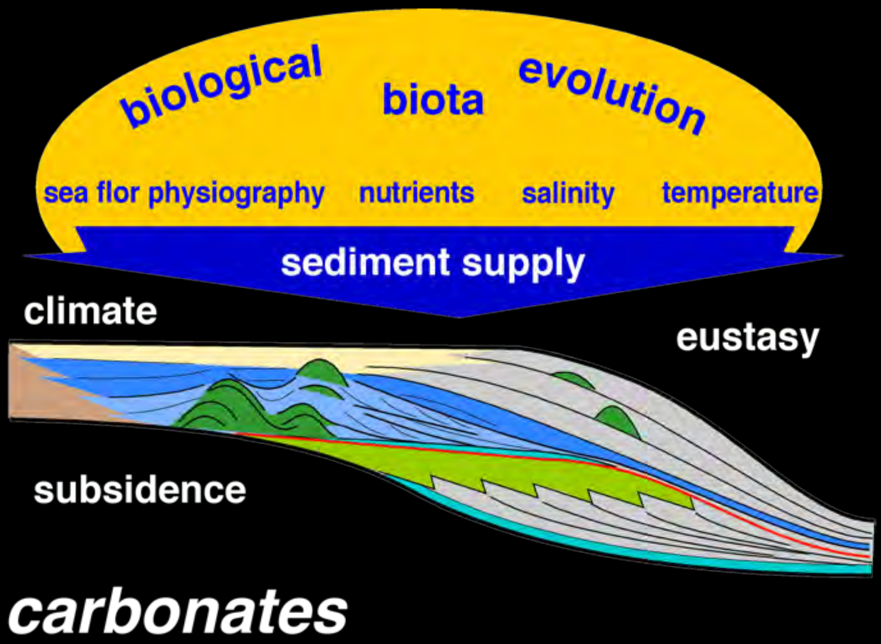
Why do Carbonates Systems buck the trends of Sequence Stratigraphic Models?

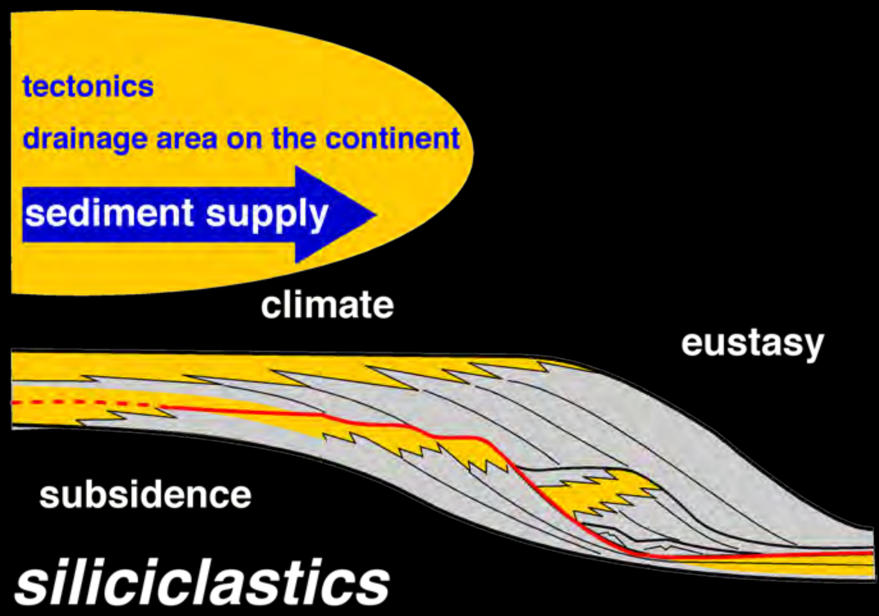
Luis Pomar

Universitat de les Illes Balears

because major differences exist in the processes controlling platform architecture

- in the **source**: many different production modes





- in the **sink**: different building up capacities (the source is in the sink)

OBJECTIVE OF SEQUENCE STRATIGRAPHIC ANALYSIS

- constructing a meaningful reservoir model

PREREQUISITE:

- need of realistic depositional models: e.g.,
    - coral buildups vs. reefs; shallow water? mesophotic?
    - what about nummulitic accumulations?
    - what about rudist platforms? shallow water? pycnocline?
    - what about thick grainstone units in mid-outer ramp settings …?

OFTEN FORGOTTEN:

- changing components, rock textures, lithofacies, platform type and architecture throughout time, is a uniqueness of carbonate rocks.

WHITHIN THIS CONCEPTUAL FRAMEWORK

- the use of bedding patterns/bounding surfaces **alone** may or may not make any sense
- grain size trends or changes in sediment patterns may or may not be meaningful

IN CARBONATES, the architectural trends allowing to subdivide the stratigraphic record in genetically-related packages

- are better captured through the occurrence and preservation of components and rock textures

INDUSTRIAL ASPECTS:

Exploration

- requires recognition of the carbonate production modes for the time window of the exploration target

Hydrocarbon production

- understanding facies heterogeneities is crucial
- HR sequence analysis leads to understanding of flow units and existence of baffles and barriers

examples illustrating the singularities of carbonate systems

the sink:
physical accommodation

1- Infralittoral prisms

2- Lower Tortonian ramp
3- Oligocene-Lumignano

4- Oligocene-Castelgomberto
low-angle ramp

source & sink:
ecological accommodation

5- Upper Miocene Llucmajor Pl.
reef-rimmed platform

the source:
several factories

6- Upper Miocene Llucmajor Pl.

7- Upper Jurassic Arroyo Cerezo

8- Upper Cretaceous, Vilanoveta

changing accommodation
without changing relative sea level

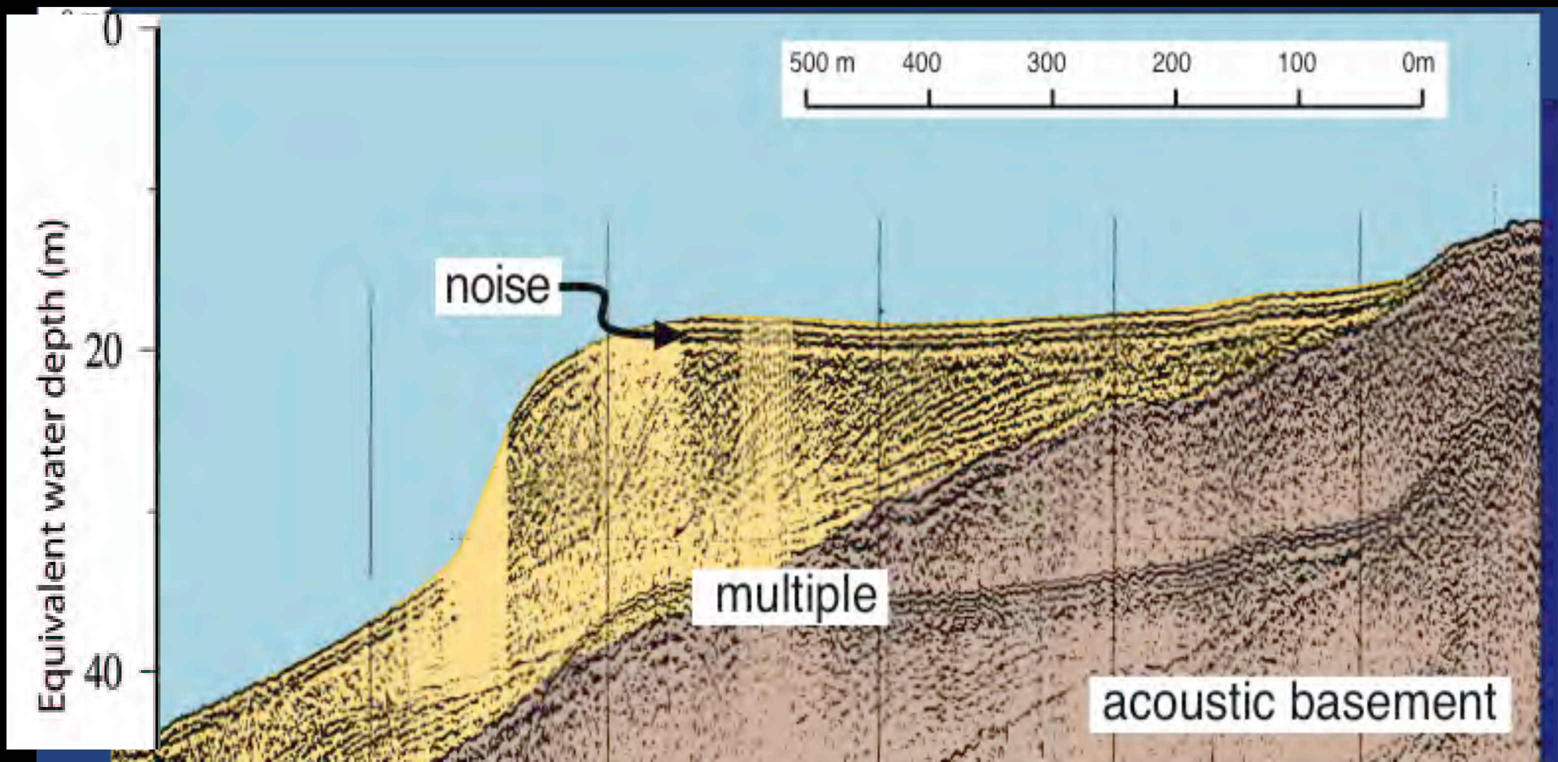
9- Upper Miocene, Balearic Islands

subsurface example

10- Oligo-Miocene;
Perla Field, offshore Venezuela

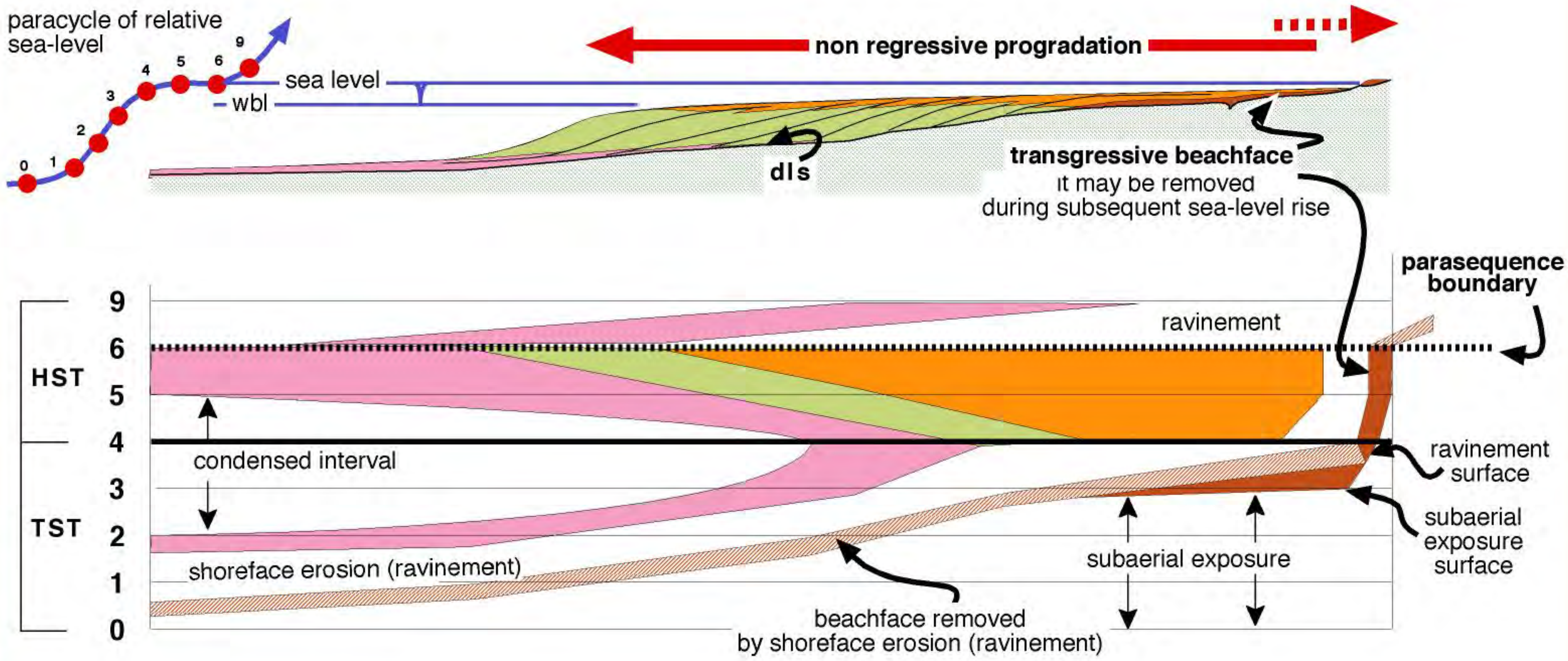
1.- Infralittoral (within the wave action zone) prograding wedges, several localities

On clastic shelves, **base level** (erosional wave action zone) for sediment accumulation tends to be the **shelf equilibrium profile**



