Control of Lower Jurassic Microbial Reef Communities on Carbonate Platform Geometry (Djebel Bou Dahar, Hign Atlas, Morocco)*

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Abstract

The Djebel Bou Dahar (DBD) carbonate platform (Early Jurassic, High Atlas, Morocco) was deposited on the footwall high of an active marine rift. It contains six depositional sequences bounded by footwall unconformities and correlative flooding surfaces along the adjacent hanging wall. The DBD evolved from a low-relief ramp profile (Sequences I-III) to a high-relief steep-fronted platform with slopes up to 30° and 600 m relief (Sequences IV-VI). The architectural evolution was controlled by fault-block rotation, regional subsidence in an extensional tectonic setting, third order eustatic sea level and sediment production and dispersal rates, while the margin geometry was, at least in part, controlled by changing reef communities on the slope and margin.

Sequence III consisted of siliceous sponge microbial mud mounds associated with coated grain skeletal packstone and grainstone in middle and outer ramp regions. This Deepwater carbonate factory did not build into wave-agitated shallow-water and lacked the capability to construct a high-relief margin geometry.

During sequences IV (retrogradational) and V (progradational) the growth of a highly productive coral stromatoporoid microbial reef at the platform margin and on the slope (10-60 m depth), adjacent to deeper water siliceous sponge microbial lenses (60-140 m), promoted the accretion of a high-relief and steep slope and the development of a productive shallow-water platform top.

Sequence VI record increased accommodation space creation and retrogradational patterns prior to final platform drowning. Coral stromatoporoid microbial boundstone similar to Sequence V slope lithofacies extend on the outermost platform, 200-500 m inward of the platform break.

The DBD Lower Jurassic carbonate platform demonstrates the influence of various carbonate factories and microbialites in building and stabilizing a high-relief geometry. It also shows, in contrast with the generally accepted belief that Lower Jurassic reefs are dominated by platform bivalve bioherms, that similar age reef systems can have substantial contributions by microbialite components.

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CONTROL OF LOWER JURASSIC MICROBIAL REEF COMMUNITIES ON CARBONATE PLATFORM GEOMETRY (DJEBEL BOU DAHAR, HIGH ATLAS, MOROCCO)

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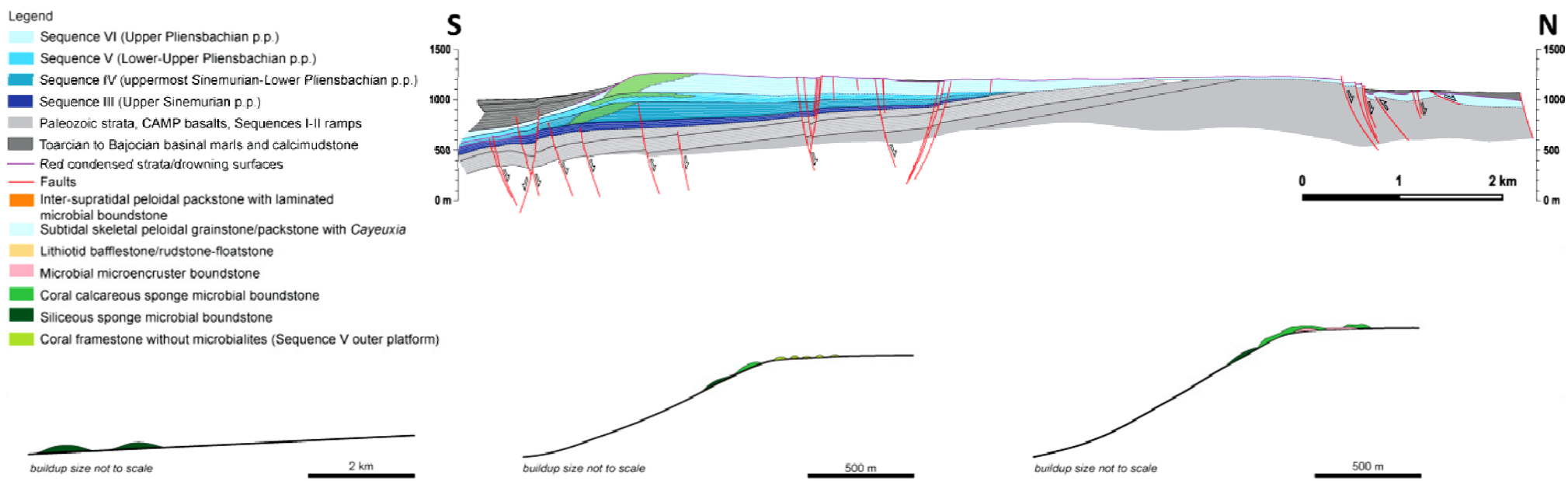
Lessons learned from the Djebel Bou Dahar (DBD, Lower Jurassic, Morocco)

- **DBD platform evolved from low-relief ramp (Sinemurian) to a high-relief platform (slopes 20-32°, 600 m relief (uppermost Sinemurian-Pliensbachian);**

- **Platform geometry change driven by:**
  - **extensional tectonics (fault block rotation) ;**
  - **highly productive coral calcareous sponge microbial boundstone on the slope (10-60 m depth), lateral to siliceous sponge microbial boundstone (60-140 m below the platform break);**

  - **both factories promoted the accretion and stabilized a high-relief and steep depositional slope.**



Seq. III Sinemurian

Seq. IV-V Pliensbachian p.p.

Sequ. VI Upper Pliensbachian

Lessons learned from the Djebel Bou Dahar

The DBD Lower Jurassic carbonate platform demonstrates that:

1. **microbialites were common in the Early Jurassic, in contrast with the generally accepted idea that bivalve bioherms dominated Lower Jurassic platform margins;**

2. **different carbonate factories, from the upper slope to the inner platform, contributed to the building and aggradation of the high-relief geometry on the hanging wall of an extensional fault block;**

3. **the coral-microbial platform margin had typical basinward dipping, outer-platform "falling beds";**

4. **the main components of Upper Jurassic reefs were already present in the Early Jurassic rift basin of Morocco;**

5. **DBD reefs and geometry similar to Upper Jurassic North Atlantic platforms (Nova Scotia, Portugal).**

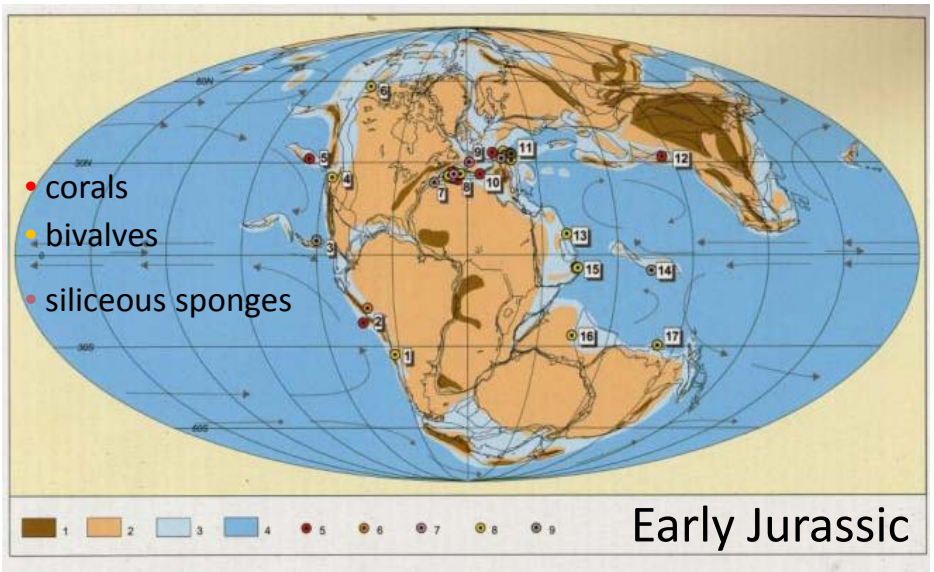
Jurassic reefs

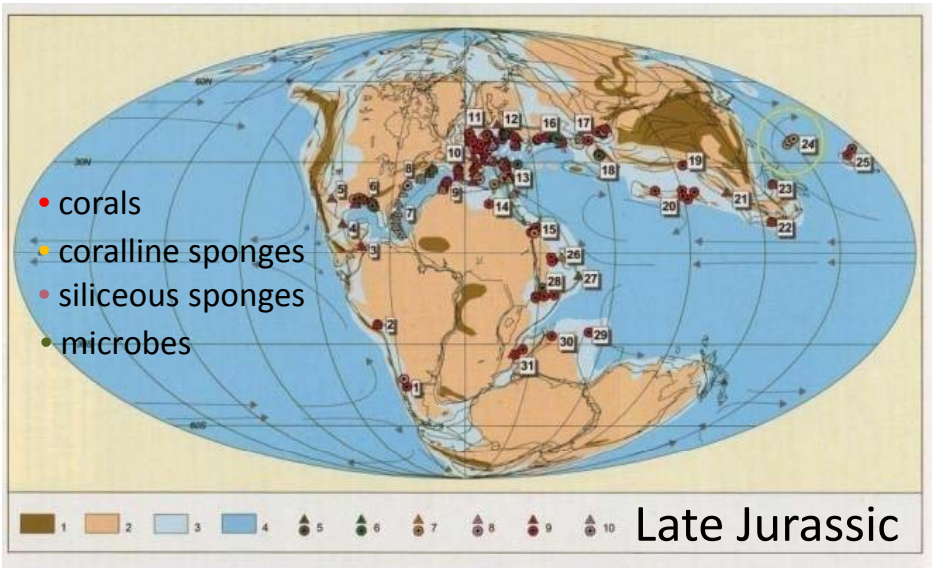
Jurassic time:

- a) peak in abundance of Mesozoic coral reefs and siliceous sponge mounds (Leinfelder et al., 2002);
- b) time of important plate tectonic, paleogeographic and climatic changes due to the rifting that brought to the break-up of Pangea and opening of the Atlantic Ocean.

- Several Jurassic reef models, mostly based on Upper Jurassic reefs: Crevello and Harris (1984); Insalaco et al. (1997); Leinfelder et al. (1994, 2002, 2005).

- Jurassic carbonate systems are important carbonate reservoirs
  - in the US Gulf Coast (Baria et al., 1982; Harris and Crevello, 1983; Mancini et al., 2004, 2008),
  - offshore Nova Scotia, Canada (Weissenberger et al., 2006; Wierzbicki et al., 2006),
  - in Southern UK (Sun and Wright, 1998),
  - in the Arabian Peninsula (Rousseau et al., 2006).



