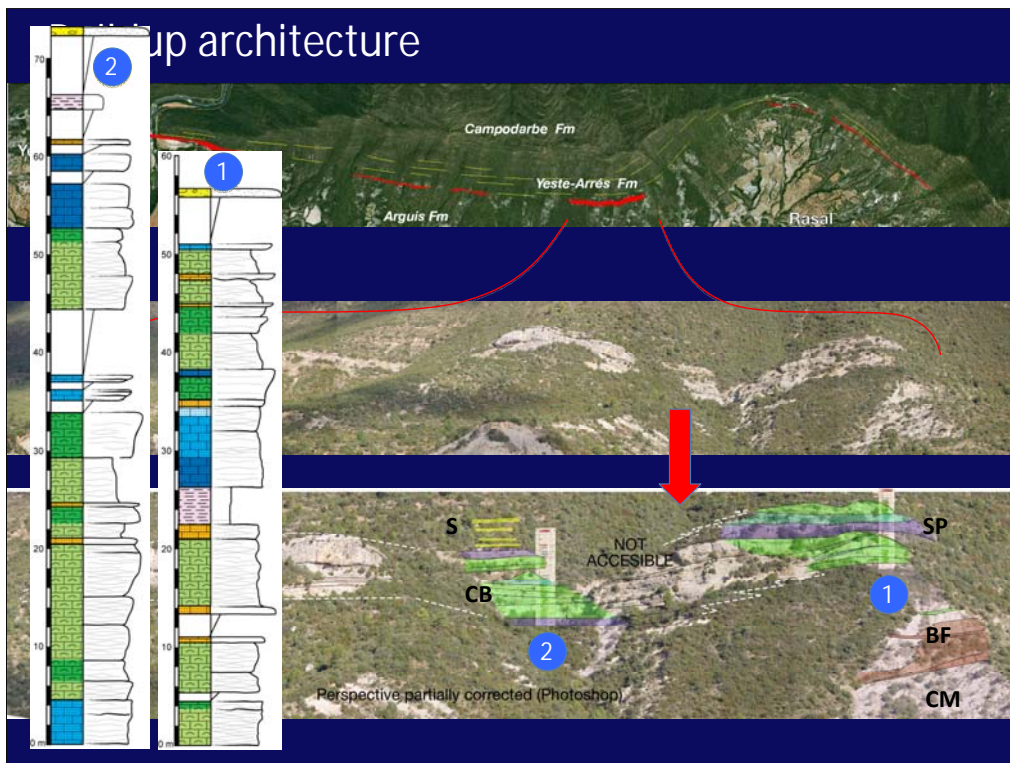


# Buildup architecture

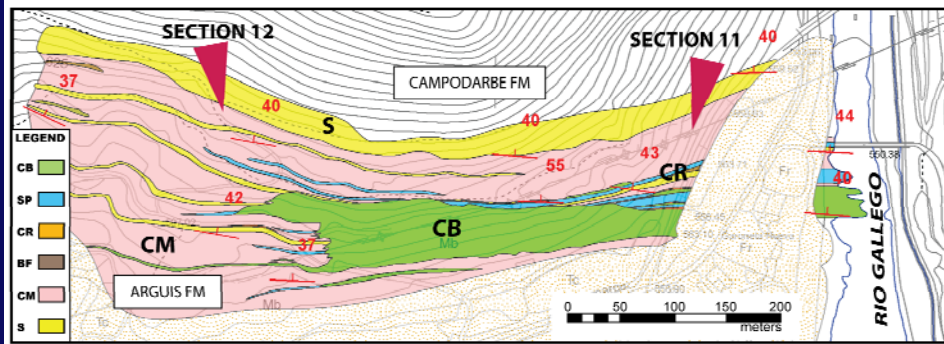




# up architecture



# Buildup architecture



## Presenter's Notes:

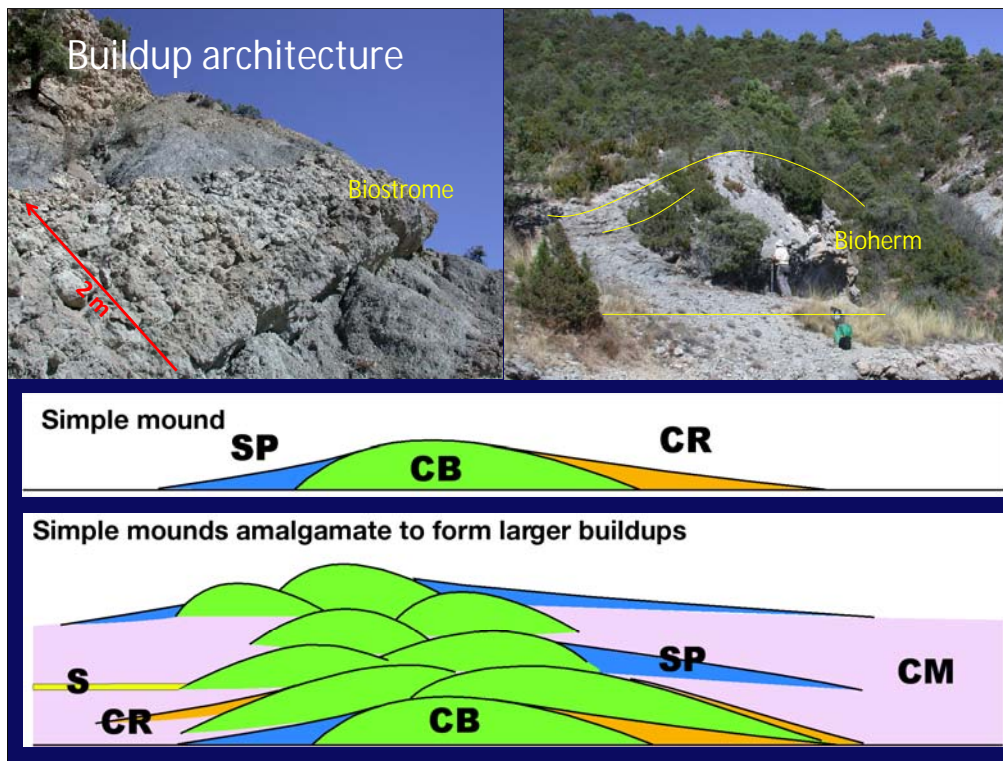
All the area is accessible; this permits reconstruction of the buildup geometry. A detailed survey has been performed, with GPS-assisted mapping of individual point; reconstruction of the various lithofacies is shown in the next slide.

# Buildup architecture



## ***Presenter's Notes:***

Lithologic model was built on detailed field