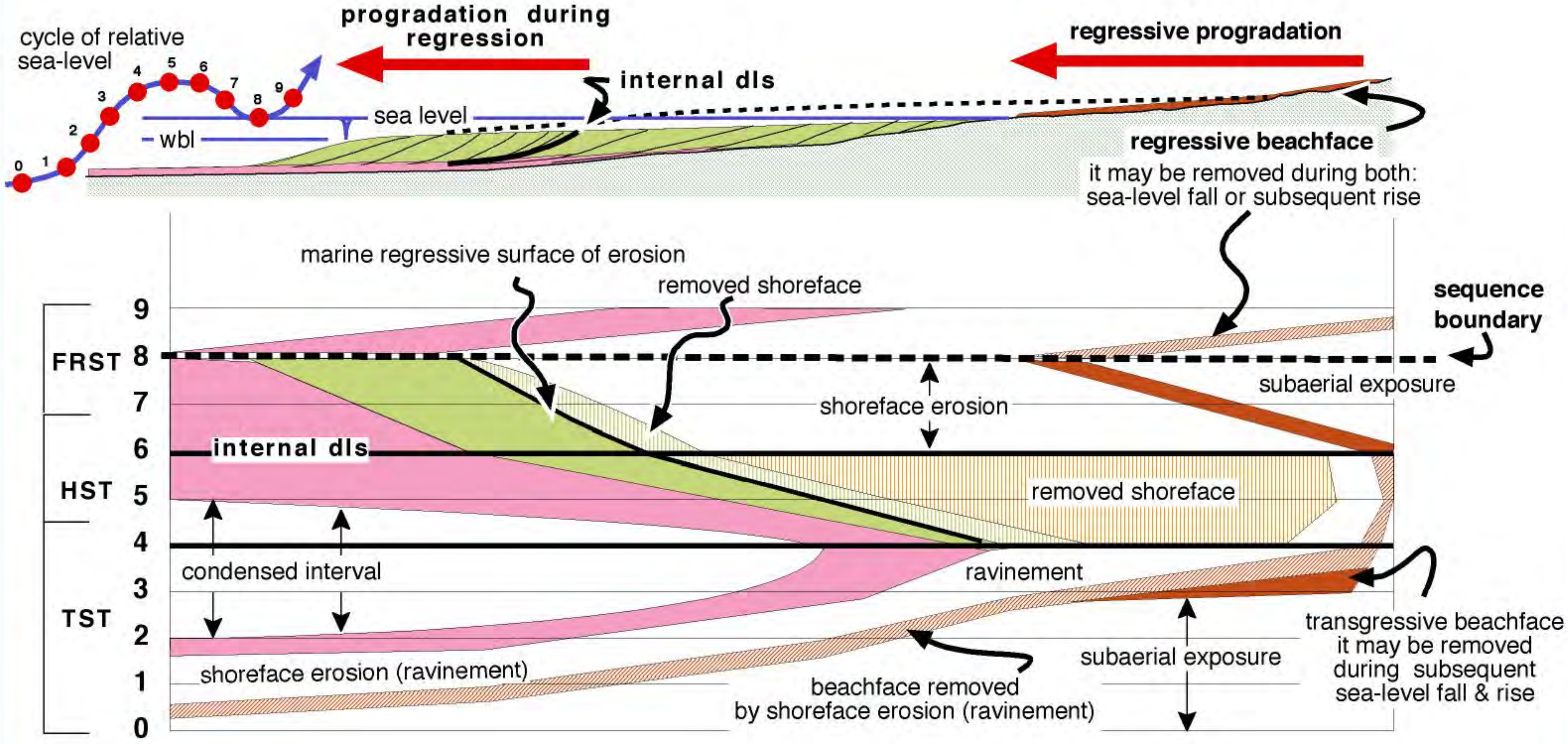
Hernandez-Molina et al., 1995

The sink: the base level concept (physical accommodation)



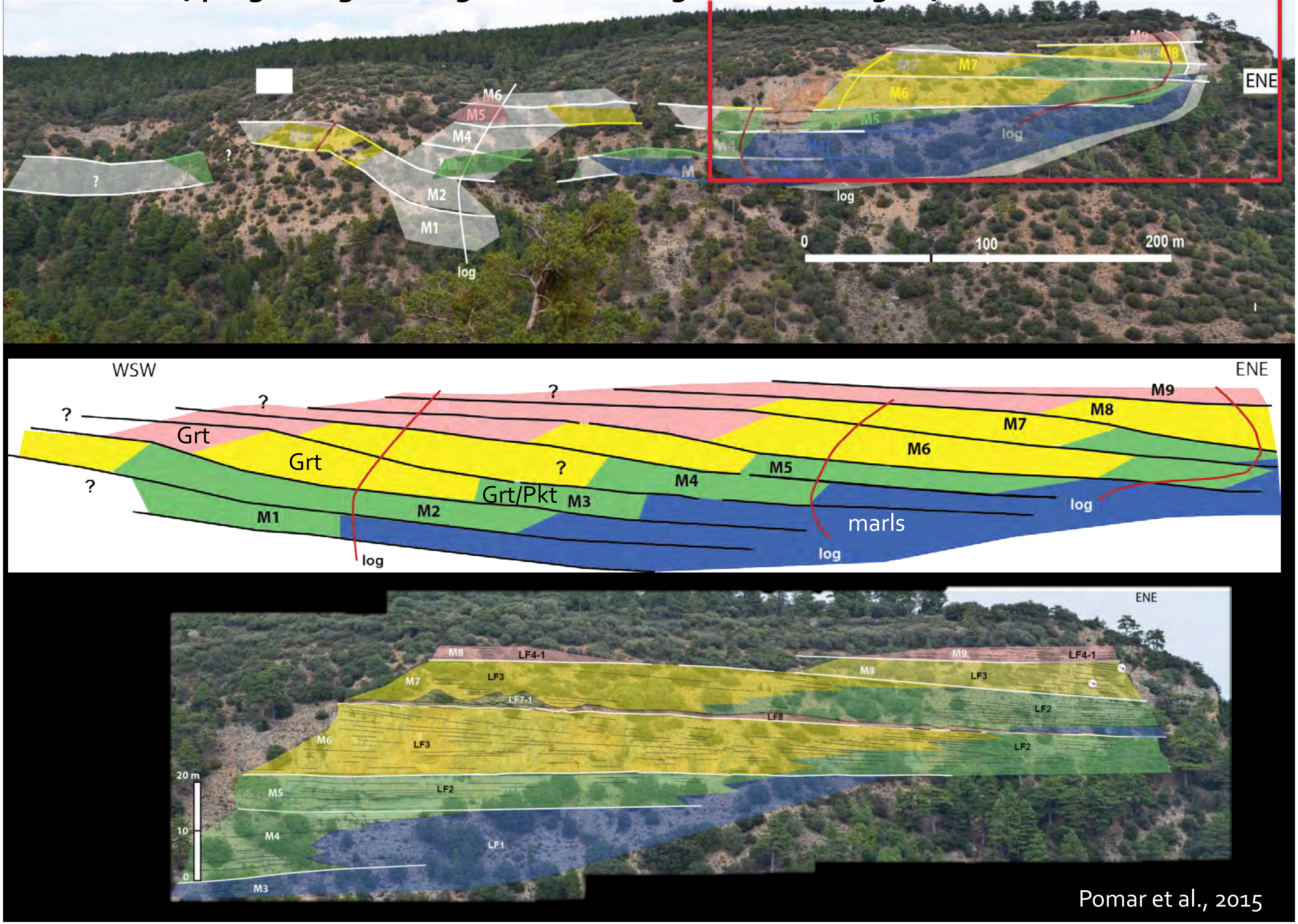
Pomar & Tropeano, 2001

The sink: the base level concept (physical accommodation)



Pomar & Tropeano, 2001

Moscardón; prograding oolitic grainstone wedge – Kimmeridgian, Iberian Basin



Pomar et al., 2015

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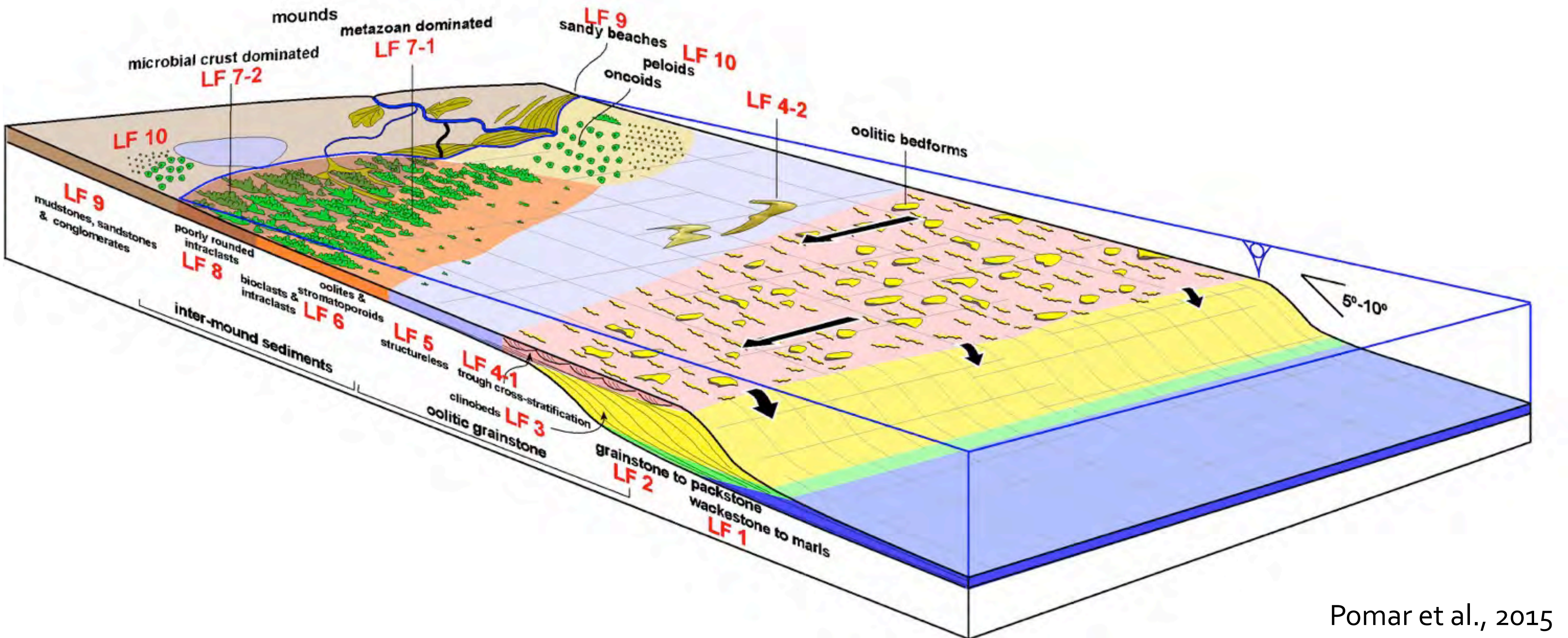
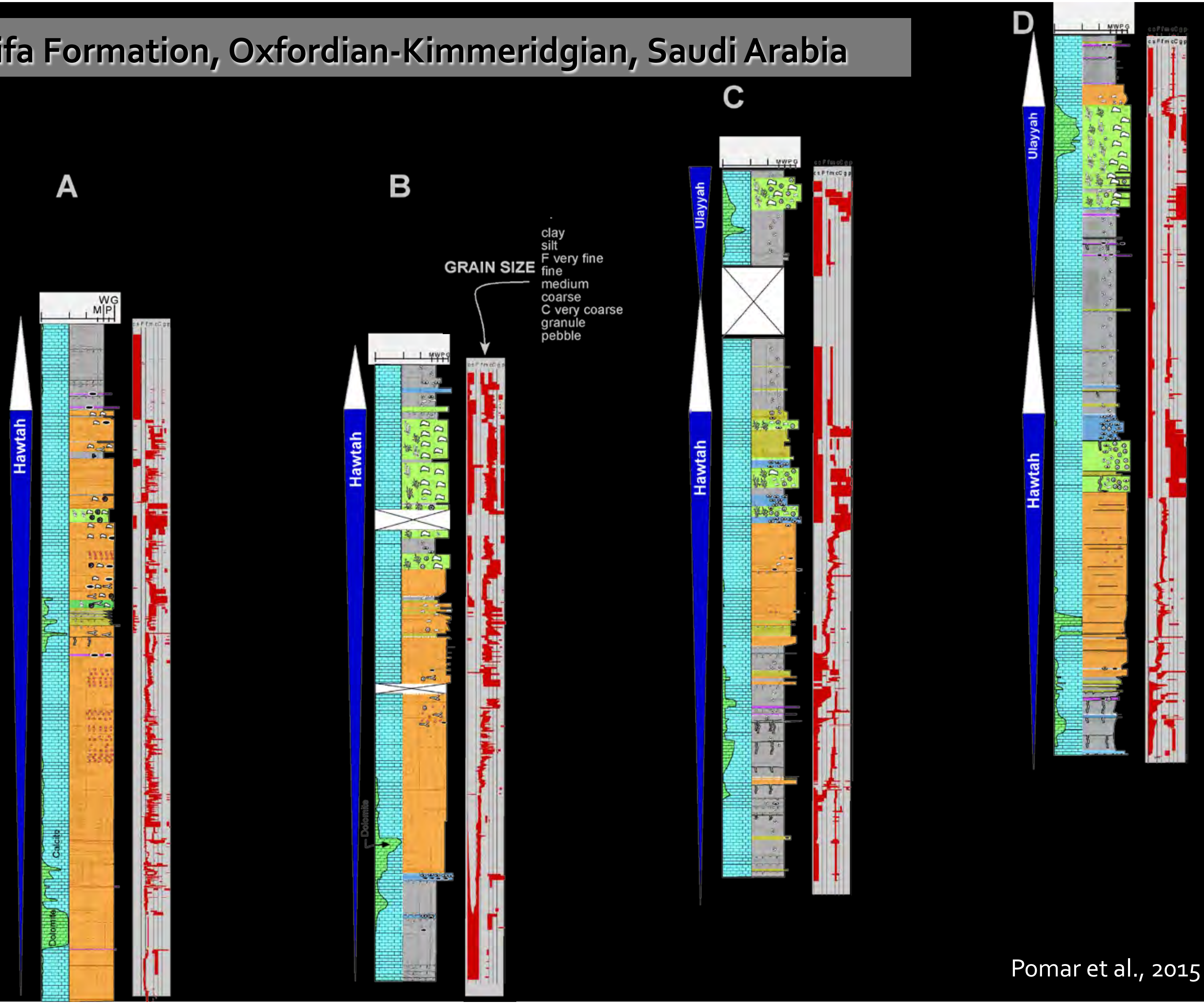