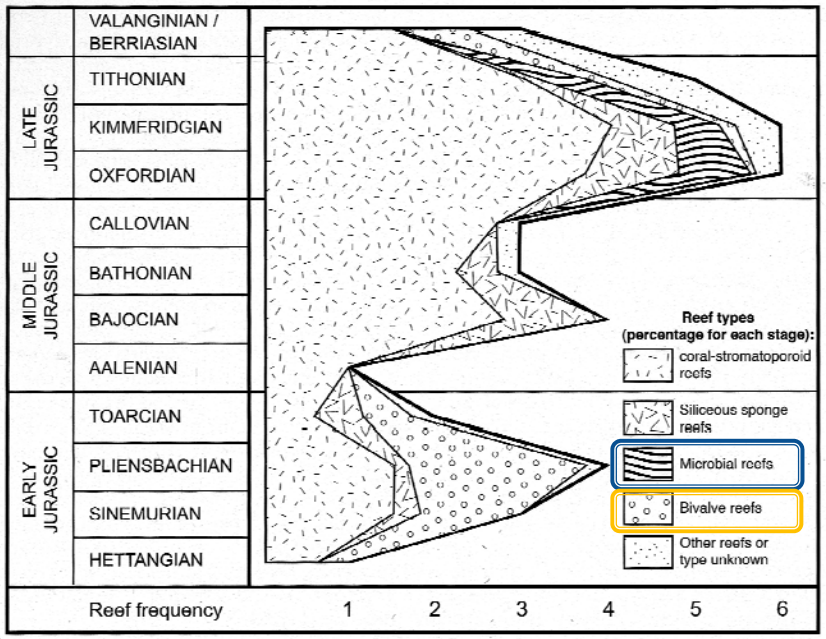


Leinfelder et al. (2002)

Lower Jurassic reef models

- Early Jurassic not a favorable time for reefs, following the end-Triassic extinction event (Leinfelder et al., 2002).

- Important Early Jurassic reef domain in Morocco favored by rift tectonics (structural highs) and arid climate.



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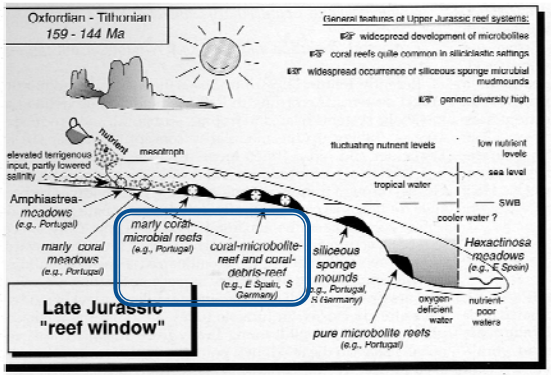
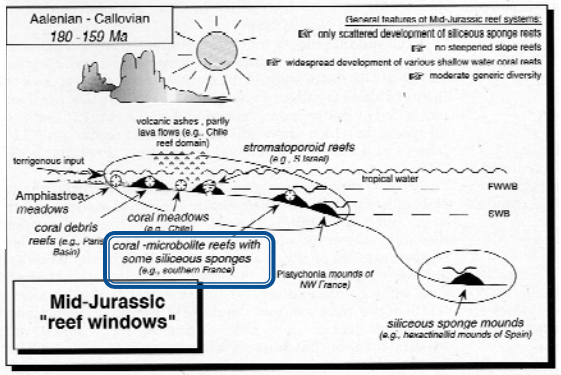
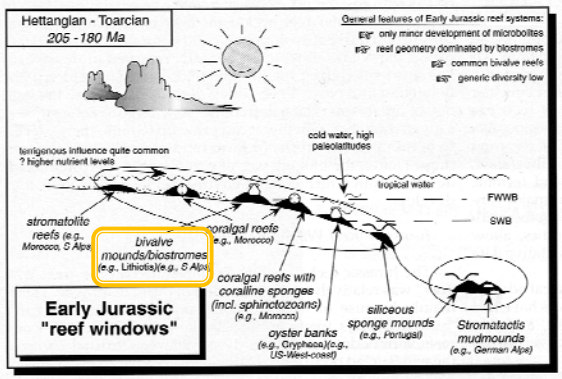




- Lower Jurassic reefs in Morocco : sponge mounds, coral reefs (without microbialites) and lithiotid bivalve banks.

- Microbialites were a key feature of Upper Jurassic reefs, but lacked in coral reefs during the Early Jurassic (Leinfelder et al., 2002).

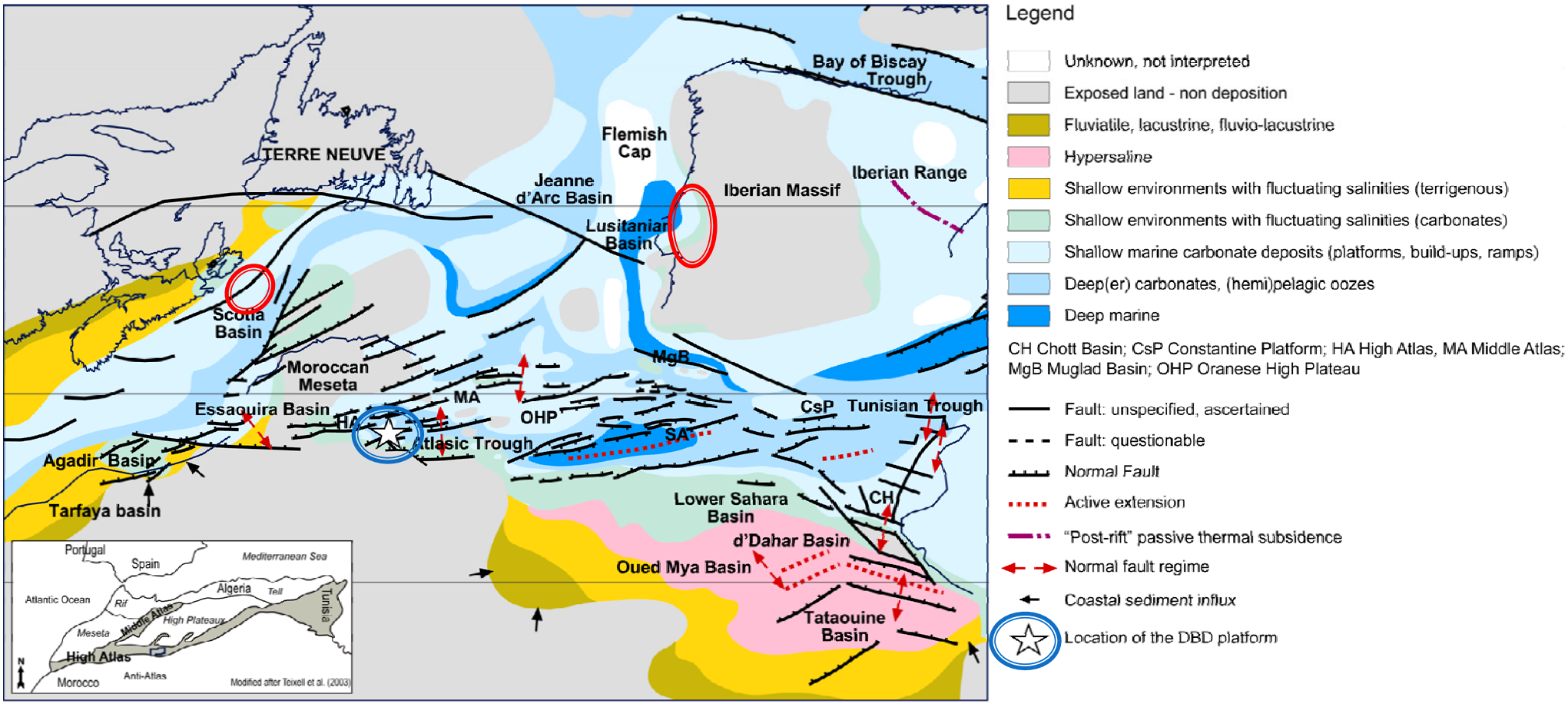


Leinfelder et al. (2002)

Early Jurassic paleogeography

- DBD: Lower Jurassic isolated carbonate platform in a marine rift basin (Eastern High Atlas, Morocco).

- Similar platforms (for geometry, reef composition) occur in the North Atlantic during the Late Jurassic (Lusitanian Basin -Portugal, Nova Scotia Basin).



Modified after Thierry et al. (2000)

Djebel Bou Dahar carbonate platform architecture

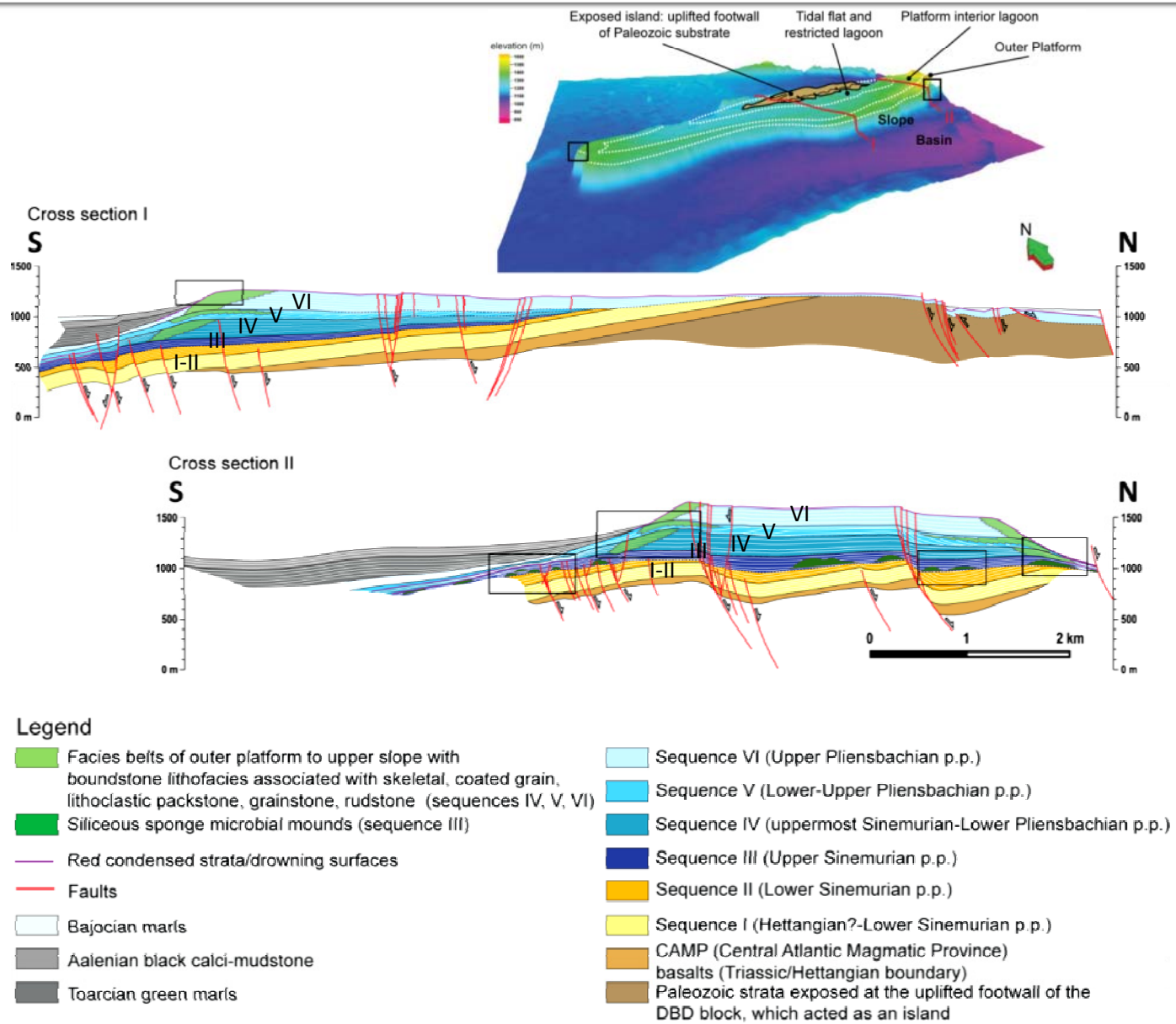
- Six depositional sequences I-VI.