mapping, using GPS control (of locations) and continuous following of the facies. Vertical exaggeration is 2:1. Note the asymmetry.



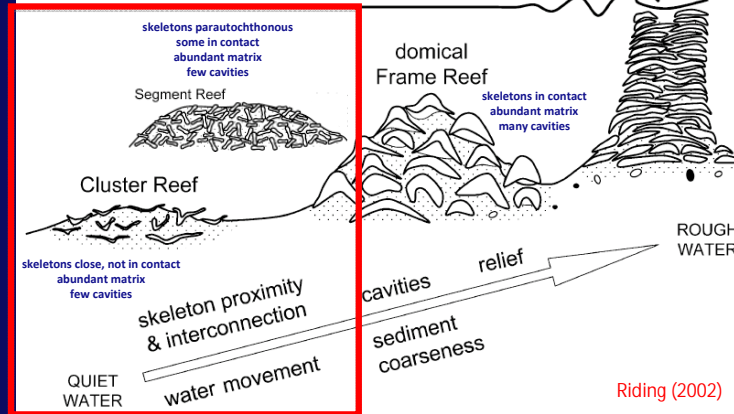
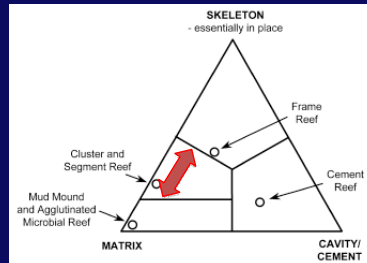
## Presenter's Notes:

Origin of the coral buildups. In the mesophotic zone, corals, along with red algae, formed small bioherms. Episodic high hydrodynamic pulses shed skeletal fragments off the buildup and produced the rudstone and packstone wedges on the flanks. Larger coral buildups resulted from coalescence and vertical stacking of single bioherms.