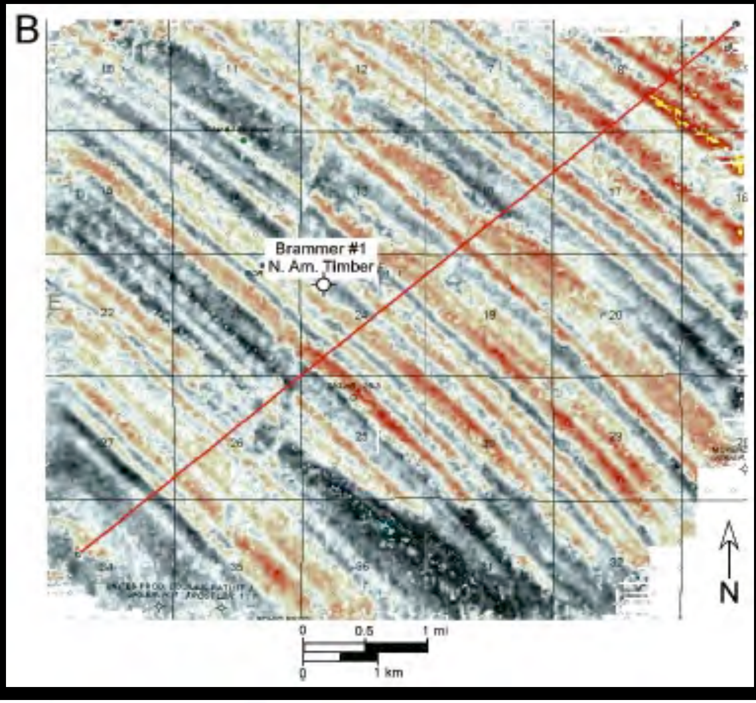
Pomar et al., 2015

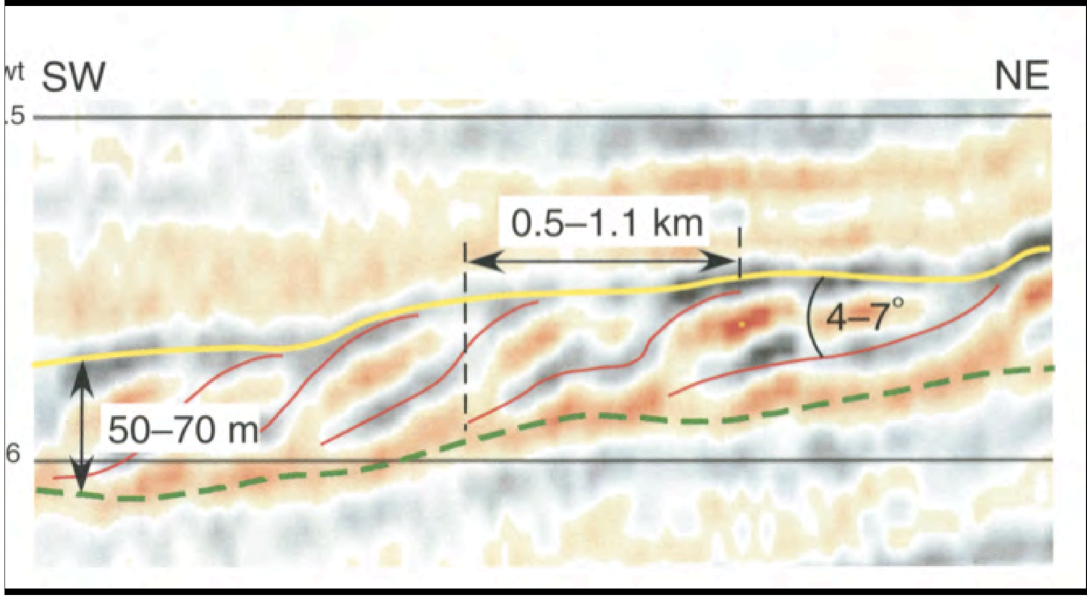
Hanifa Formation, Oxfordian-Kimmeridgian, Saudi Arabia

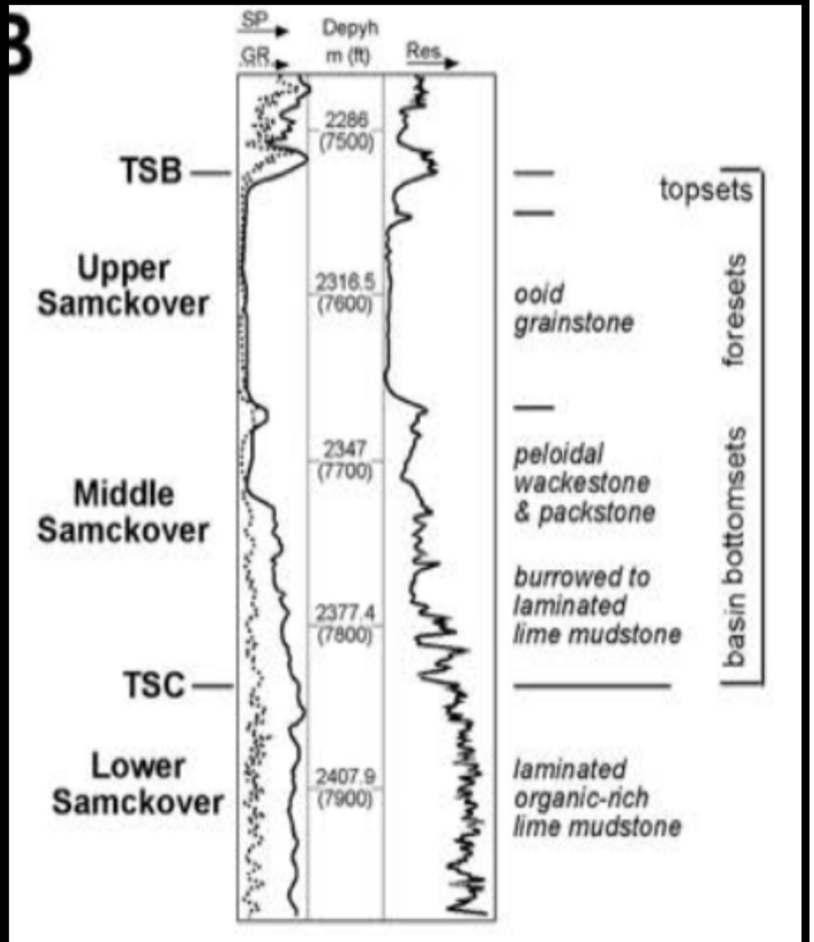


Pomar et al., 2015

Smackover Formation, Oxfordian, N. Louisiana and S. Arkansas - U.S.A.

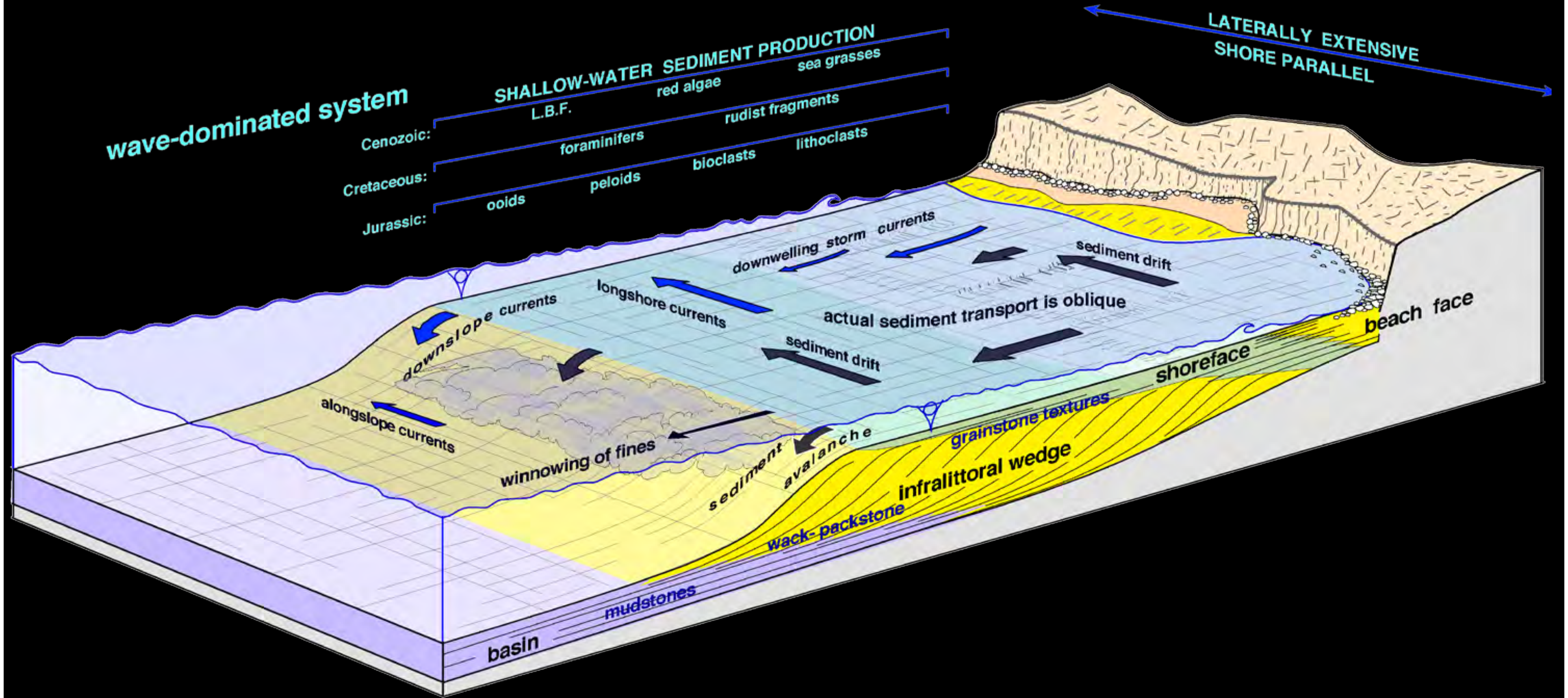






Handford and Baria, 2007

Model for the infralittoral prograding wedge



Pomar et al., 2015

lessons learned from these examples

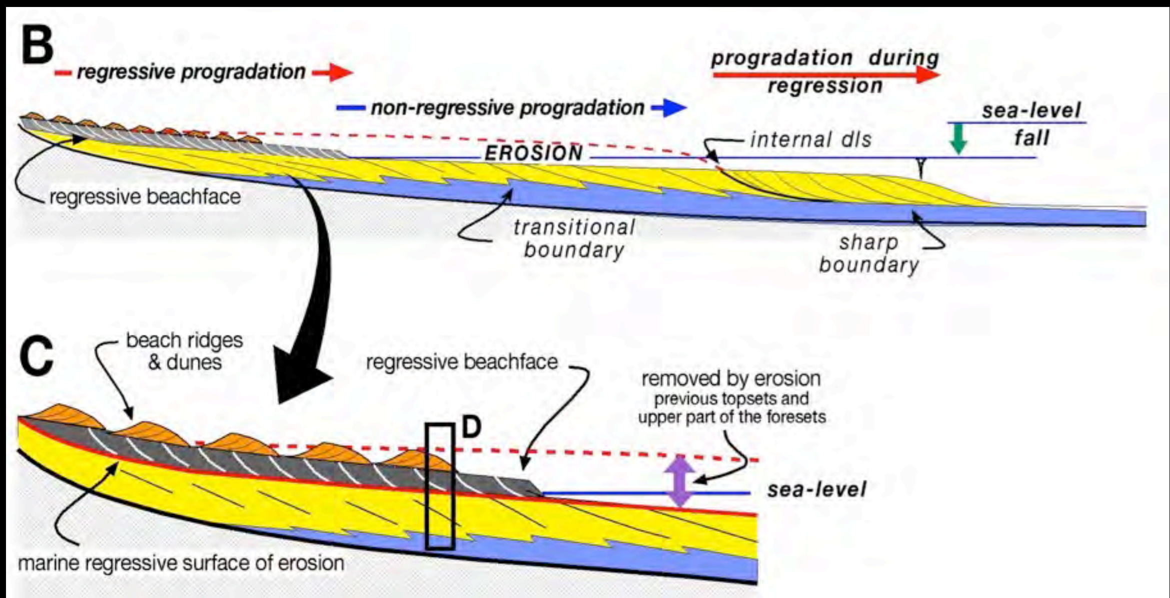
The ILPW fully display the characteristics of sequences and parasequences, because are systems dominated by physical accommodation only,

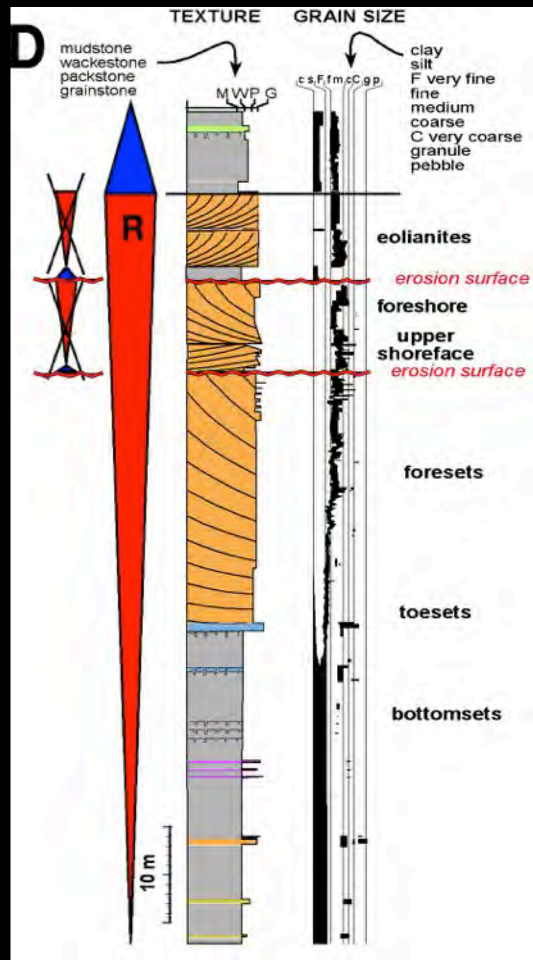
particular attributes :

grain composition is variable: time slice, latitude, climate, etc.