- Sequences modulated by:
  - o fault block rotation (footwall uplift/hanging wall rotational subsidence),
  - o3rd order eustasy,
  - o changes in the carbonate factory (Verwer et al., 2009; Merino-Tomé et al., 2012).

- Depositional geometry evolved:

  - o from a low-relief ramp profile (Hettangian p.p.-Sinemurian Sequences I-III)

  - o to a high-relief (600 m) platform with 20-32º slopes (uppermost Sinemurian-Pliensbachian – Squences IV-VI).



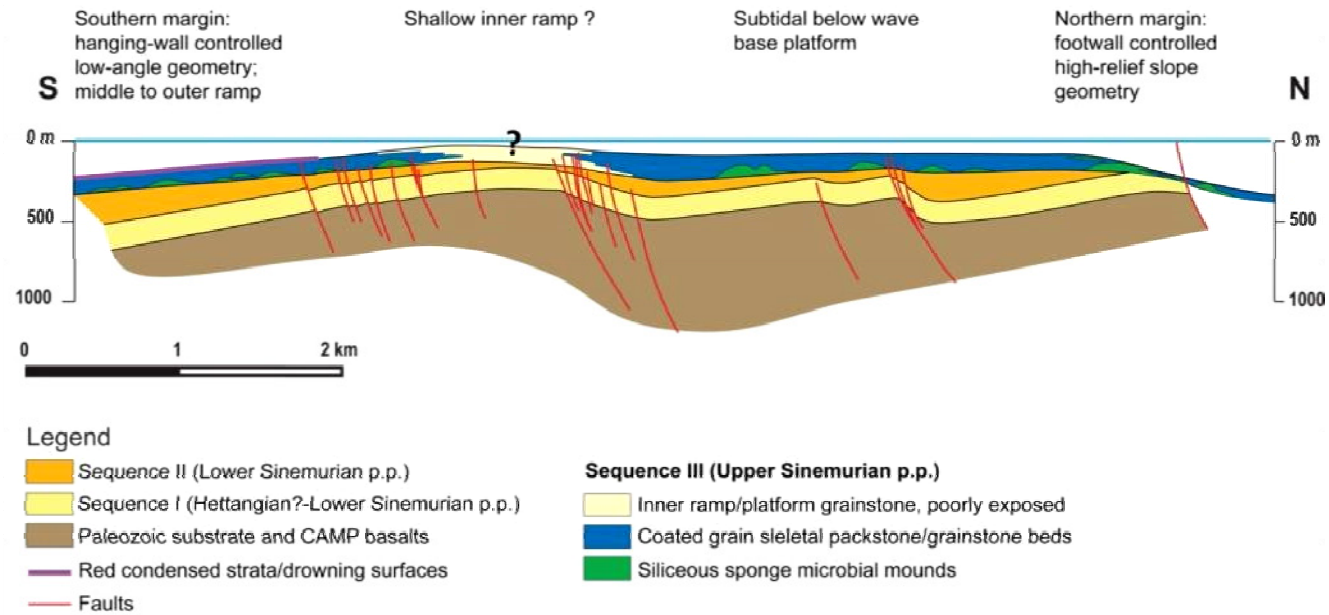
Upper Sinemurian low-relief aggradational carbonate system (Sequence III)

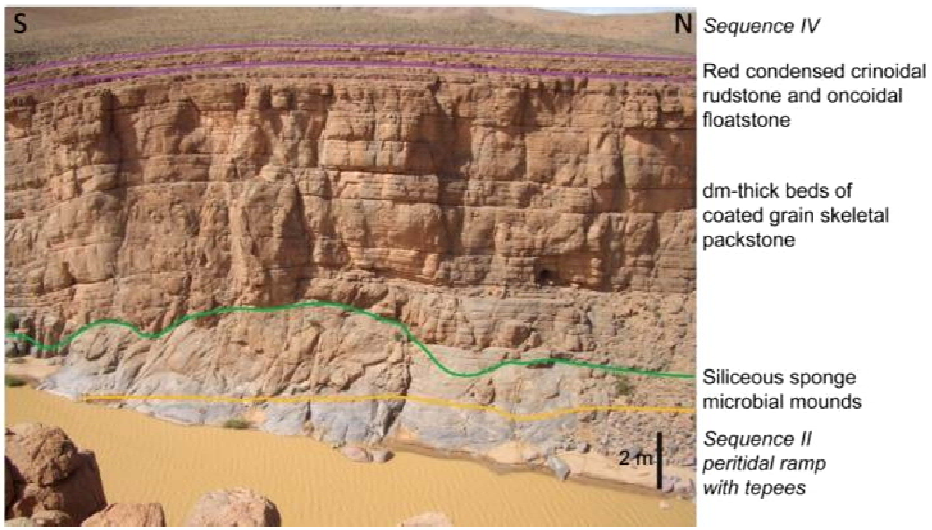
- **Siliceous sponge microbial mounds (10-20% area in cross section)** + coated grain skeletal packstone-grainstone (90-80%) in middle and outer ramp facies belts (sequence III).

- The system maintained a low-relief geometry because:

o the *in situ* deep-water carbonate factory lacked the capability to build into wave-agitated shallow settings;

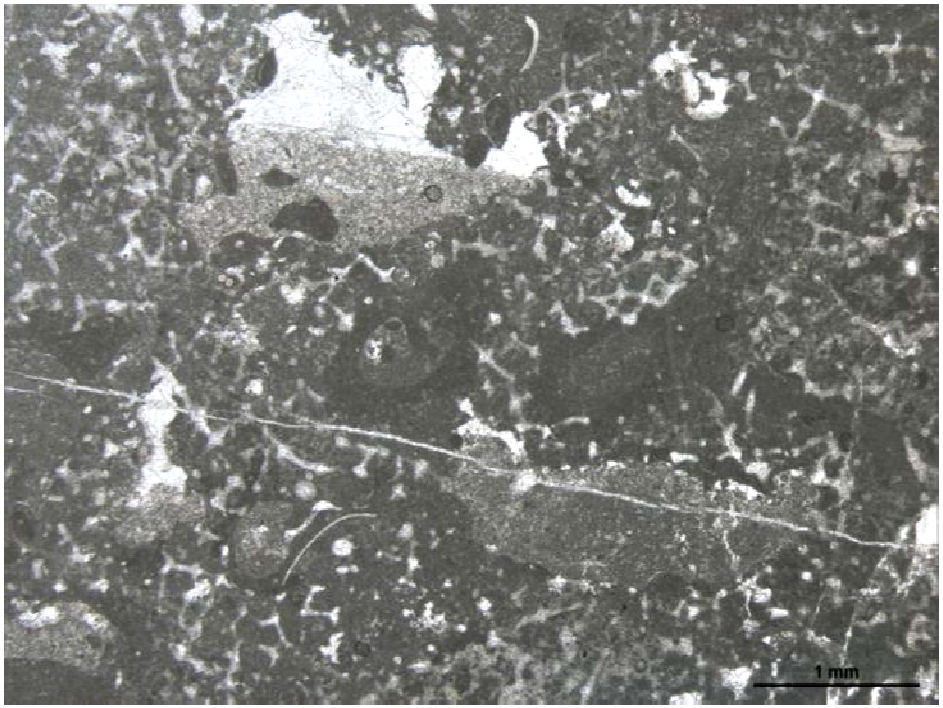
o shallow-water and uncemented coated grain carbonate sands were redistributed by waves and currents.



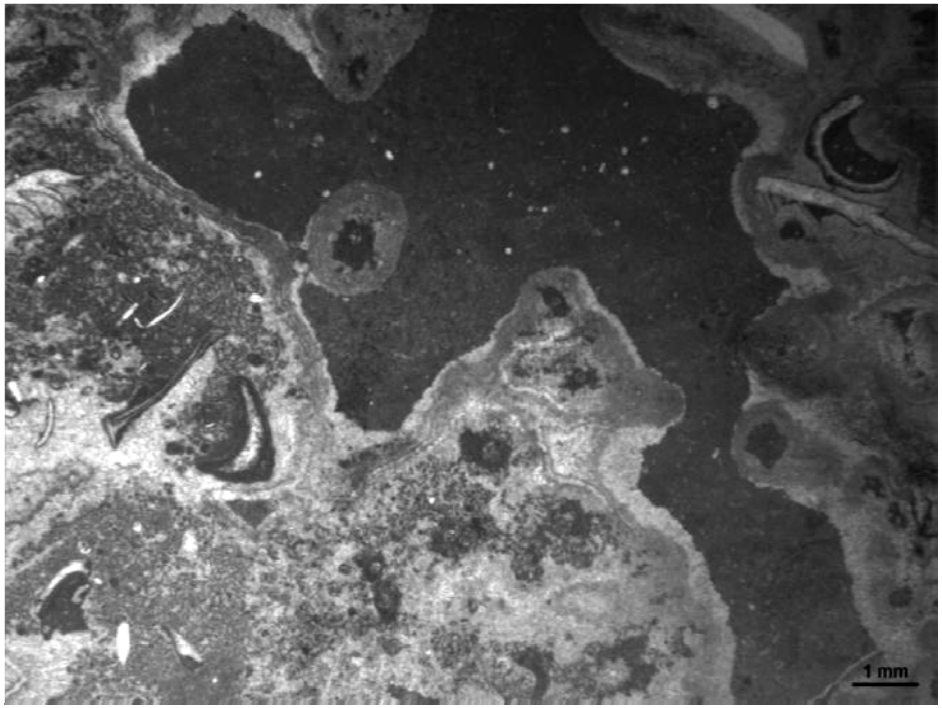


Upper Sinemurian siliceous sponge microbial mounds (middle-outer ramp)

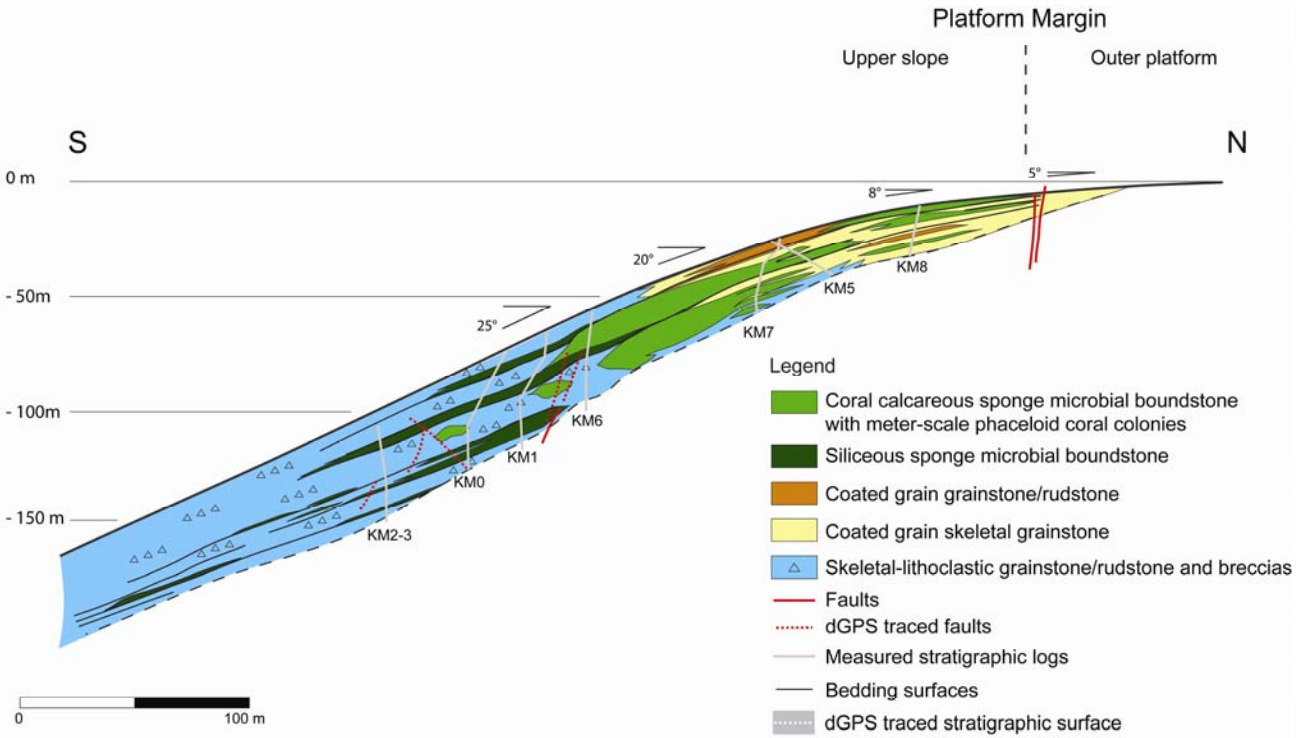
Microbial boundstone with hexactinellid sponges, clotted peloidal and leiolitic microbial micrite and *Terebella* worm tubes.