CB: coral boundstone; CR: coral rudstone; SP: skeletal packstone; CM: clay and marls; S: sandstone.



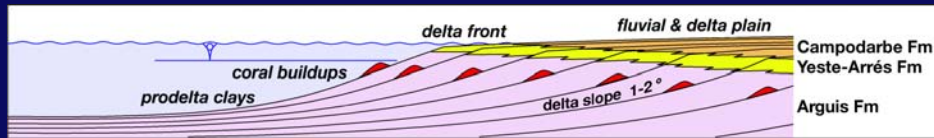
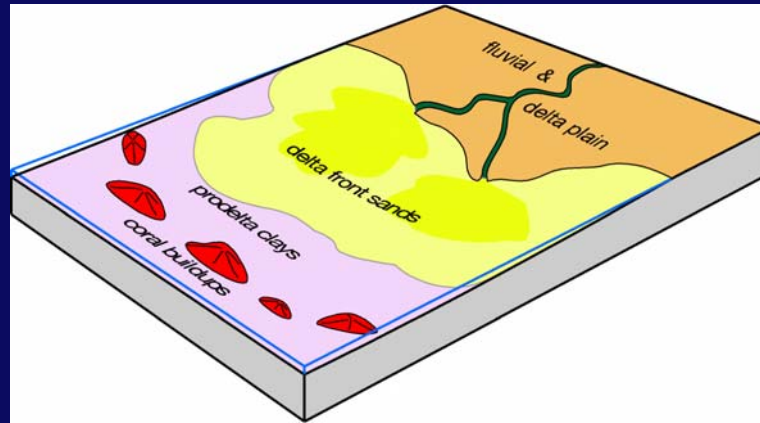
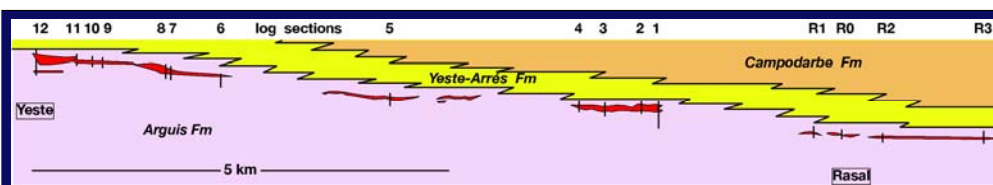
# Organic reef classification



Riding (2002)