In a supply dominated system, two unconformities may occur within the same sequence (Tropeano et al., 2002)

good targets: clean grainstones





lessons learned

often interpreted as sand shoals or even beach ridges

despite they do not share the dimension and sedimentary structures

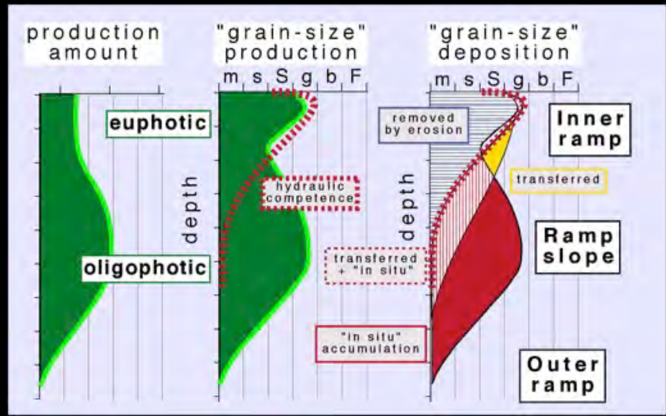
(Ball, 1967)

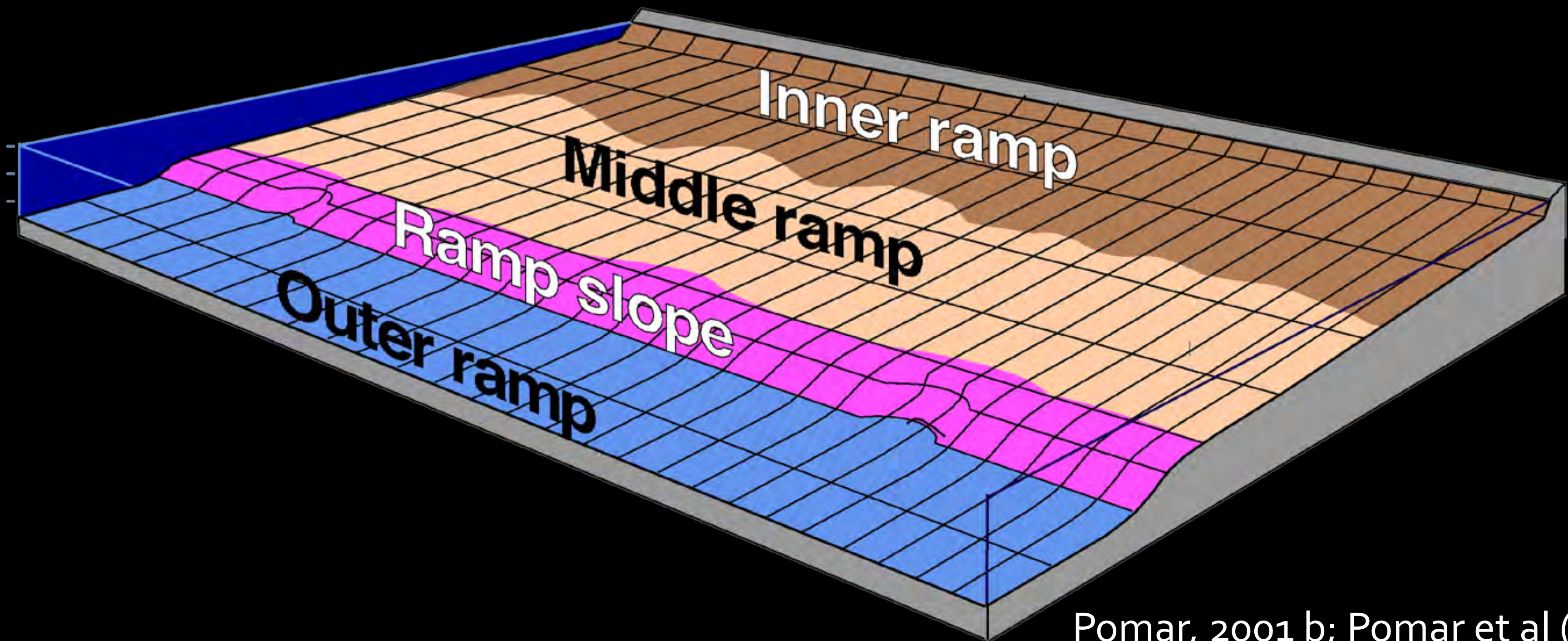
this misinterpretation hinders the HR sequence interpretation and the construction of realistic reservoir models

2.- Lower Tortonian, Migjorn distally-steepened ramp, Menorca, Spain

two carbonate factories coexisted:

- euphotic seagrass epiphytes
- enhanced oligophotic red algae





Pomar, 2001 b; Pomar et al (2002)

2.- Lower Tortonian, Migjorn distally-steepened ramp, Menorca, Spain

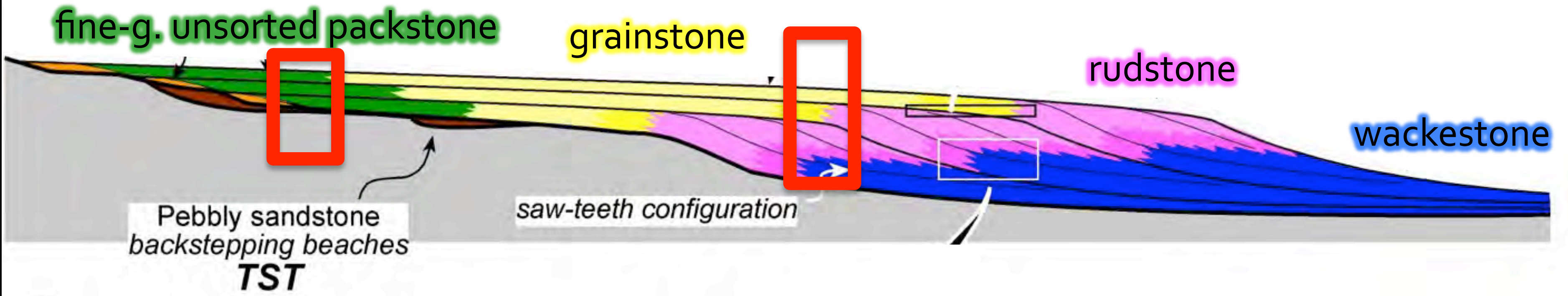
two carbonate factories coexisted:

- euphotic seagrass epiphytes
- enhanced oligophotic red algae

neither the stratal patterns nor the changes in the grain-size variation are reliable criteria for sequence interpretation

euphotic factory shifted landward and increased the area of production,

oligophotic factory shifted up and downslope inducing the platform to prograde



Pomar, 2001 b; Pomar et al (2002)

4.- Oligocene, Castellgomberto, northern Italy

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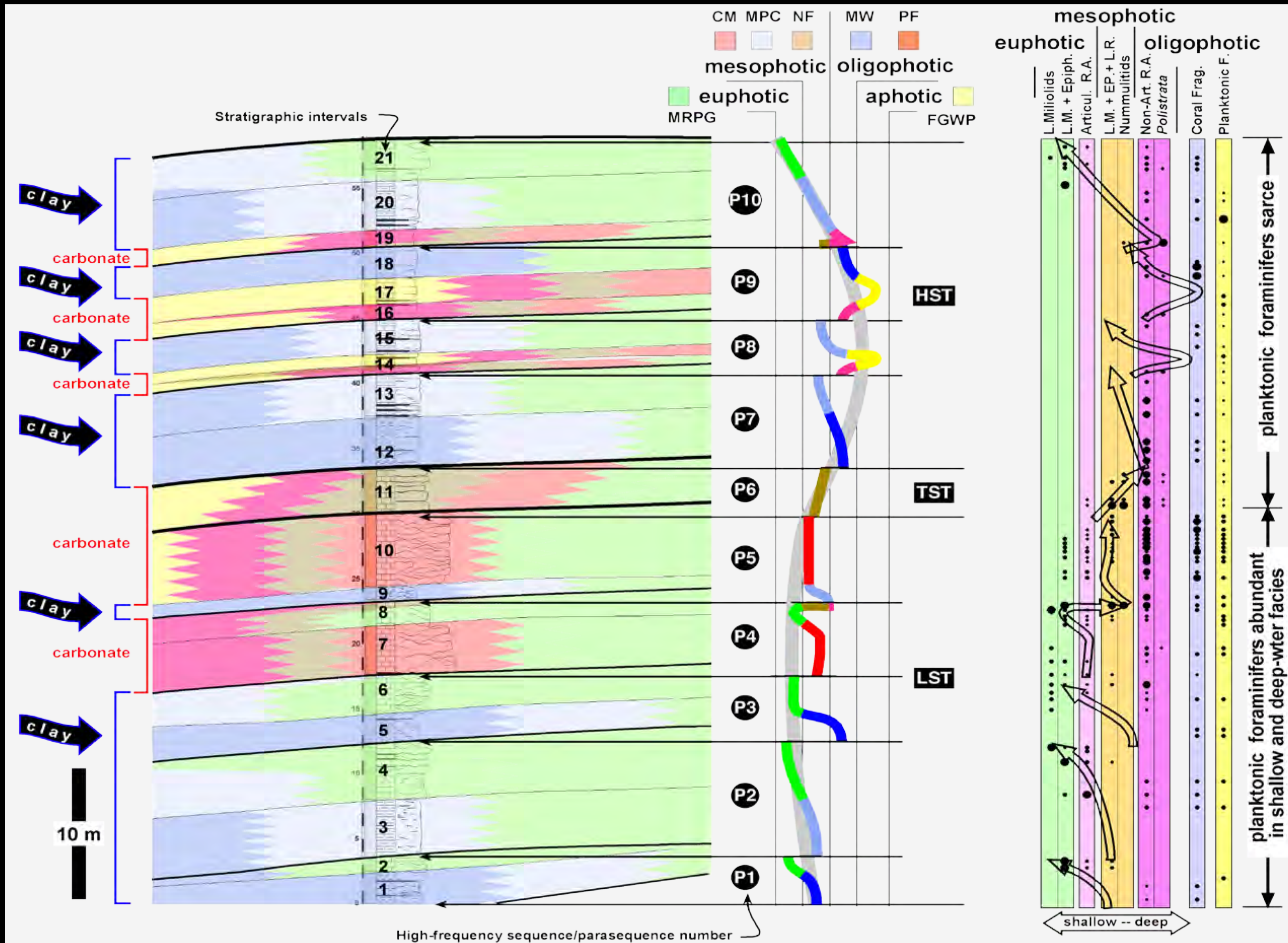
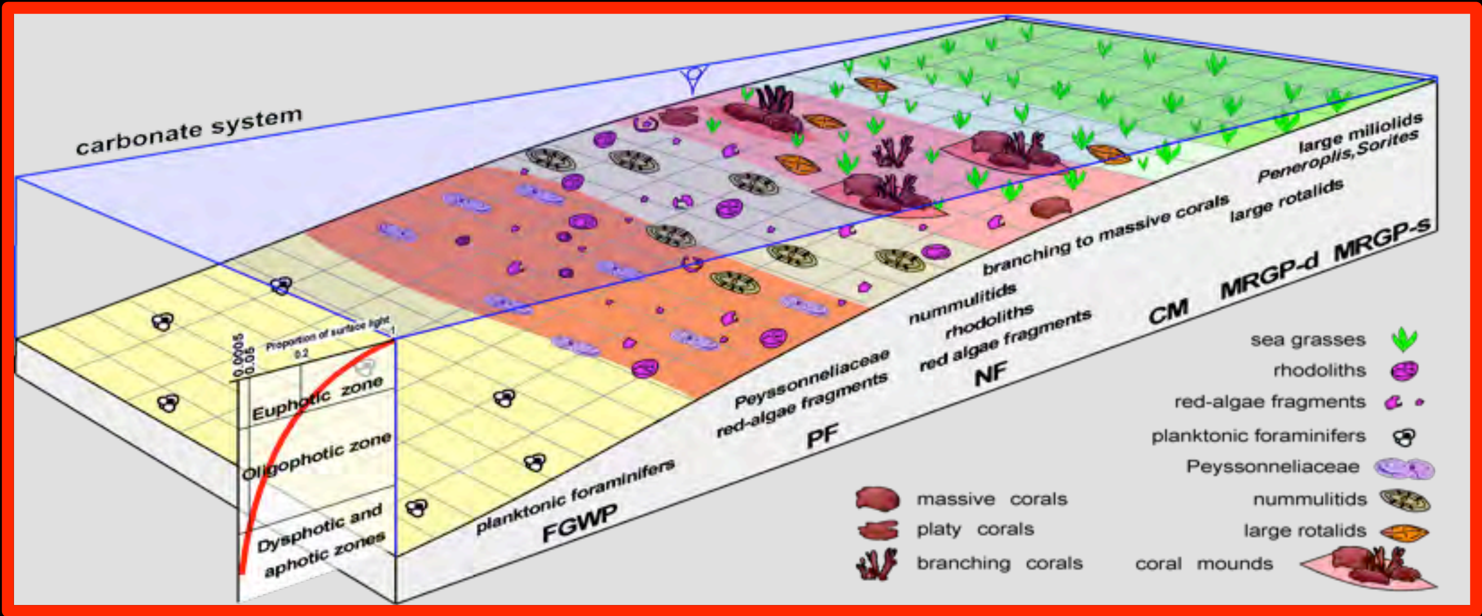
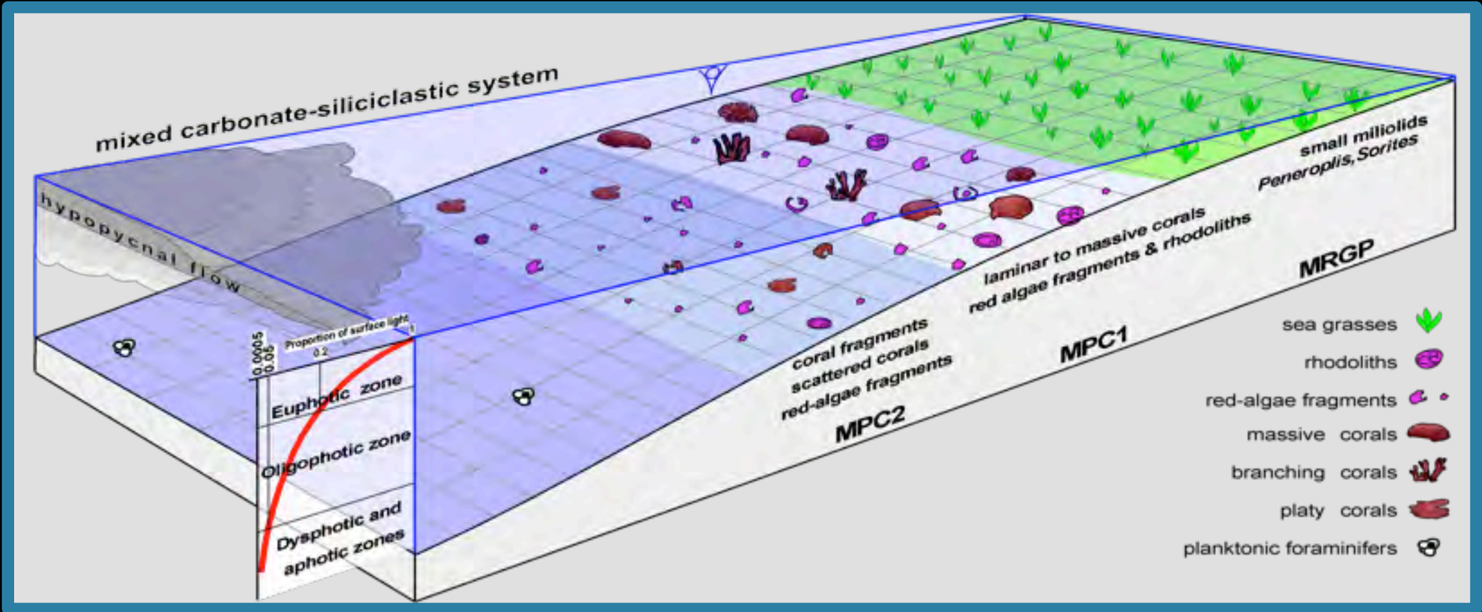