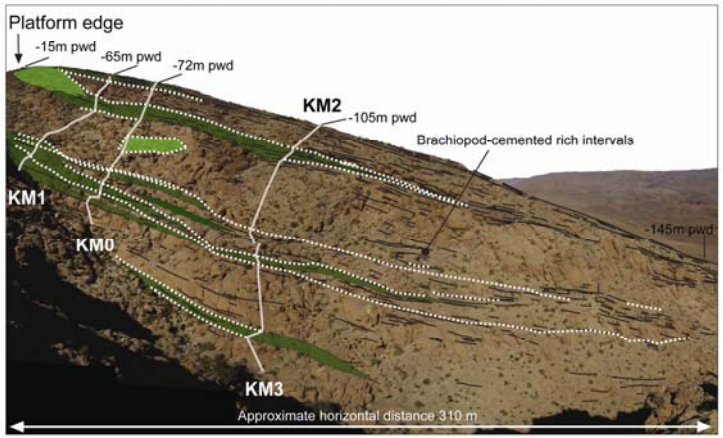


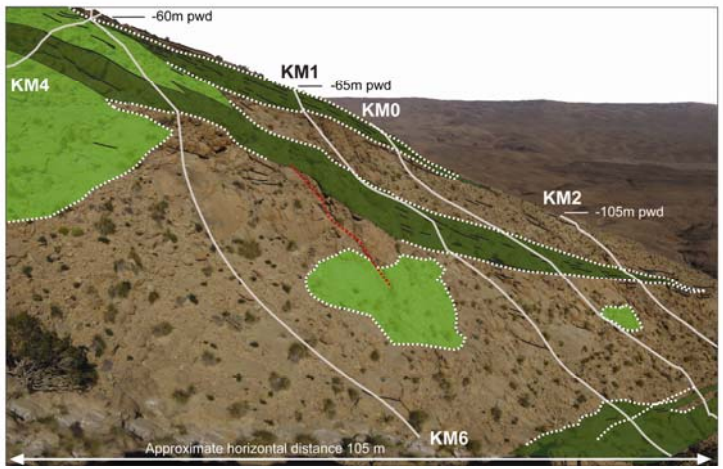
Microbial boundstone with accretionary growth forms of clotted peloidal micrite and microsparite.



Pliensbachian high-relief progradational platform (Sequence V)







During the Pliensbachian (Sequence V) progradation:

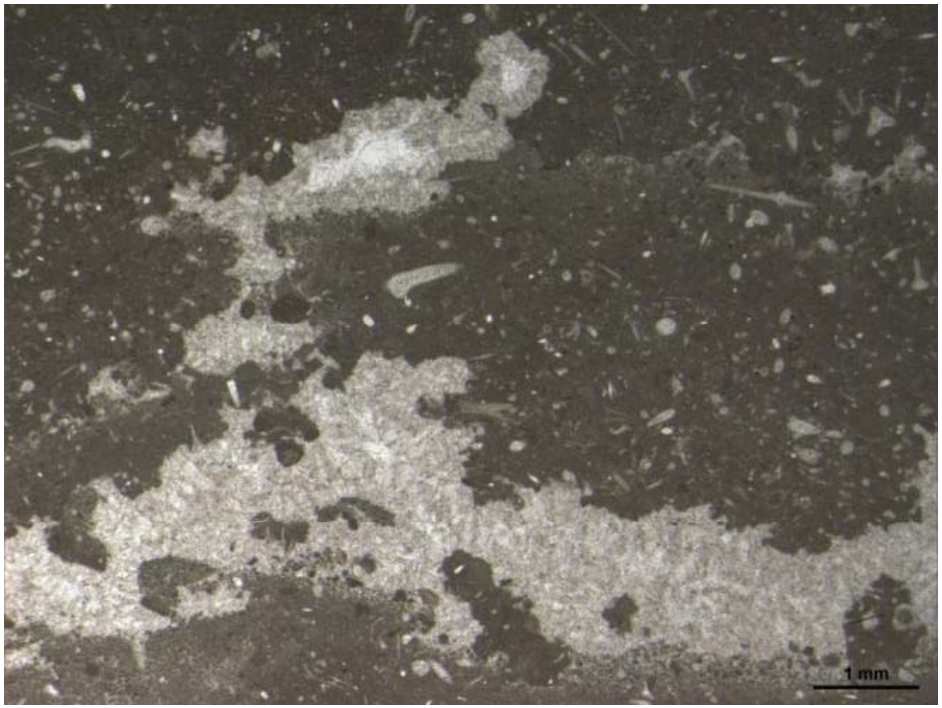
- the high-relief steep slopes consisted of:

  - **siliceous sponge microbial boundstone** (from 60 to140 m below the platform break);
  - **coral calcareous sponge microbial boundstone** at the platform margin and on the slope (from 10 to 60 m depth).

- Both carbonate factories promoted the accretion and stabilized the high-relief and steep depositional slope associated with lithoclast skeletal rudstone and coated grain skeletal grainstone.

Siliceous sponge microbial boundstone on the upper slope (60-140 m depth)

Microbial boundstone with leiolitic automicrite, siliceous sponge spicules and stromatactis-like cavities filled by marine radial fibrous cement

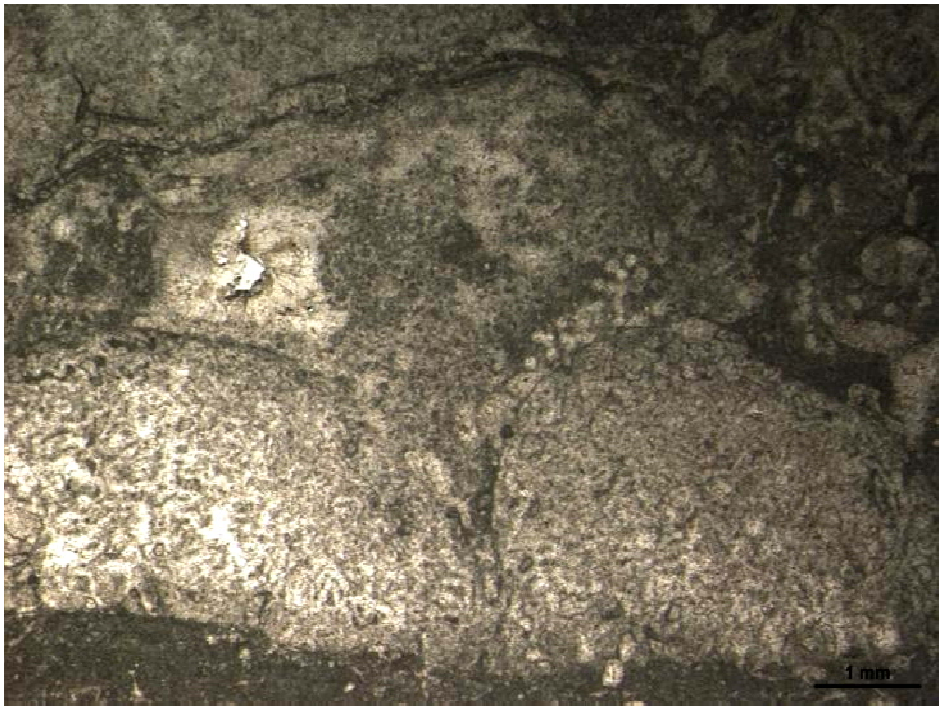


Microbial boundstone with leiolitic automicrite and siliceous demosponges.

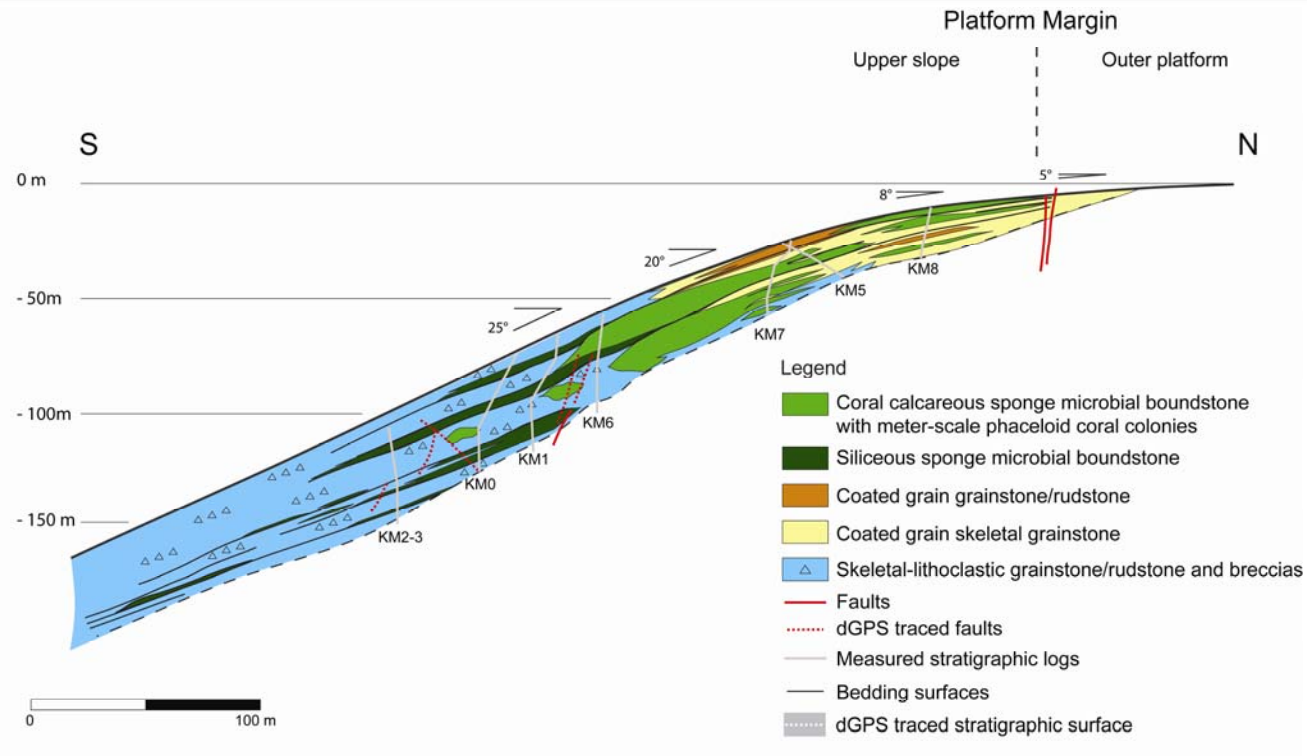
Coral calcareous sponge microbial boundstone on uppermost slope (10-60 m depth)

Branching phaceloid corals (*Phacelophyllia bacari*) surrounded by microbial micrite crusts.