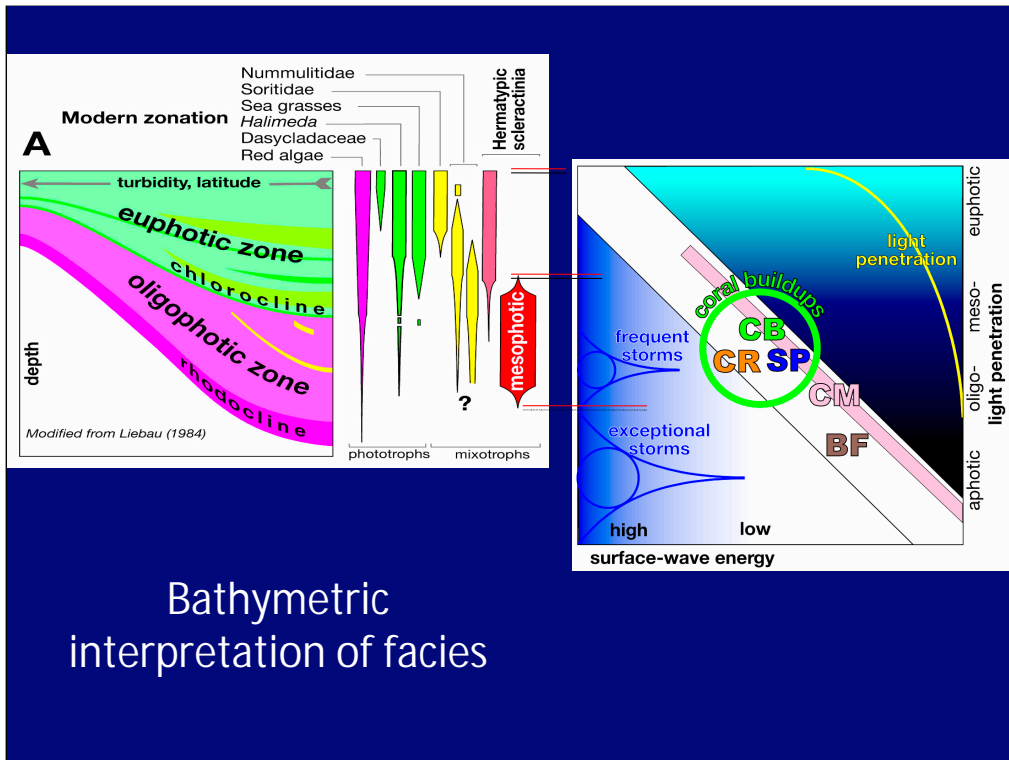
## **Presenter's Note:**

This reef formed in quiet water below the wave base.



**Presenter's Note:**

Depositional model. Coral buildups developed below the base of wave action in a prodelta setting.

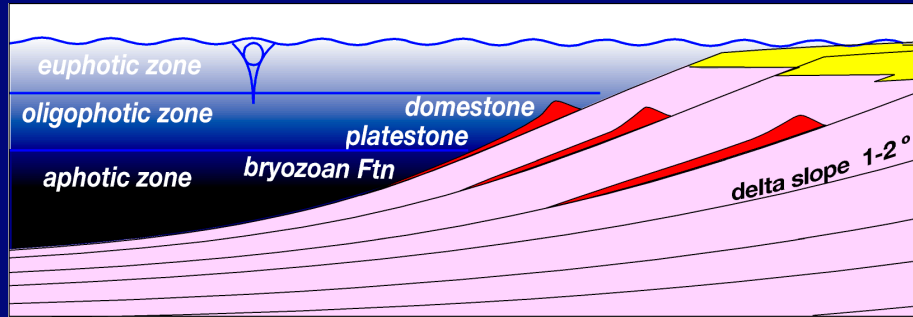
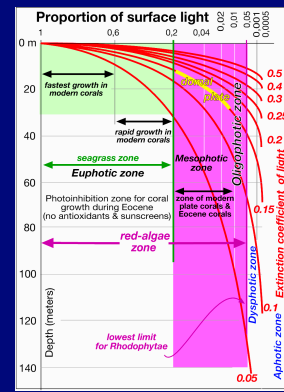
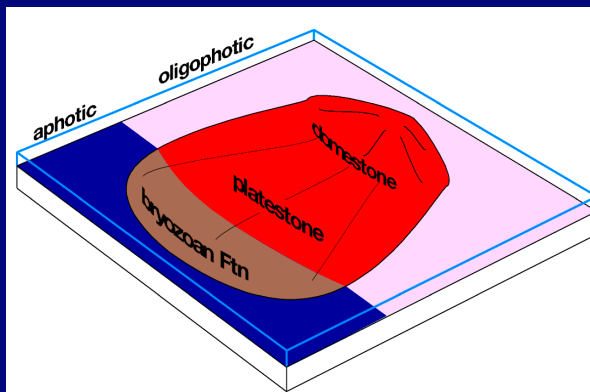


## Bathymetric interpretation of facies

### Presenter's Notes:

Coral domestone growth fabrics developed in the upper part of the mesophotic zone. In this setting, episodic high-hydrodynamic events hitting the buildups provided the energy to produce coral rudstone and skeletal packstone wedges. Coral platestone developed in the lower part of the mesophotic zone and bryozoan floatstone in the aphotic zone.