Bortot et al., ongoing work

4.- Oligocene, Castellgomberto, northern Italy





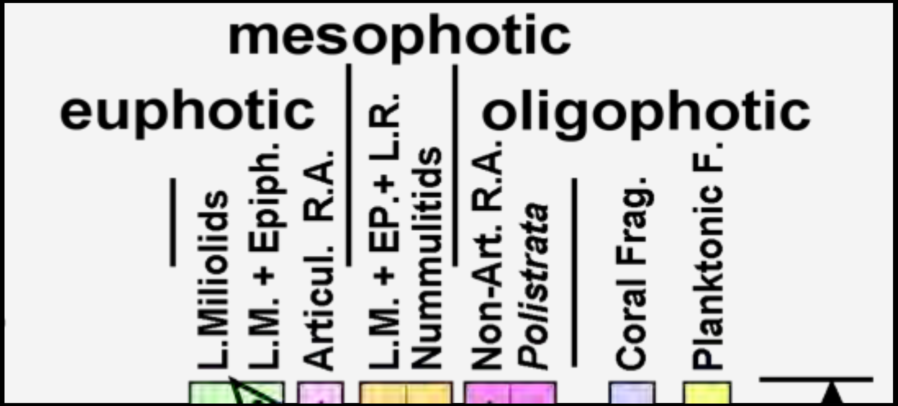
Bortot et al., ongoing work

lessons learned from this example

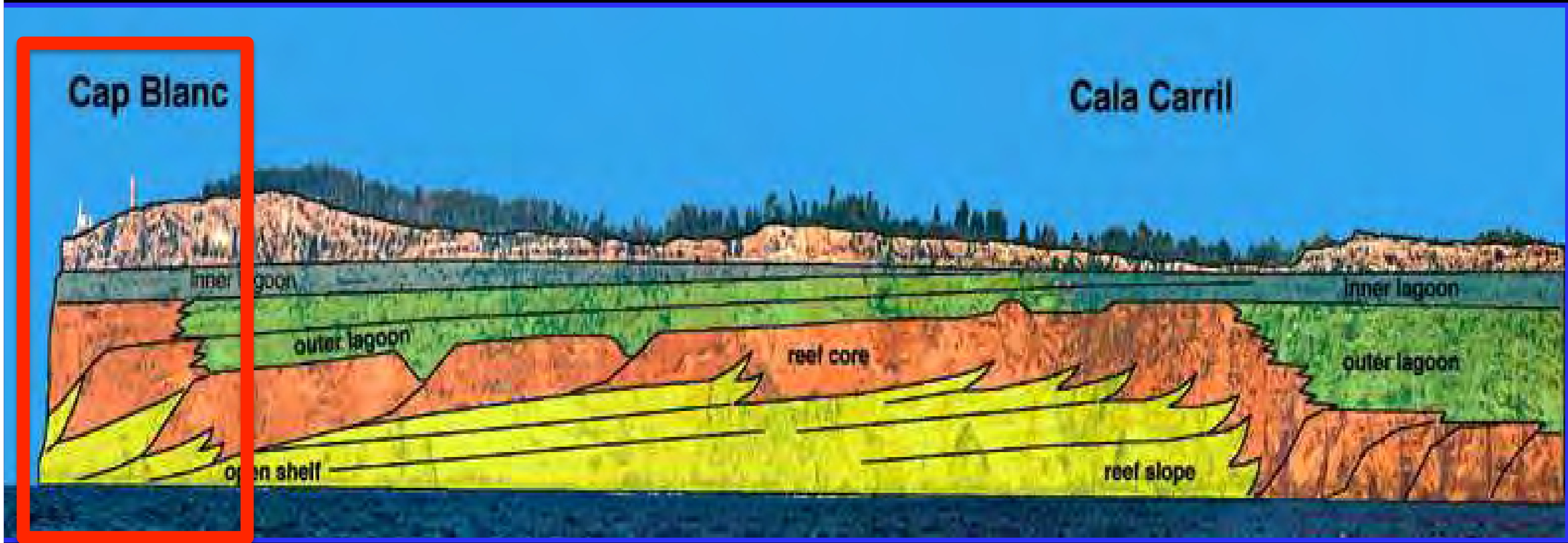
- with, or without visible bedding patterns,
- without evidences of key bounding surfaces and
- without changes in sediment sizes and texture

the depositional models can be identified and the sedimentary record be subdivided in genetically-related packages

through the distribution of components and rock textures



5.- Upper Miocene, Llucmajor Reef Complex, Mallorca, Spain

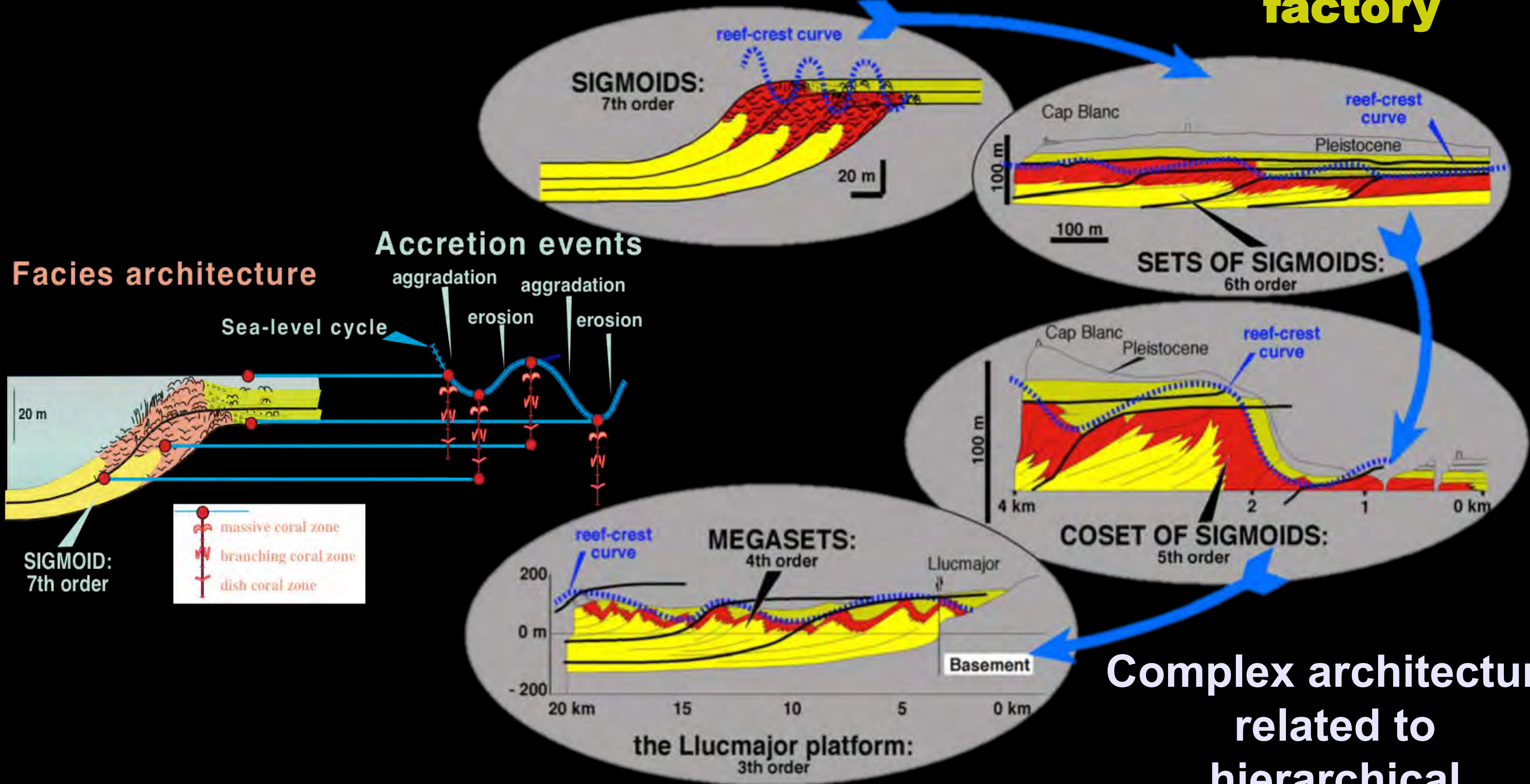


Pomar and Ward, 1994, 11995, 1999
Pomar, 1991, 1993

5.- Tortonian-Messinian Llucmajor Reef Complex, Mallorca, Spain

the **architecture** is better captured from the **sea-level trajectories (reef-crest line)**