Boundstone with stromatoporoid calcareous sponges and clotted peloidal microbial micrite sustaining primary framework voids filled by marine radial cement.



Pliensbachian high-relief progradational platform (Sequence V)



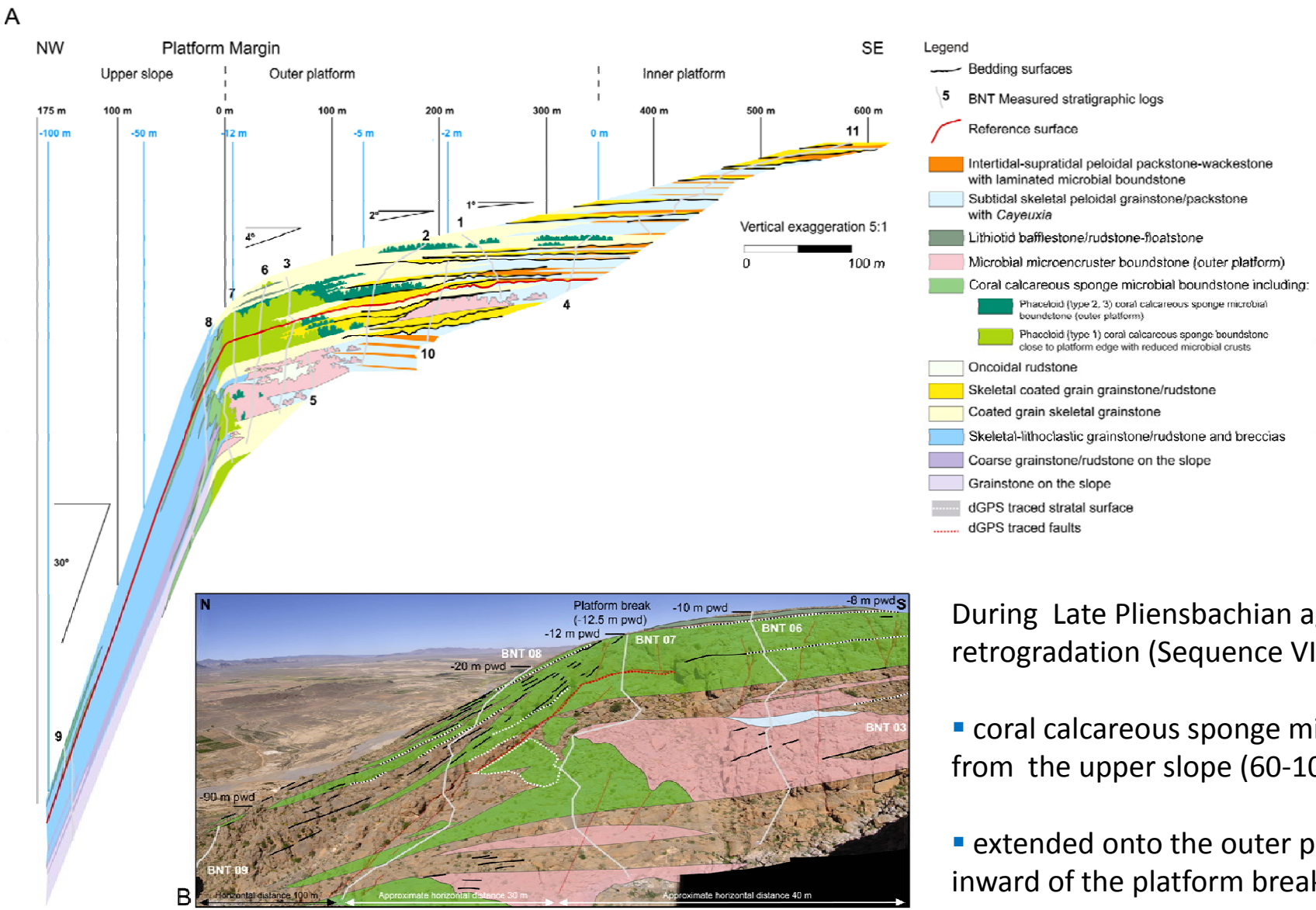
Massive cerioid coral (*Actinastrea plana*) in outer platform (0-400 m inward from platform break) lacking microbialites.

During the Pliensbachian (Sequence V) progradation:

- **siliceous sponge microbial boundstone: 16%** area in cross section on the lower part of upper slope between 60 to140 m depth (11% of whole upper slope);
- **coral calcareous sponge microbial boundstone: 44%** sediment area on the upper slope between 10 to 60 m depth (18% of whole upper slope);

- in the outer platform (0-400 m inward from platform break**) coral colonies with scarce to absent microbialites are 15-10% of sediment area** (coated grain skeletal grainstone and subtidal peloidal packstone 85-90%).

Upper Pliensbachian high-relief retrogradational-aggradational platform (Sequence VI)

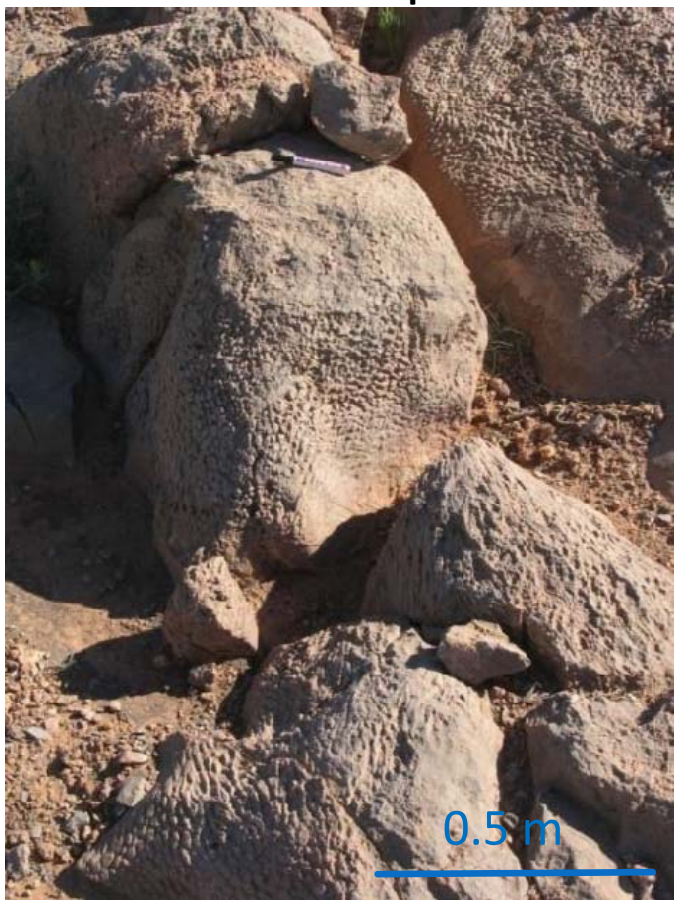


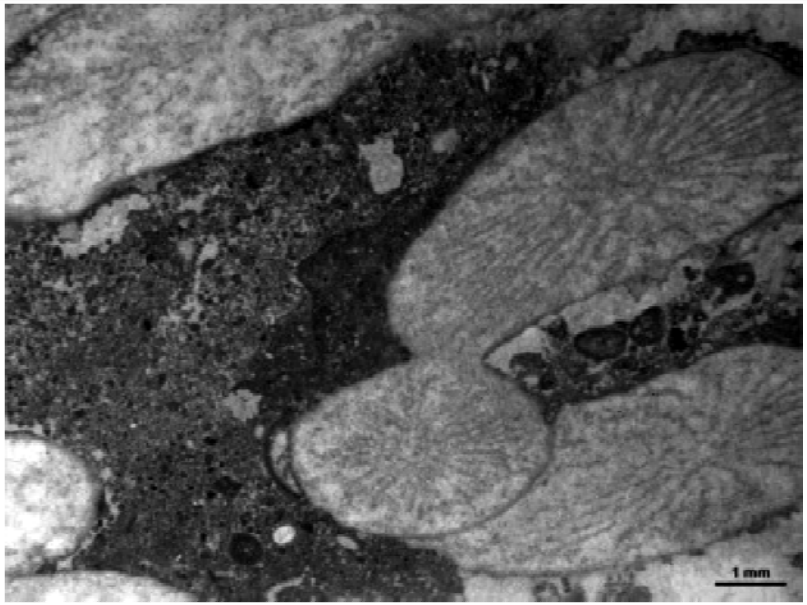
During Late Pliensbachian aggradation-retrogradation (Sequence VI):

- coral calcareous sponge microbial boundstone from the upper slope (60-10 m depth)
- extended onto the outer platform, 350 m inward of the platform break.

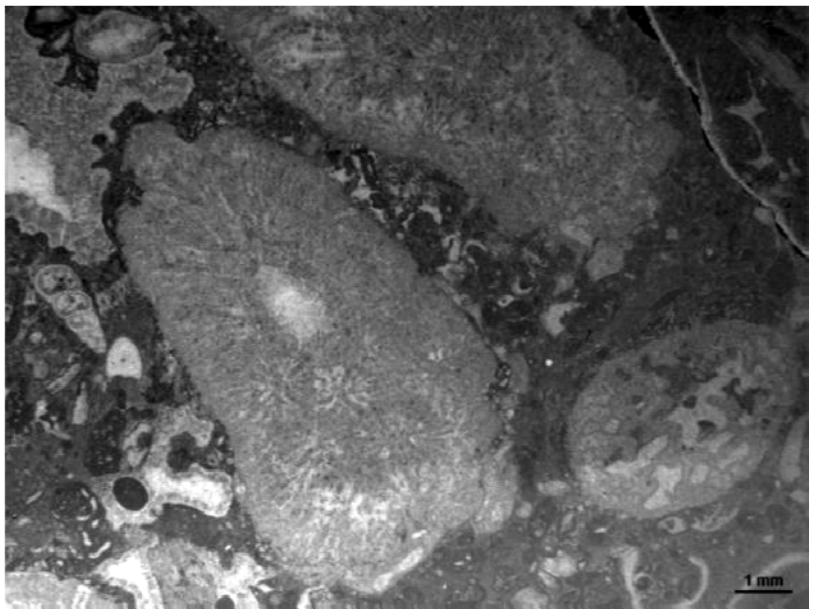
Coral calcareous sponge microbial boundstone from upper slope (10-60 m depth) to outer platform (350 m)

Meter-scale colonies of phaceloid corals



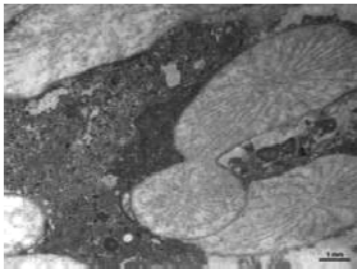


Phaceloid corals (*Phacelophyllia bacari*) with microbial clotted peloidal crusts and peloidal packstone.