(CB: coral boundstone; CR: coral rudstone; SP: skeletal packstone; CM: clay and marls; S: sandstone)



### Presenter's Notes:

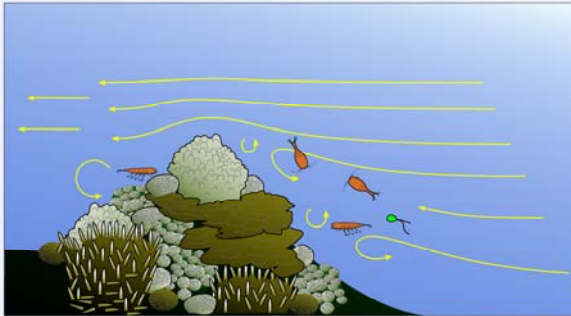
Absolute depth of light-penetration zones depends on water transparency and latitude (irradiance at sea surface). Light intensity decreases along a continuum depth gradient and subdivision into "euphotic", "oligophotic", and sometimes intermediate "mesophotic" zones, permits a general, non-quantitative, depth-dependent light-penetration zonation of the carbonate production

Depositional model. Coral domestone growth fabrics developed in the upper part of the mesophotic zone. Coral platestone developed in the lower part of the mesophotic zone and bryozoan floatstone in the aphotic zone.

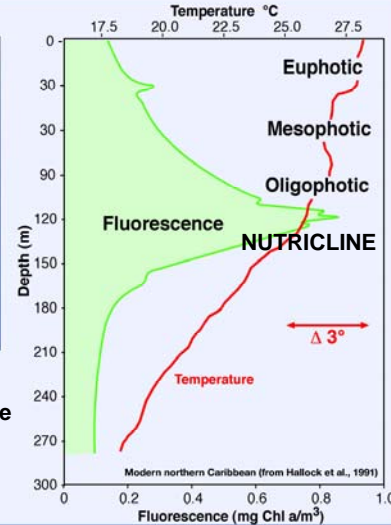
Eocene corals occupied the mesophotic bathymetric zone, the zone occupied by modern plate corals. Yellow line indicates the bathymetric estimation used in this paper for the Eocene corals according to light penetration in modern deltaic systems. Note the horizontal scale is not linear, in order to better show the curves in the lowest-light range.



## WHY THEY THRIVED IN THIS POSITION?



Elevation of the sea floor increases feeding competence for suspension feeders as it increases the impinging efficiency of currents carrying pico- and phytoplankton.



Prevalence of catchers (corals & bryozoans) over pumper metazoans (sponges and molluscs) may indicate a higher availability of phyto- and zooplankton over picoplankton (bacteria).

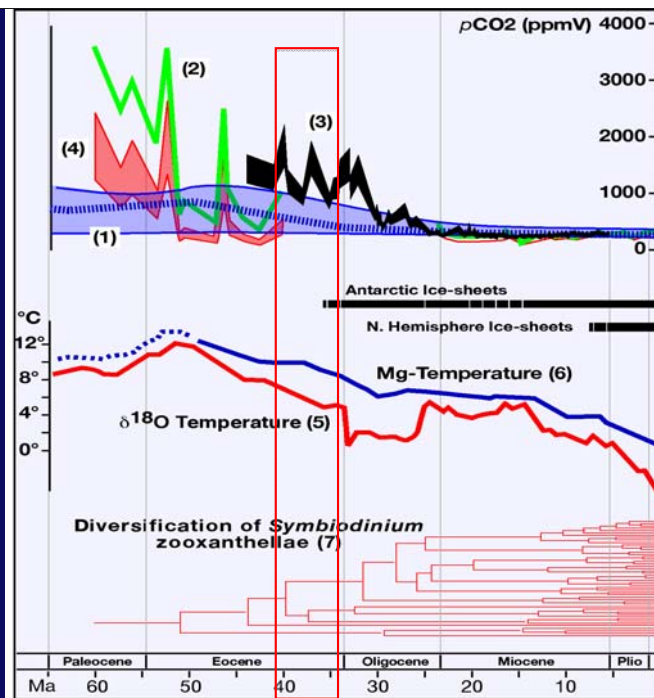
### Presenter's Notes:

The nutricline depth is defined by that depth at which the dissolved nutrient concentration exceeds  $1.5 \times 10^{-3} \text{ mol N m}^{-3}$

### Bathymetric gradients and internal waves (from Hallock and Pomar, 2009):

In modern subtropical and tropical oceans, outside of upwelling zones, surface waters are warm and generally relatively well mixed by winds down to roughly 100 m. The base of the mixed layer/top of the thermocline also corresponds to the top of the pycnocline and nutricline, as well as the chlorophyll maximum zone (Fig. 2). In addition,  $\text{O}_2$  concentration declines and  $\text{pCO}_2$  increases relatively rapidly with depth. Above this layer, there is sufficient light for photosynthesis but generally limited nutrients. Below there is minimal light, but more organic carbon and biological activity utilizing oxygen, releasing nutrients and  $\text{CO}_2$ . This zone is very biologically and chemically dynamic.