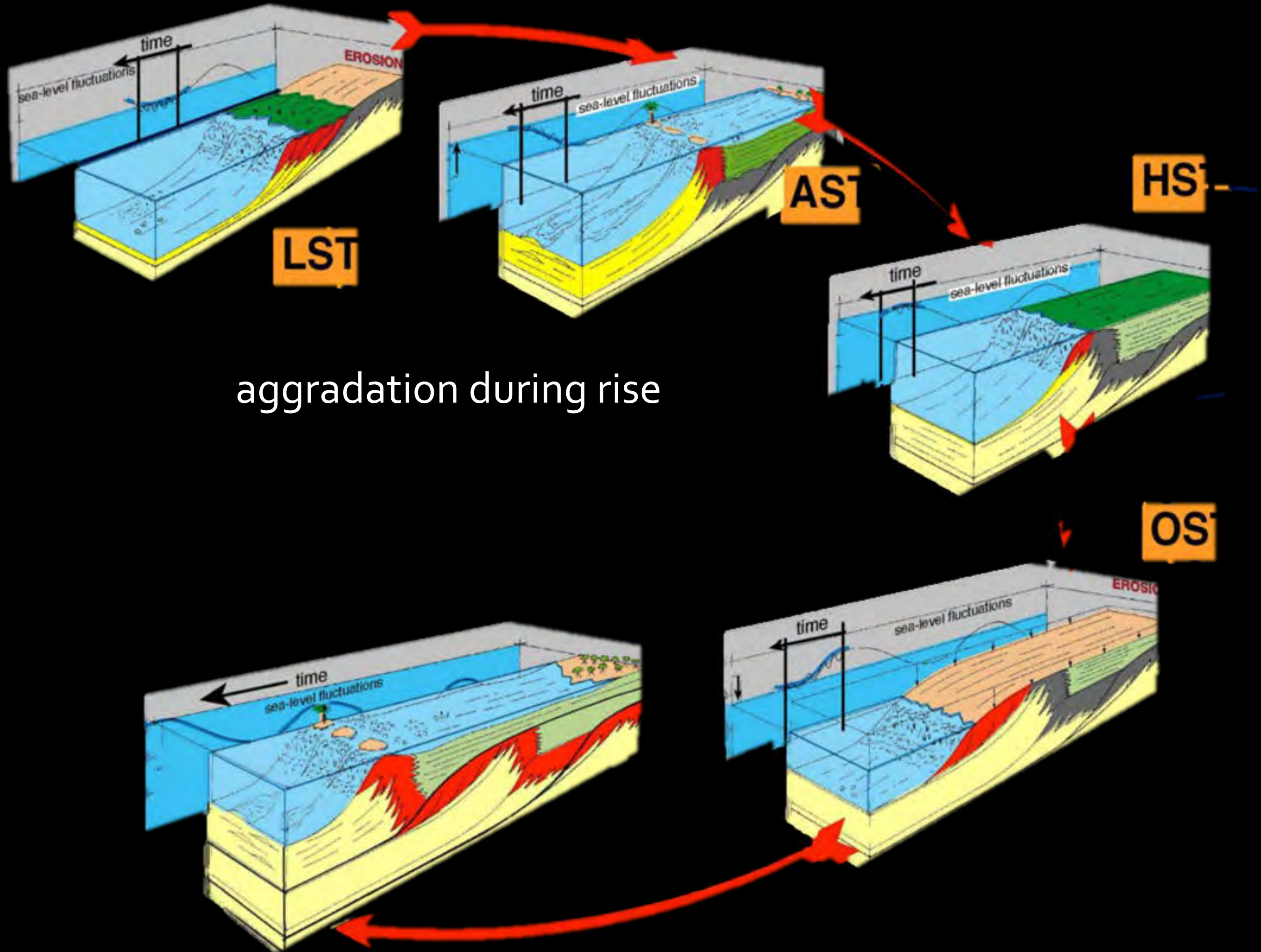
Euphotic chlorozoan factory



Complex architecture related to hierarchical sea-level fluctuations

Tortonian-Messinian Llucmajor Reef Complex, Mallorca, Spain

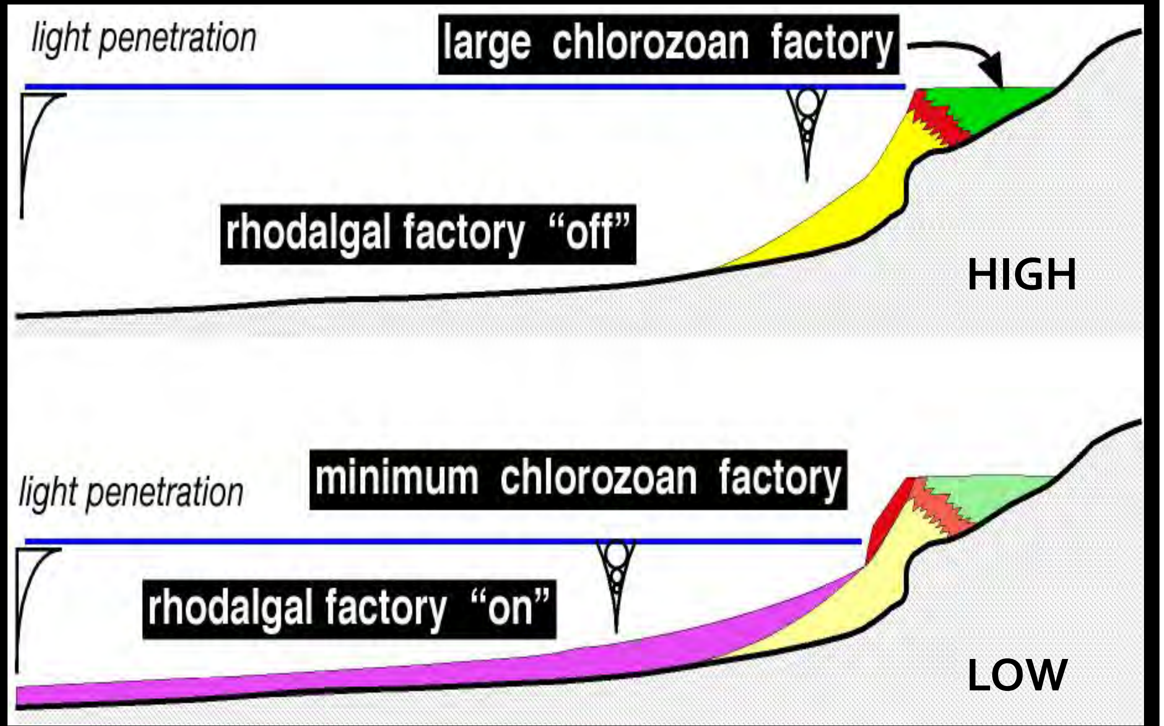
Euphotic chlorozoan factory



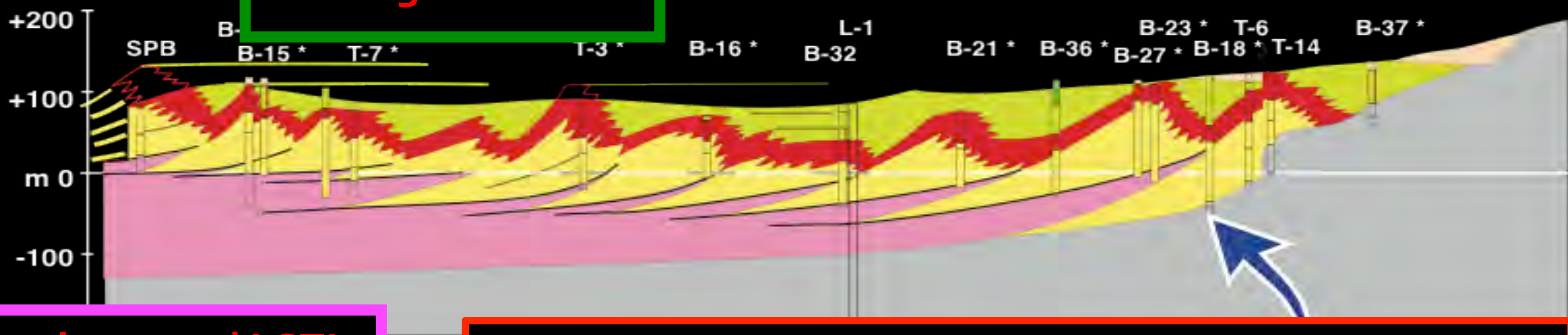
progradation with downward shift during fall.

Tortonian-Messinian Llucmajor Reef Complex, Mallorca, Spain

Oligophotic rhodalgal factory



shingled TST's



amalgamated LST's

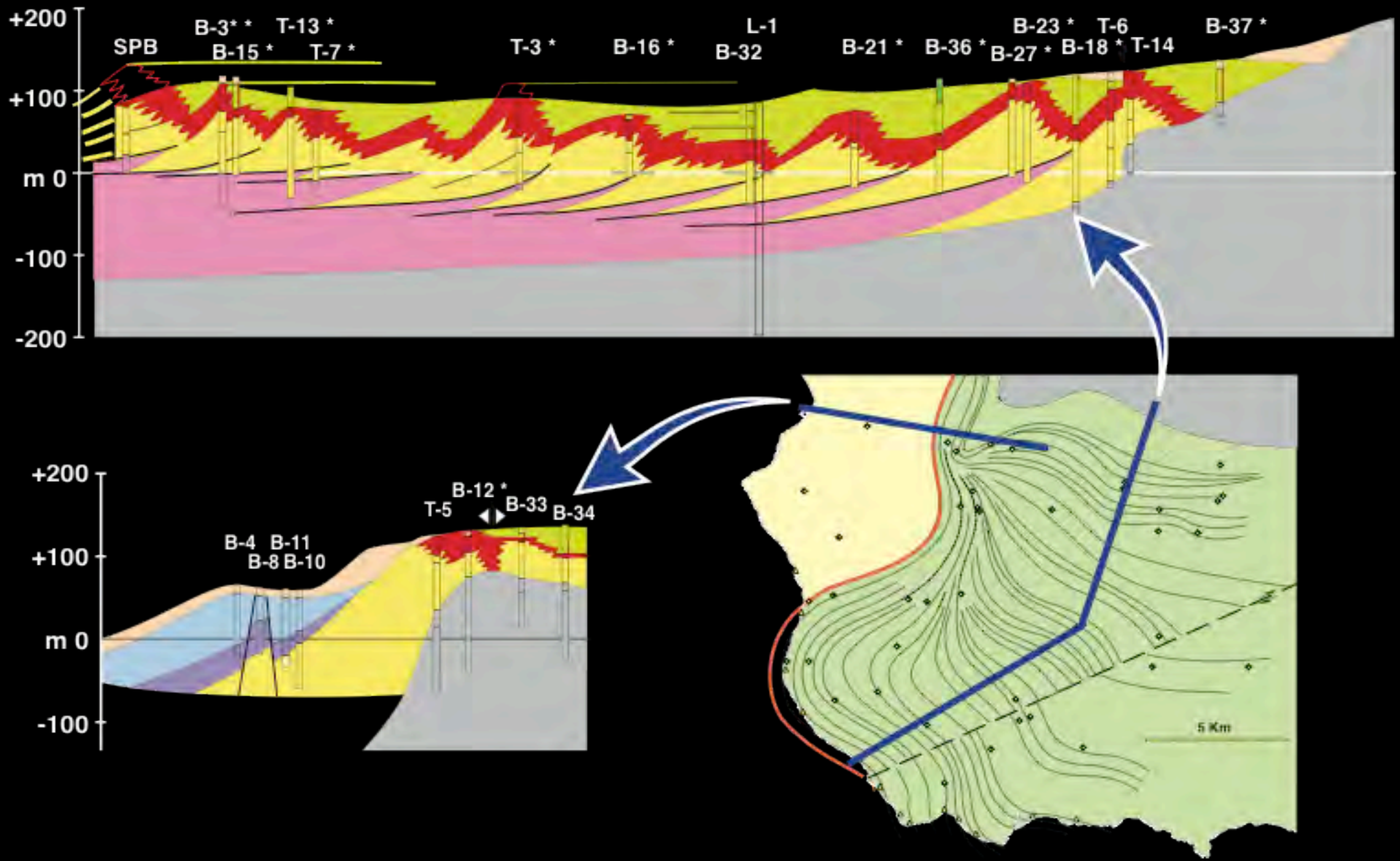
two carbonate factories: euphotic and oligophotic

Tortonian-Messinian Llucmajor Reef Complex, Mallorca, Spain

lessons learned

the control by inherited substrate

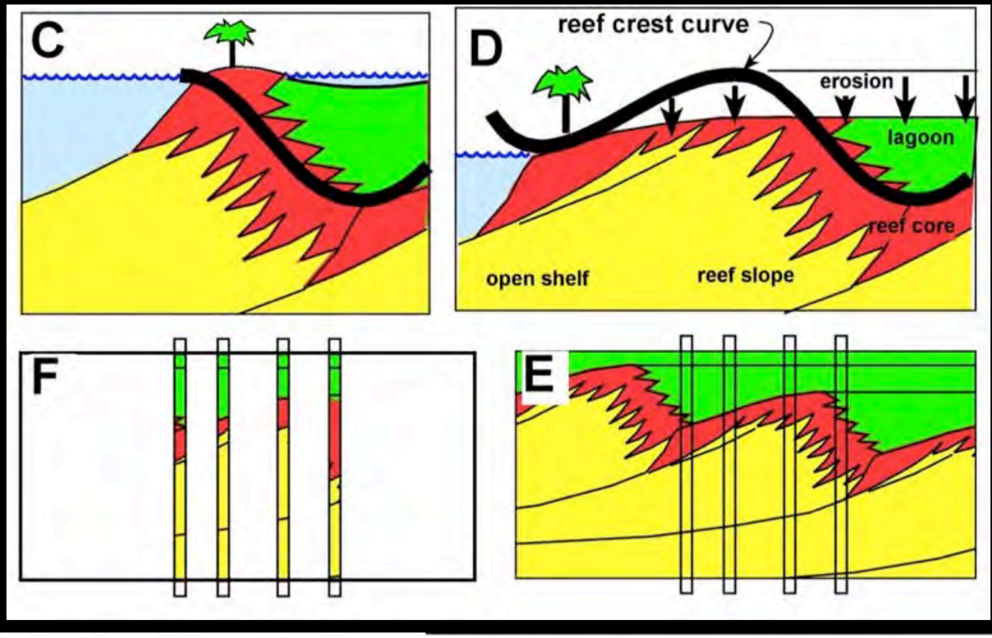
size and efficiency of the carbonate factories



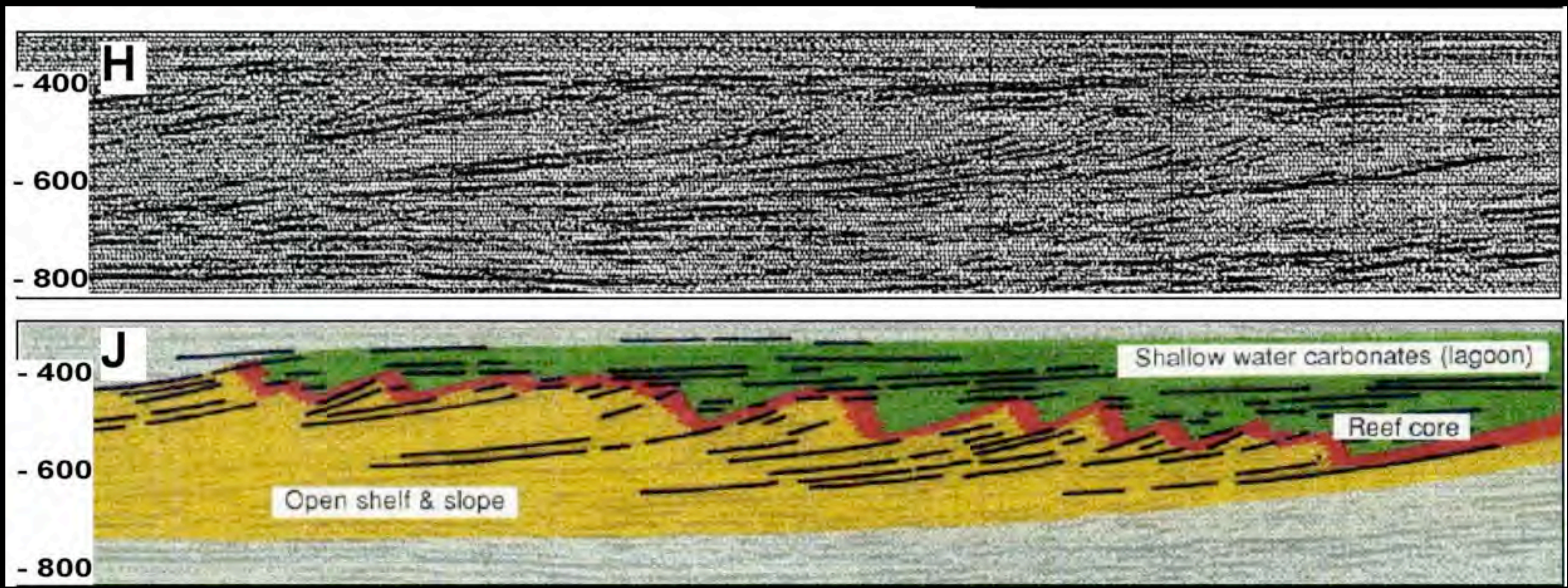
Tortonian-Messinian Llucmajor Reef Complex, Mallorca, Spain

lessons learned

but the conceptual model:
process-based analysis provides the key to predict the architecture