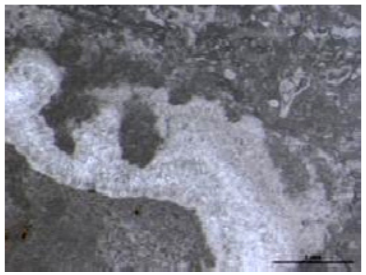


Thamnasterioid corals (*Cuifastrea lopatensis, Mesomorpha gracilis*) and massive cerioid corals are common around the break in slope.

Upper Pliensbachian outer platform boundstone lithofacies (Sequence VI)



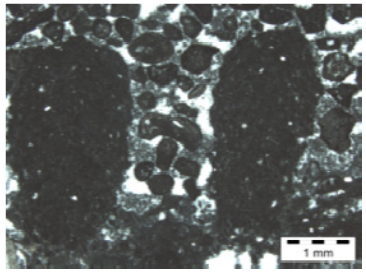
Coral calcareous sponge microbial boundstone



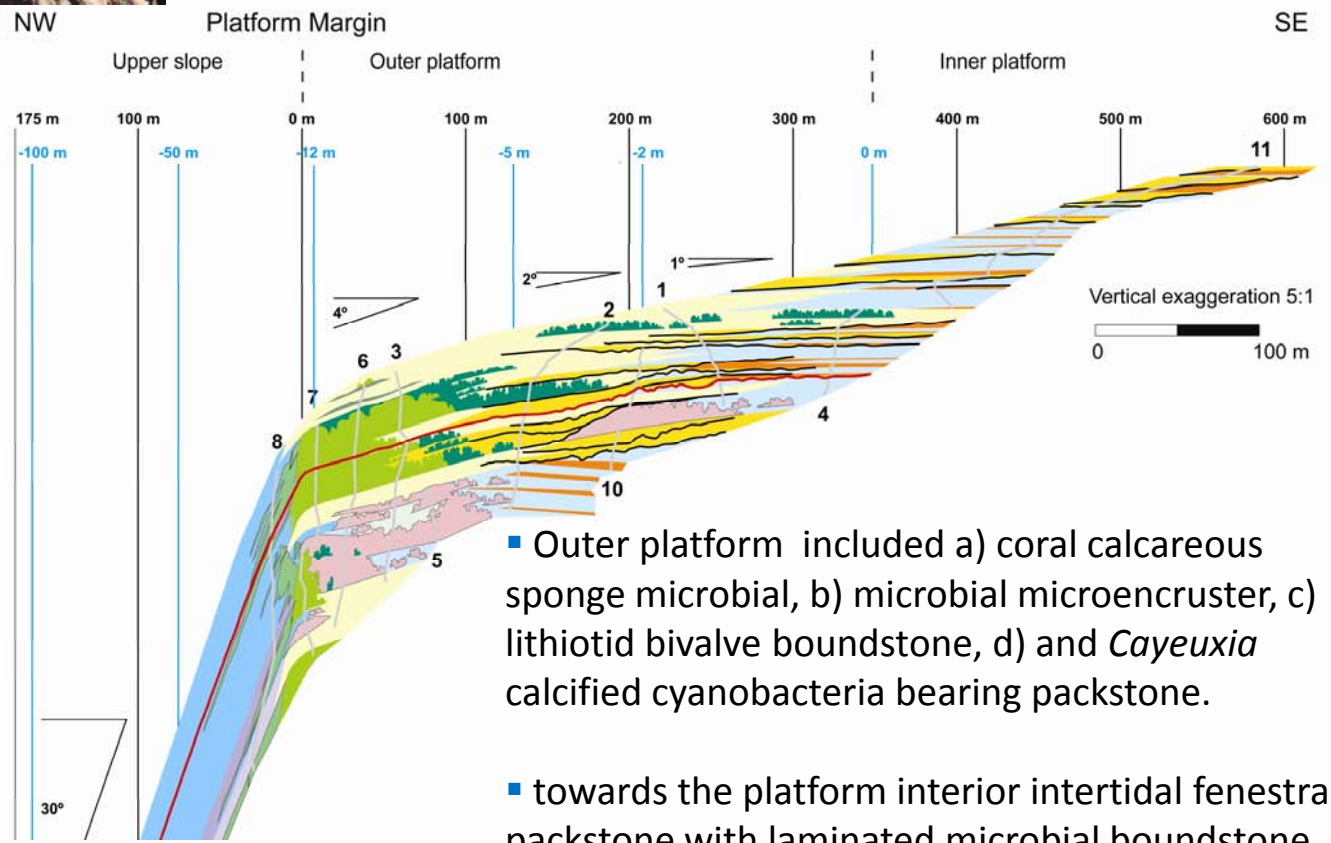
Microbial microencruster boundstone

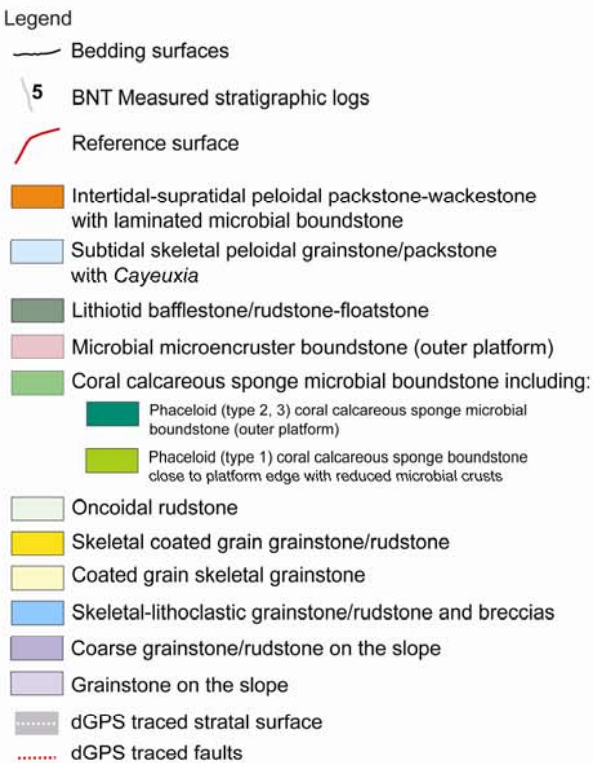
Lithiotid bivalve rudstone/floatstone

Cayeuxia bearing peloidal packstone/grainstone



Laminated columnar microbial boundstone





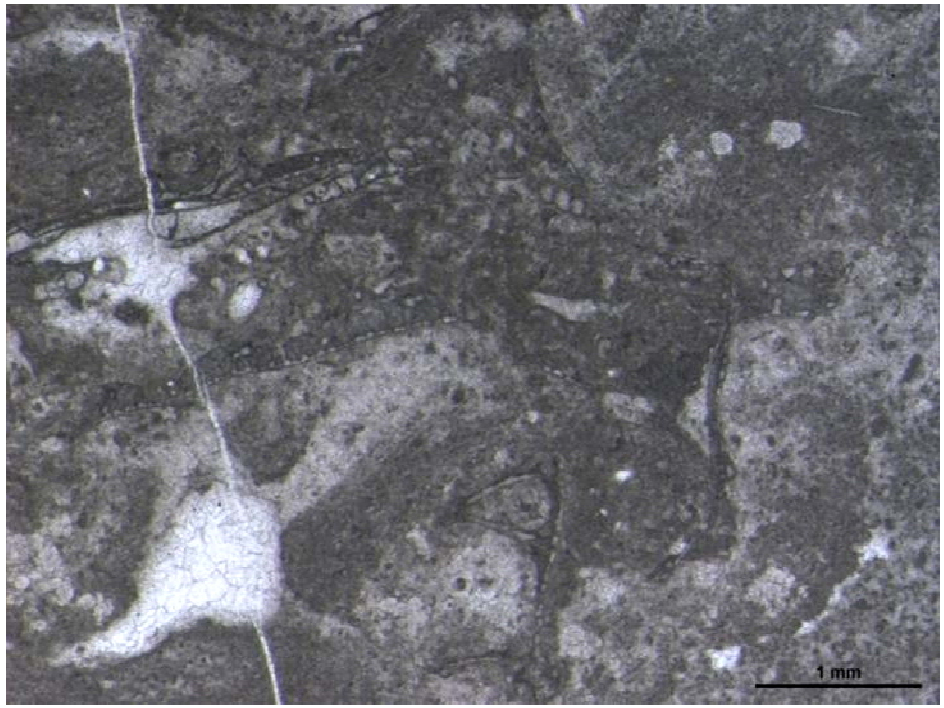
- Outer platform included a) coral calcareous sponge microbial, b) microbial microencruster, c) lithiotid bivalve boundstone, d) and *Cayeuxia* calcified cyanobacteria bearing packstone.

- towards the platform interior intertidal fenestral packstone with laminated microbial boundstone.

Microbial microencruster boundstone in outer platform (0-300 m platformward)

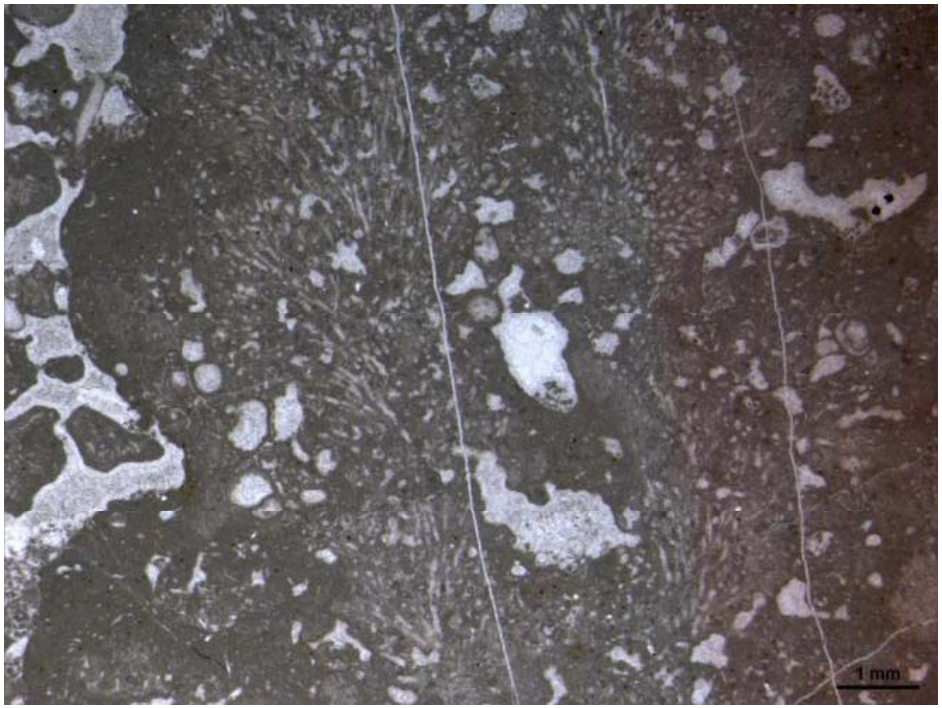
Clotted peloidal micrite microbial boundstone with *Bacinella ordinata* and mm-size marine cement filled primary voids.