The base of the mixed layer and uppermost thermocline corresponds with deeper mesophotic to oligophotic conditions described for outer shelf and ramp biotas. Thus, changes in physical and chemical conditions along that gradient would strongly influence LBF biotas. The final consideration here is the influence of internal waves on LBF in mesophotic and oligophotic environments.



(1) Berner & Kothavala, 2001; (2) Pearson & Palmer, 2000; (3) Pagani et al., 2005;  
 (4) Demicco et al., 2003 (5) Zachos et al., 2001; (6) (Leer et al., 2000);  
 (7) Pochon et al., 2006

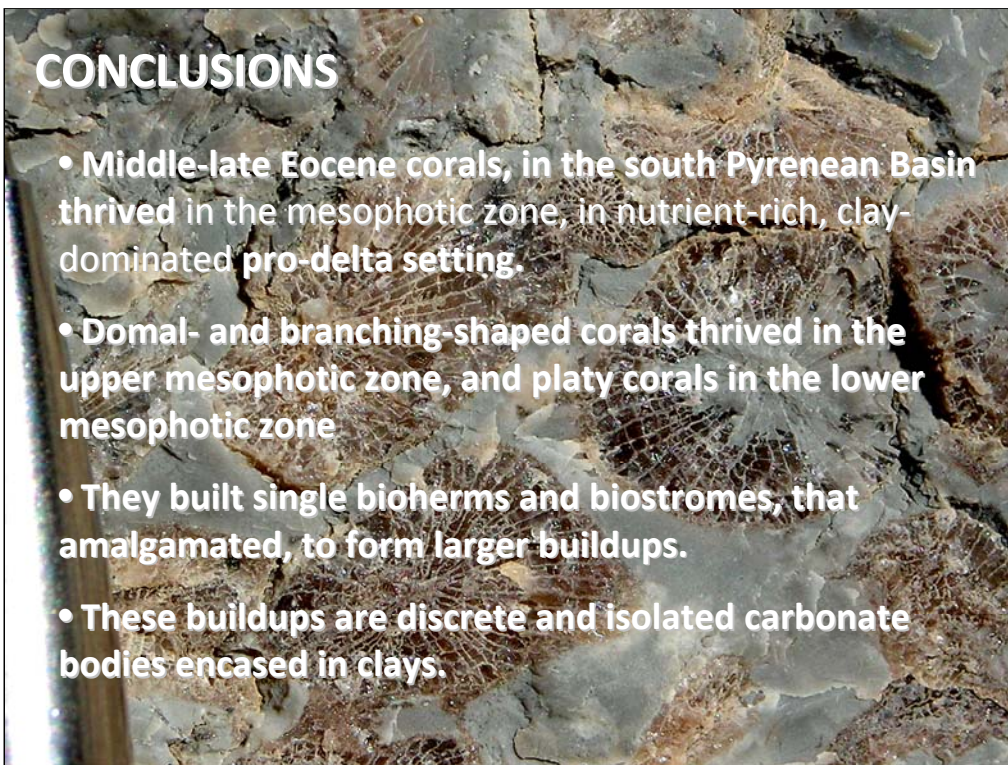
Pomar & Hallock, 2008

# **Presenter's Notes:**

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## CONCLUSIONS

- Middle-late Eocene corals, in the south Pyrenean Basin thrived in the mesophotic zone, in nutrient-rich, clay-dominated pro-delta setting.
- Domal- and branching-shaped corals thrived in the upper mesophotic zone, and platy corals in the lower mesophotic zone
- They built single bioherms and biostromes, that amalgamated, to form larger buildups.
- These buildups are discrete and isolated carbonate bodies encased in clays.



## FINAL REMARKS

- Modern type of coral reefs, both turbid-water and Caribbean, does not apply to these buildups.
- Understanding biological processes is essential to interpreting fossil reefs and, in general, carbonate rocks.
- Recognizing limitations of uniformitarianism is equally crucial.