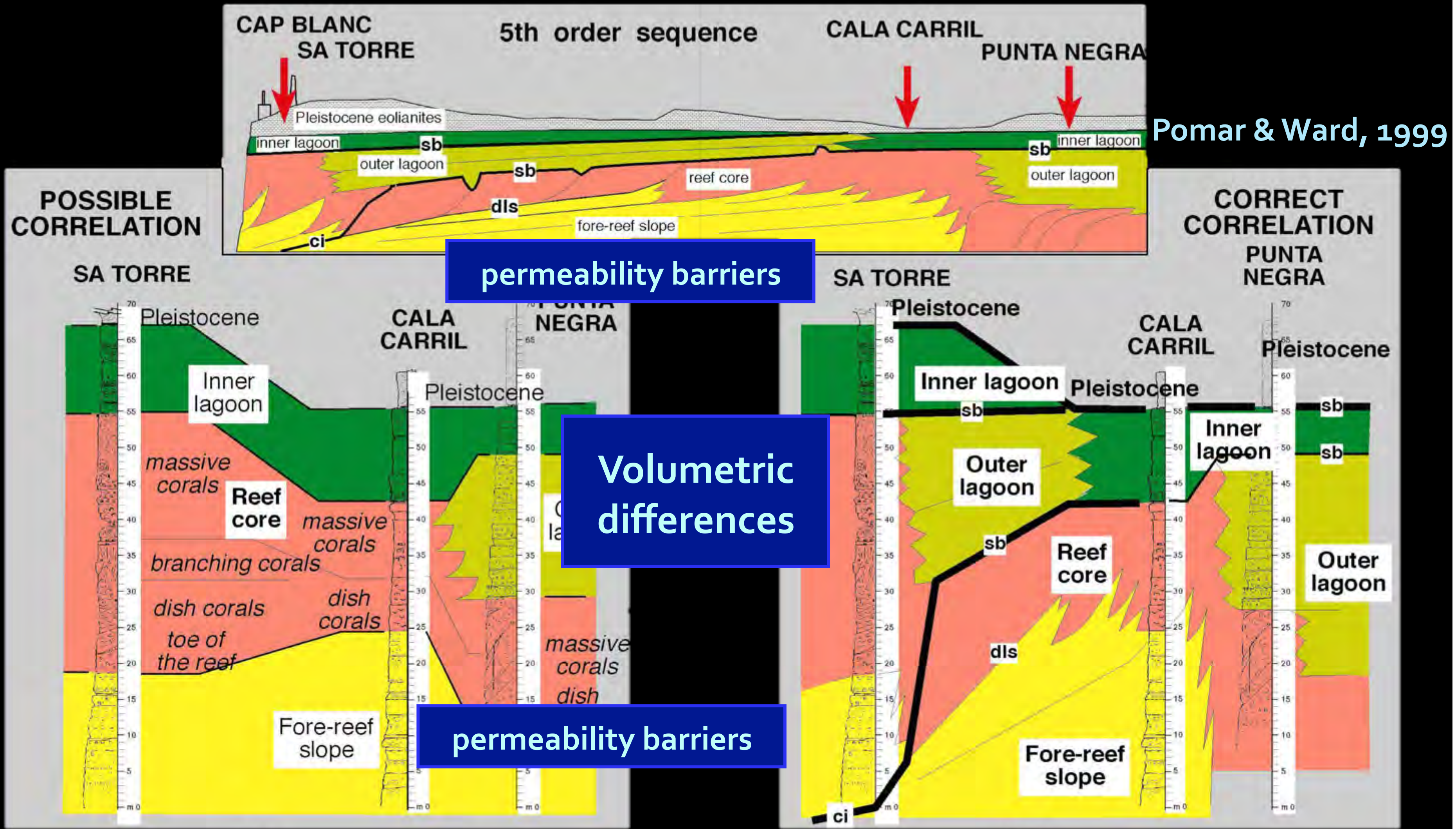


and to improve interpretation of subsurface data

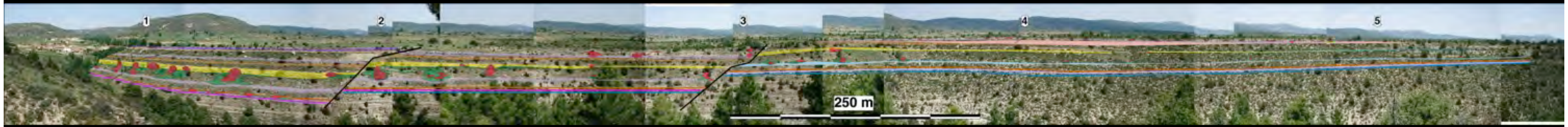


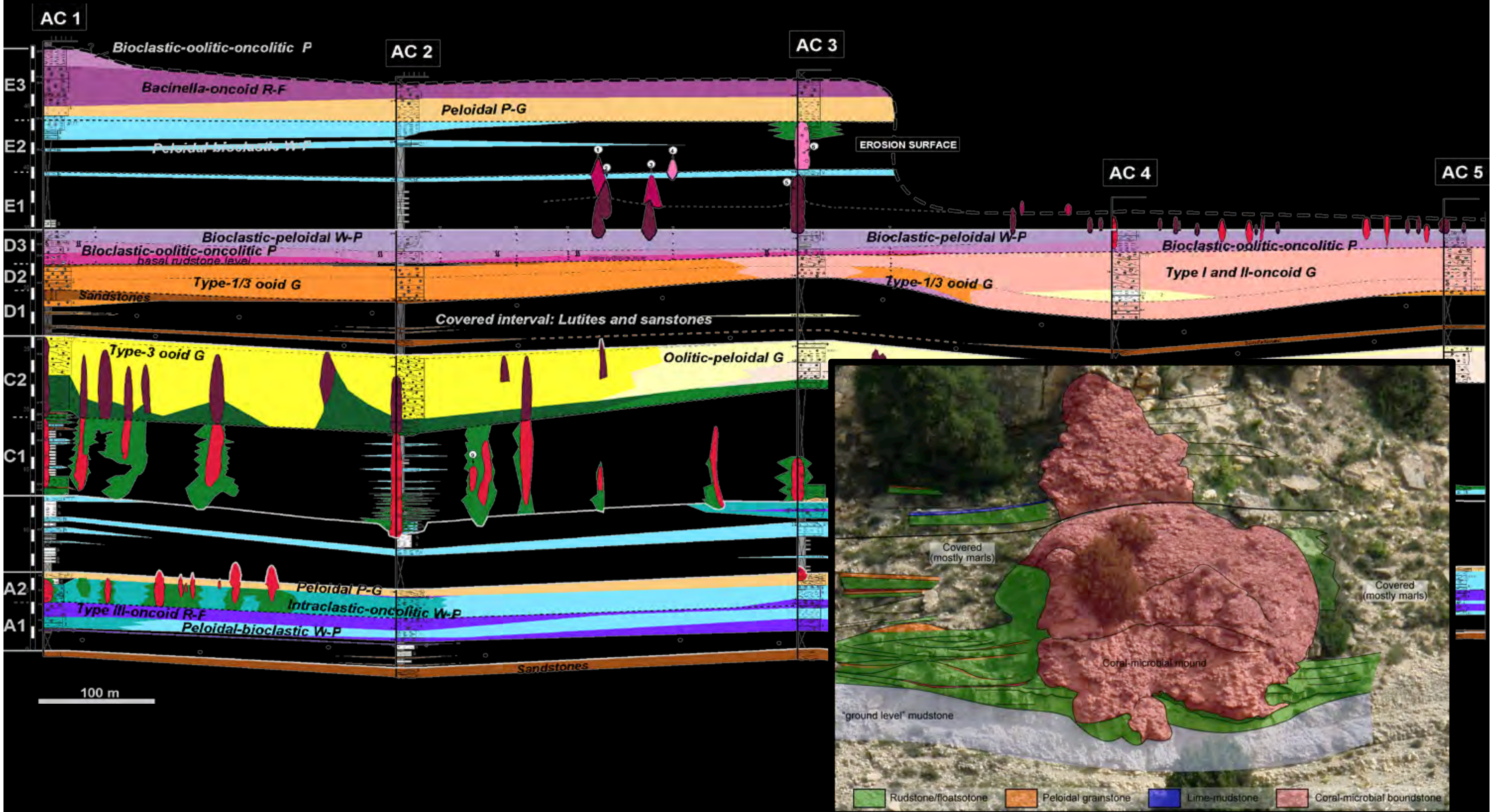
lessons learned

cores and well-logs provide a limited
perception of the volumetric heterogeneities



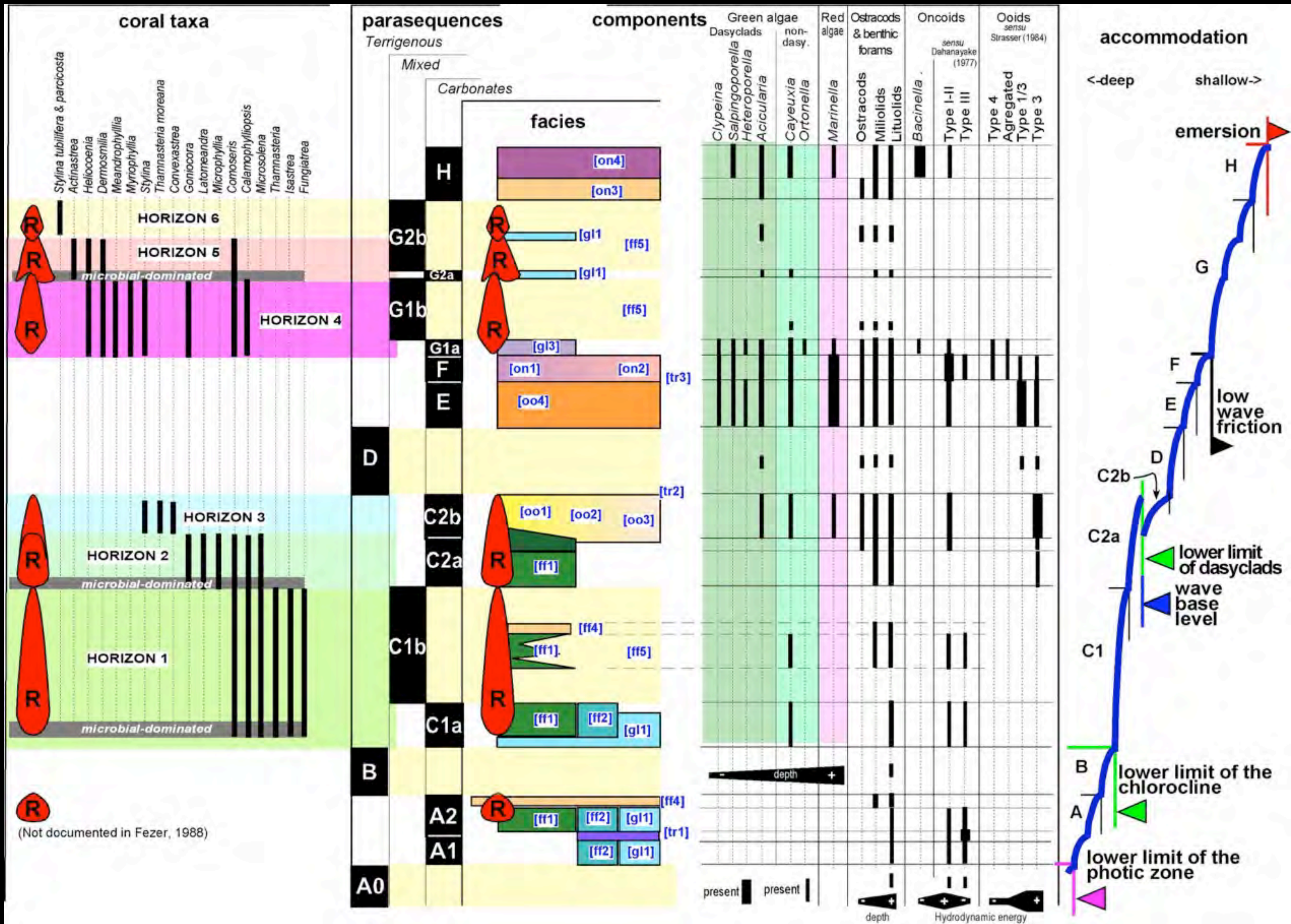
Upper Jurassic, Arroyo Cerezo, Iberian Range, Spain





Alnazghah et al. (2012)

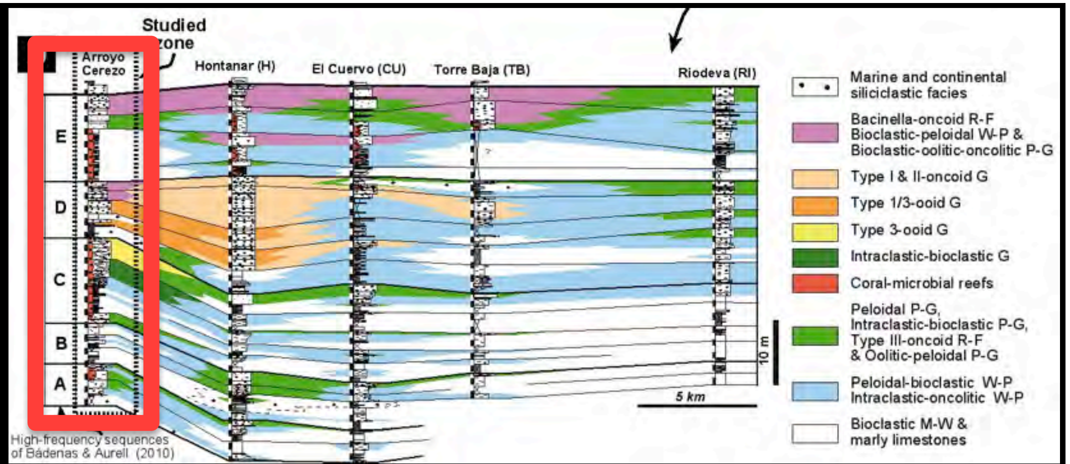
Upper Jurassic, Arroyo Cerezo, Iberian Range, Spain