***Bacinella ordinata* and clooted peloidal micrite microbial boundstone.**

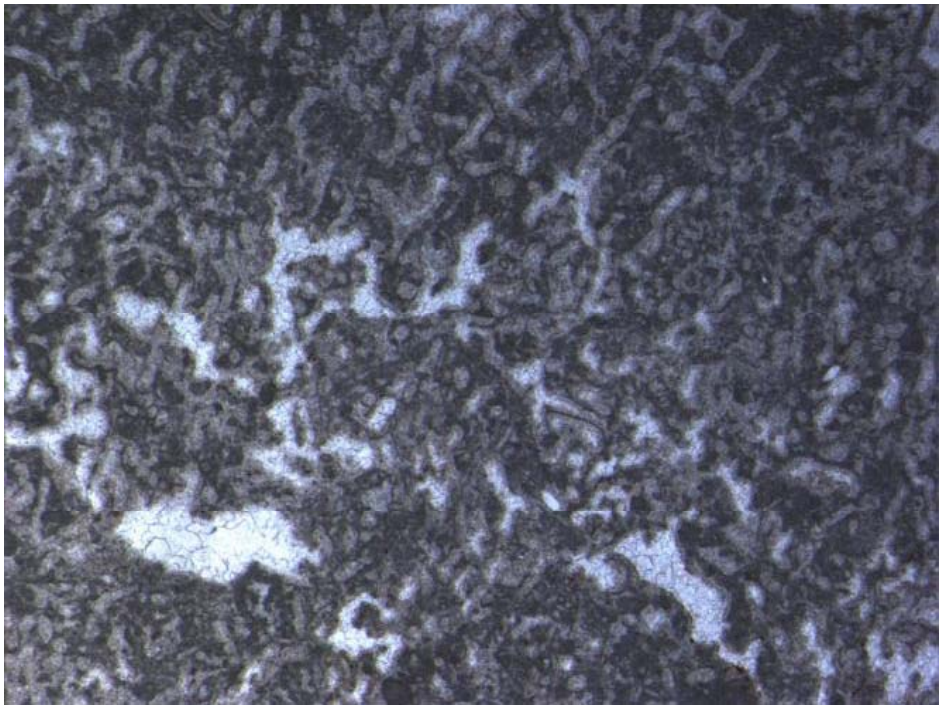


Cayeuxia-bearing peloidal skeletal packstone/grainstone from the outer to inner platform

Calcified cyanobacteria *Cayeuxia* in peloidal skeletal packstone and grainstone from subtidal low energy settings.

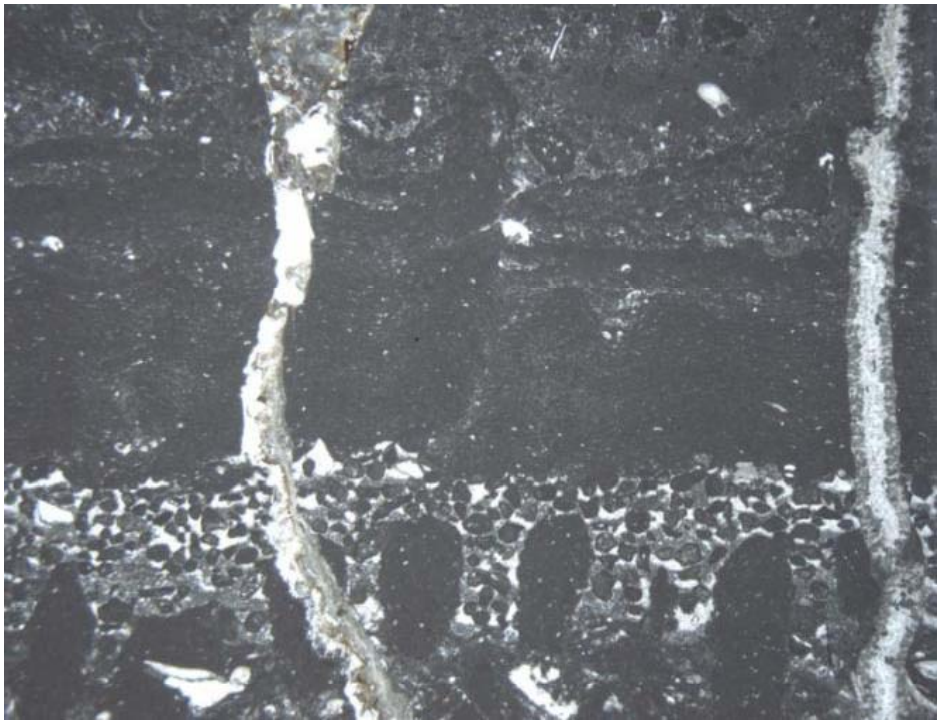


Clotted peloidal micrite and filaments (calcified cyanobacteria?) in subtidal lagoonal facies.

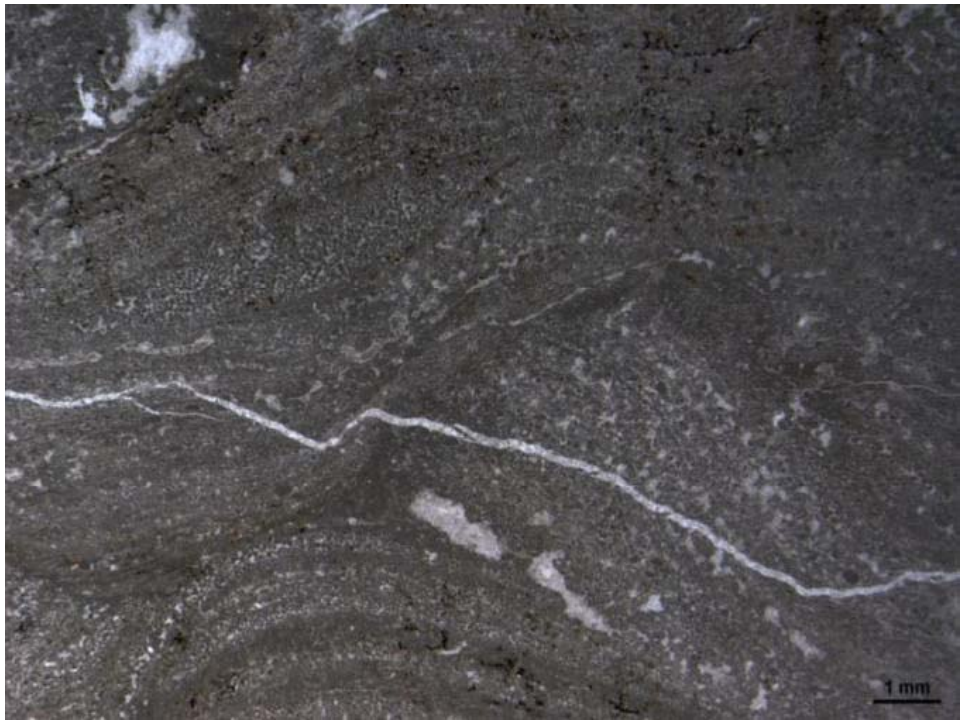


Laminated microbial boundstone in intertidal-supratidal platform interior

Columnar laminated stromatolites and coated grain grainstone.



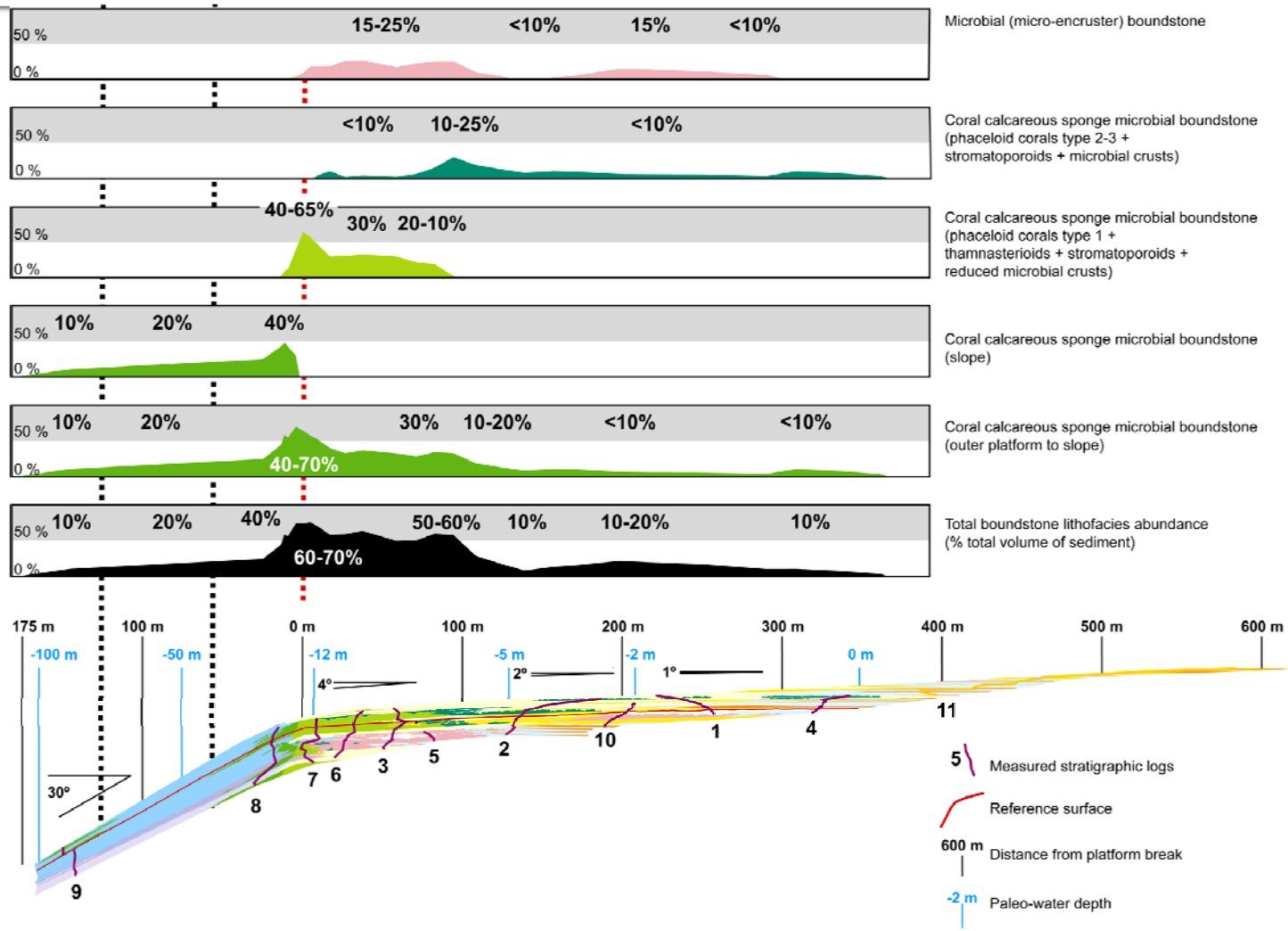
Laminated stromatolites.



Upper Pliensbachian high-relief platform (Sequence VI): boundstone lithofacies distribution and proportion

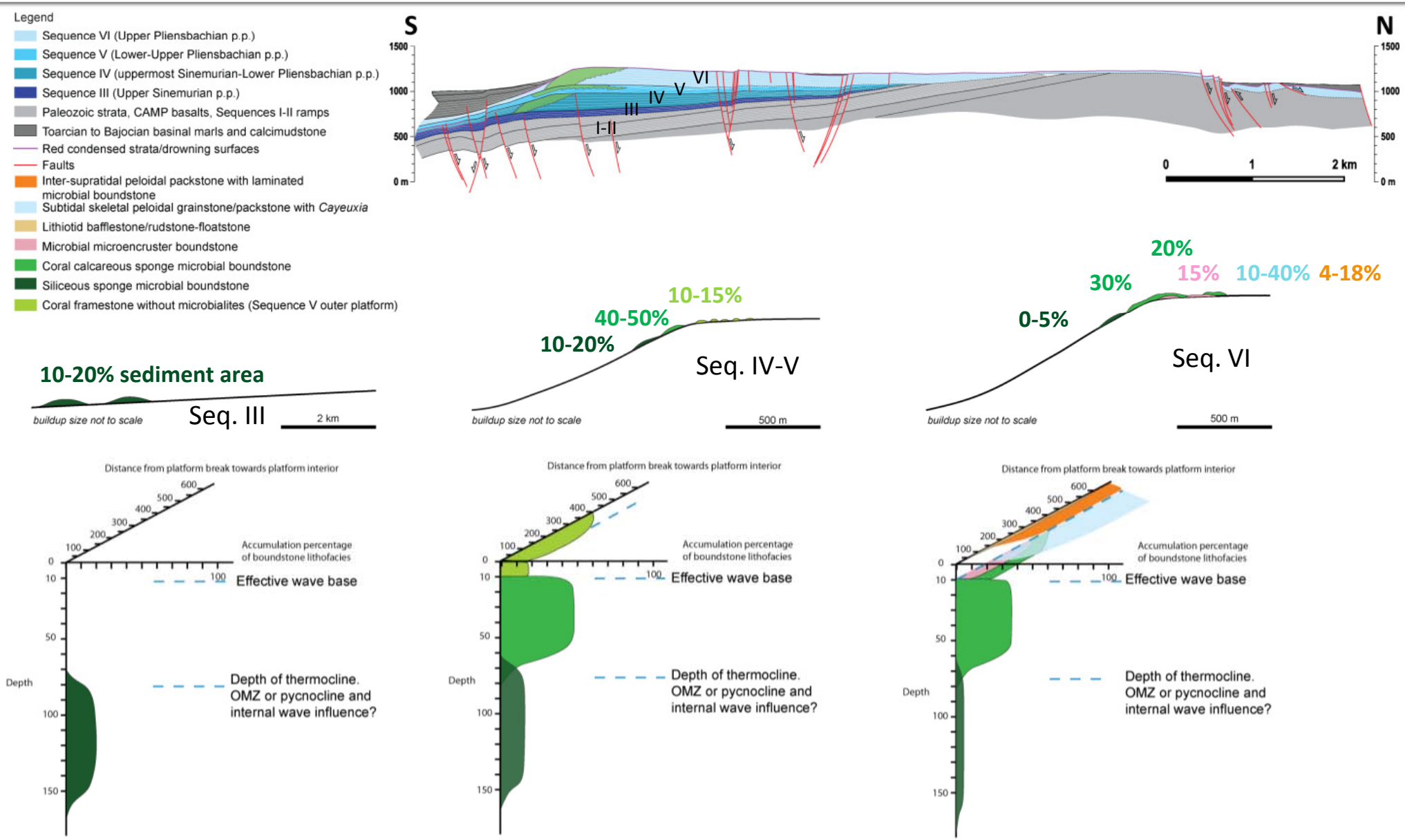
- **Upper slope**:
  - a) siliceous sponge microbial boundstone **0-2%** sediment area in cross section;
  - b) coral calcareous sponge microbial boundstone **30%** between 60-10 m depth.

- **Outer platform (0-350 m from platform break):**
  - a) coral calcareous sponge microbial boundstone (**20%** sediment volume);
  - b) microbial microencruster boundstone (**14%**);
  - c) lithiotid bivalve boundstone (**1-5%**);
  - d) *Cayeuxia* bearing packstone (**10-15%**) ;
  - e) Coated grain skeletal grainstone (**55%**)



- **Platform interior (350-600 m from platform break):** a) *Cayeuxia* bearing packstone (**40%**), b) intertidal fenestral packstone with laminated microbial boundstone (**20%**), c) coated grain skeletal grainstone (**20%**).

Platform geometry and carbonate factory percentages through time



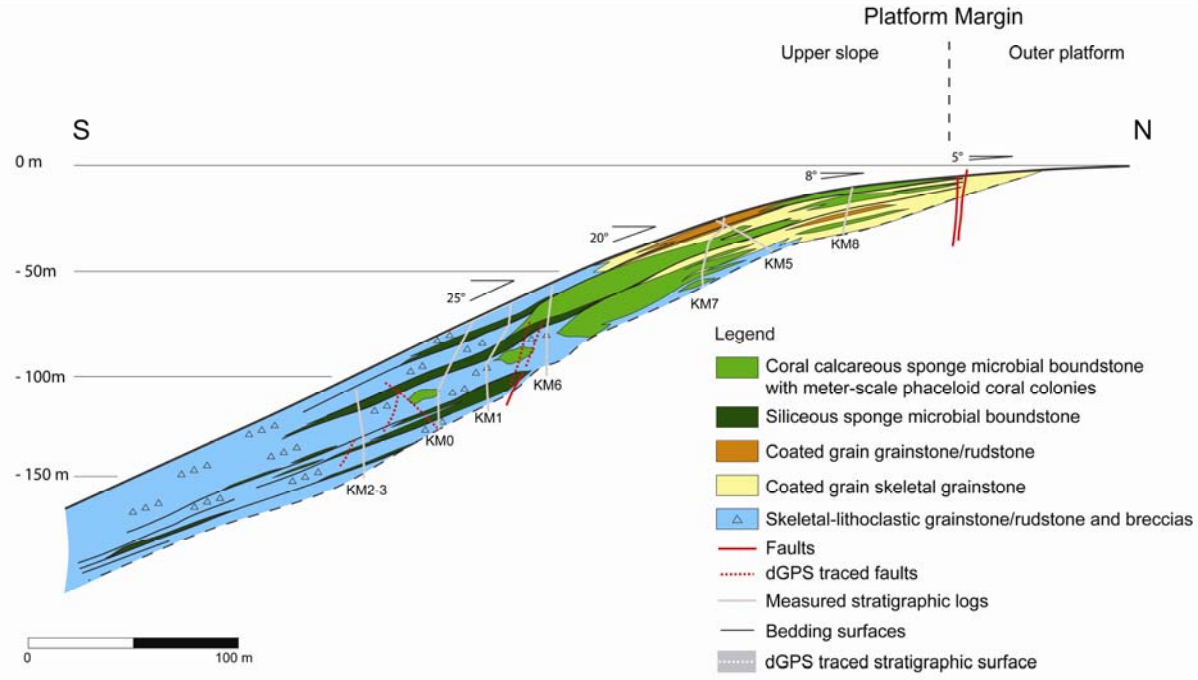
DBD microbial platform margin geometry

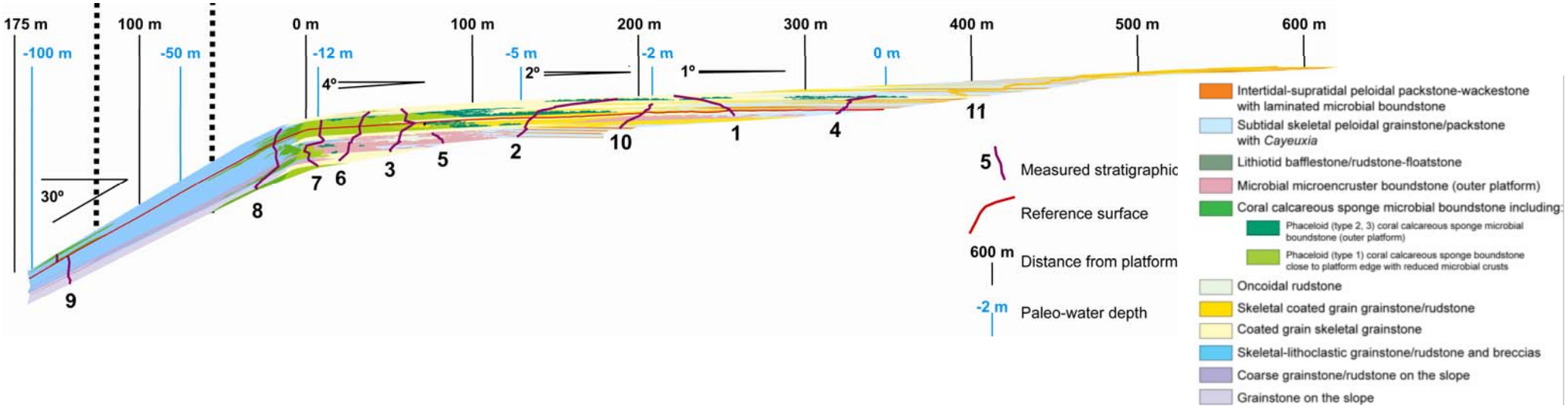
The DBD platform edge:

o no raised rim;

o typical rounded profile with outer platform "falling beds" dipping 1-5° basinward;

o similar to other Paleozoic and Mesozoic carbonate platforms with microbial boundstone dominated margins (cf. Della Porta et al., 2004; Kenter et al., 2005).





Conclusions

The DBD carbonate platform (Lower Jurassic, High Atlas, Morocco) highlights the role played by different carbonate factories and microbialites on the growth and architectural evolution of a high-relief flat-topped carbonate system on the hanging wall of an extensional fault block.

- Sinemurian ramp: **deep water siliceous sponge microbial mounds (10-20%) + transportable unlithified packstone and grainstone (90-80%)** redistributed by waves and currents maintaining a low-angle profile.

- Uppermost Sinemurian-Pliensbachian high-relief steep (20-32°) slopes with **upper slope *in situ* carbonate factories**: a) siliceous sponge microbial boundstone (10-20% at upper slope 60-140 m depth range); b) coral calcareous sponge microbial boundstone (40-50% of sediment volume at upper slope 10-60 m depth range).

- **Several lithofacies from upper slope to inner platform contributed to the late Pliensbachian platform high-relief (600 m) geometry and platform aggradation (300 m)** :

  - a) the outer platform (350 m inward from platform break) consisted of coral calcareous sponge microbial boundstone (20%) and microbial microencruster boundstone (14%) and coated grain skeletal grainstone;

  - b) the platform interior (350-600 m from platform break) aggraded thanks to the deposition of subtidal peloidal skeletal packstone with *Cayeuxia* calcified cyanobacteria (40%), intertidal-supratidal fenestral peloidal packstone with laminated microbial boundstone (nearly 20%) and skeletal grainstone (20%).

Conclusions

1. **Lower Jurassic coral microbial platform margin (DBD) vs. Lithiotid bivalve margin (published reef models).**

2. **Microbial falling beds (basinward dipping outer platform) stratal patterns.**

3. **Lower Jurassic DBD reefs already had the components of the Upper Jurassic reefs (e.g., corals, stromatoporoids and microbialites)**

4. **DBD shares similarities with Upper Jurassic intra-Tethys isolated platforms and North Atlantic platforms (Portugal, Nova Scotia).**

5. **Similarities between Lower Jurassic DBD and North Atlantic Upper Jurassic reefs (e.g. Nova Scotia) provides tools for new exploration of Jurassic carbonate reservoirs.**

Thank you!

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