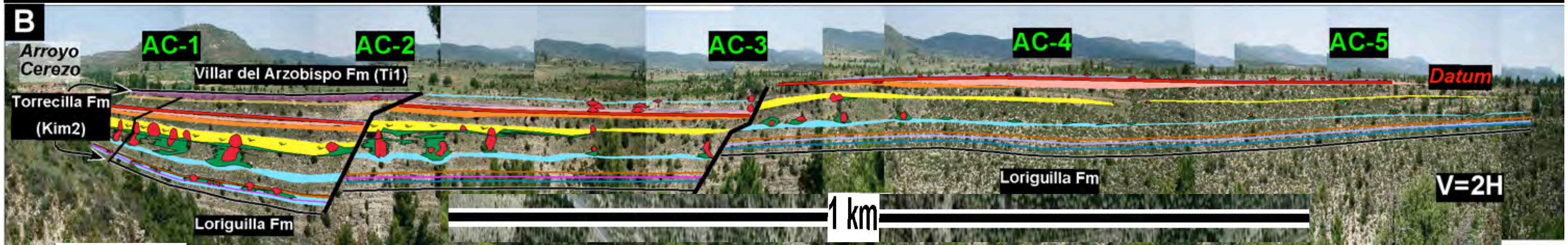


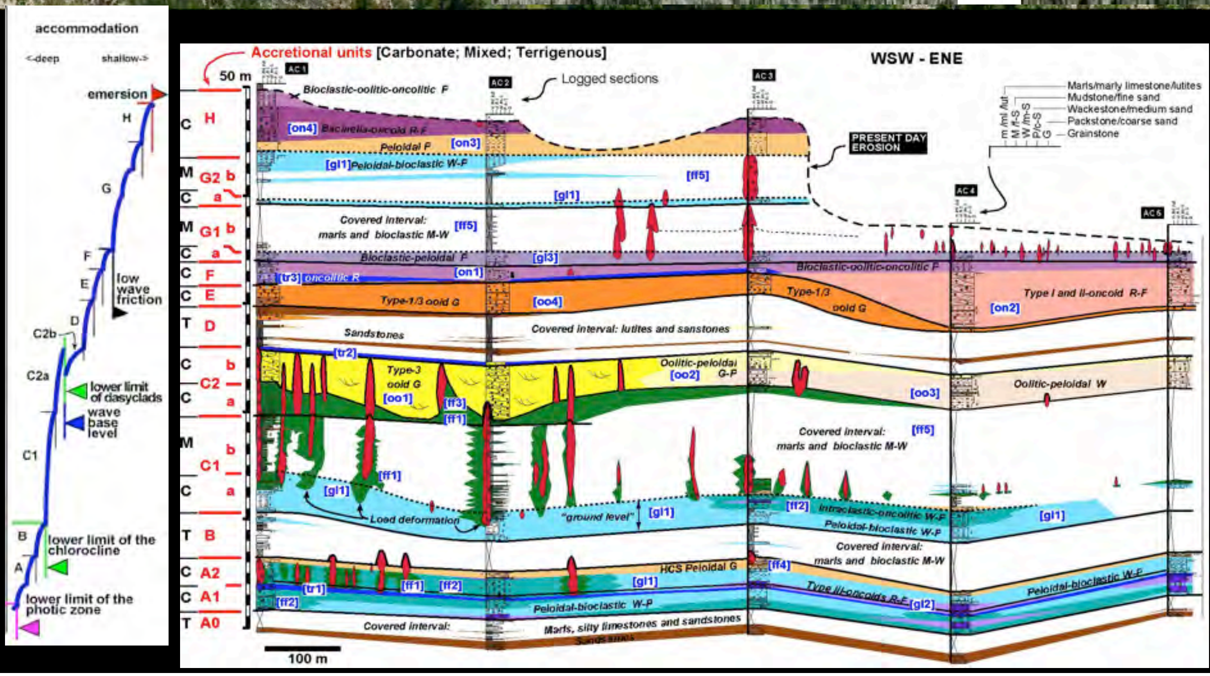
Alnazghah et al. (2012)

lessons learned

addresses critical questions about inter-well scale heterogeneity and correlation patterns for low-angle ramp systems







lessons learned

Arroyo Cerezo ramp, Kimmeridgian, Iberian Range (Alnazghah et al., 2013)

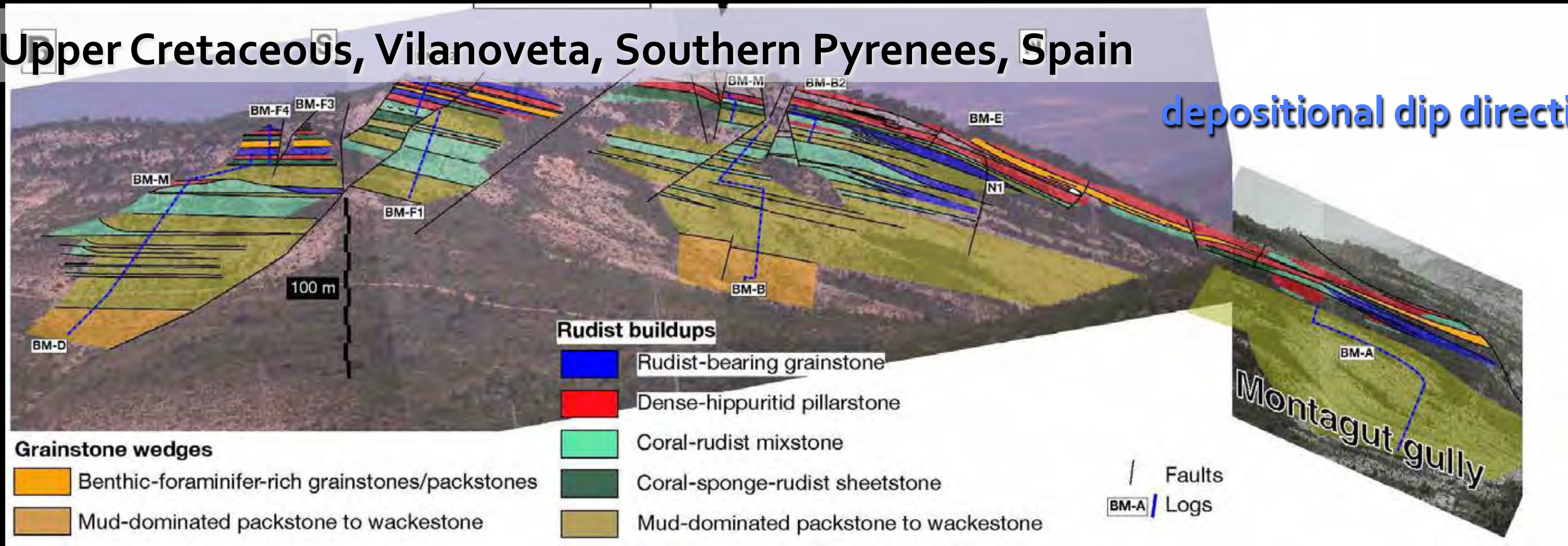
bed geometries or types of bounding surfaces are not helpful,

but the distribution of components and textures within the different accretional units proved to be the best approach.

two types of carbonate ramps:

- buildup-dominated systems (with no coated grains)
  - microbialites,
  - stromatoporoids
  - corals
  - sponges
- coated-grain dominated systems, (with no mounds)
- and both, in turn, alternating with siliciclastic sediments

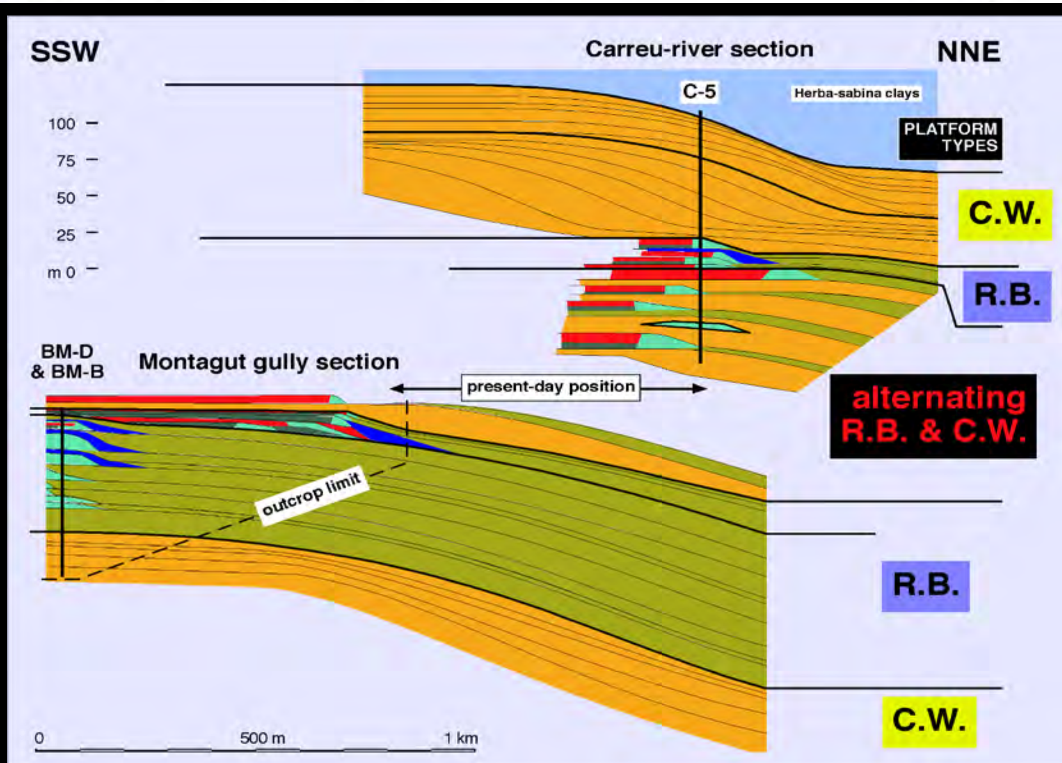
Upper Cretaceous, Vilanoveta, Southern Pyrenees, Spain



two alternating production modes:

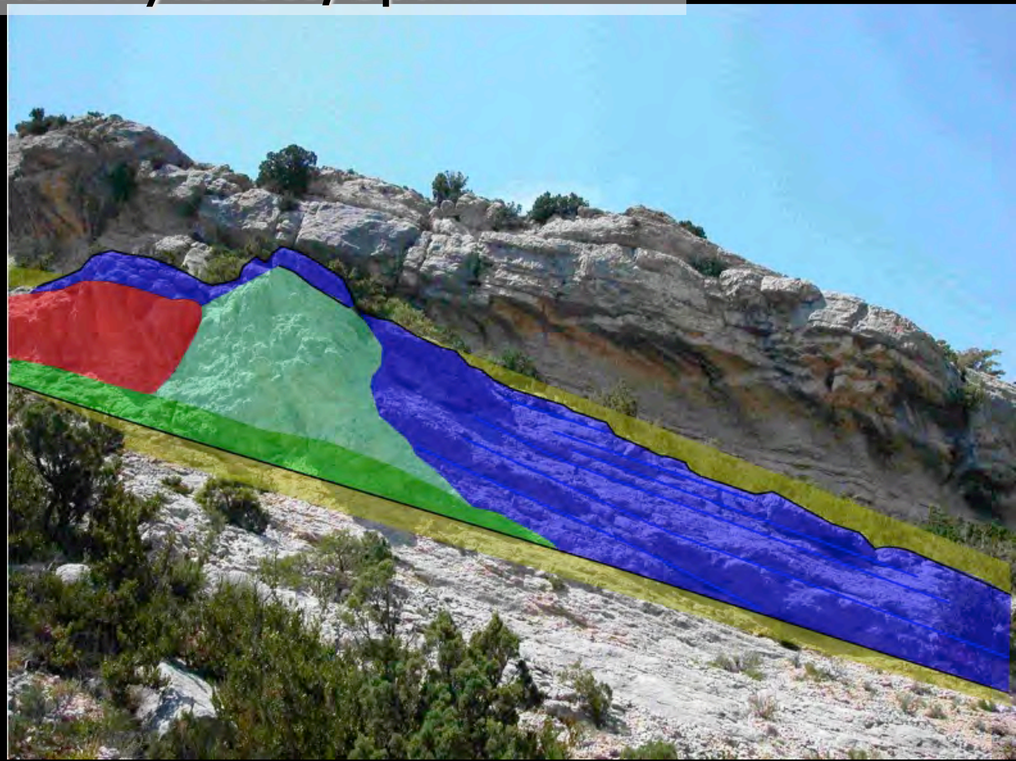
- rudist buildups
- calcarenite wedges

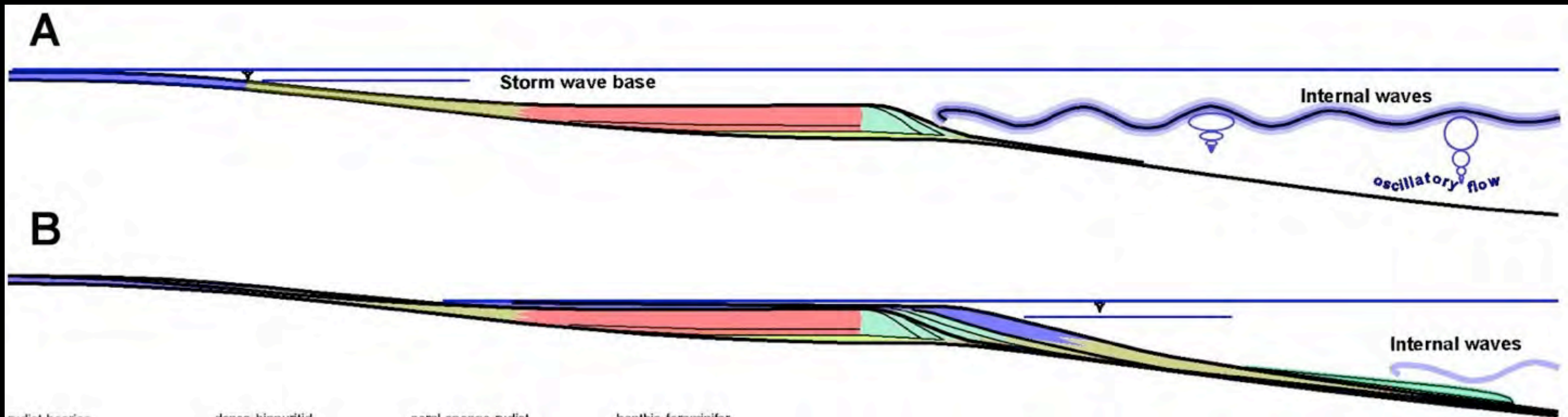
driven by external factors independent of sea level changes



Pomar et al., 2005

Upper Cretaceous, Vilanoveta, Southern Pyrenees, Spain





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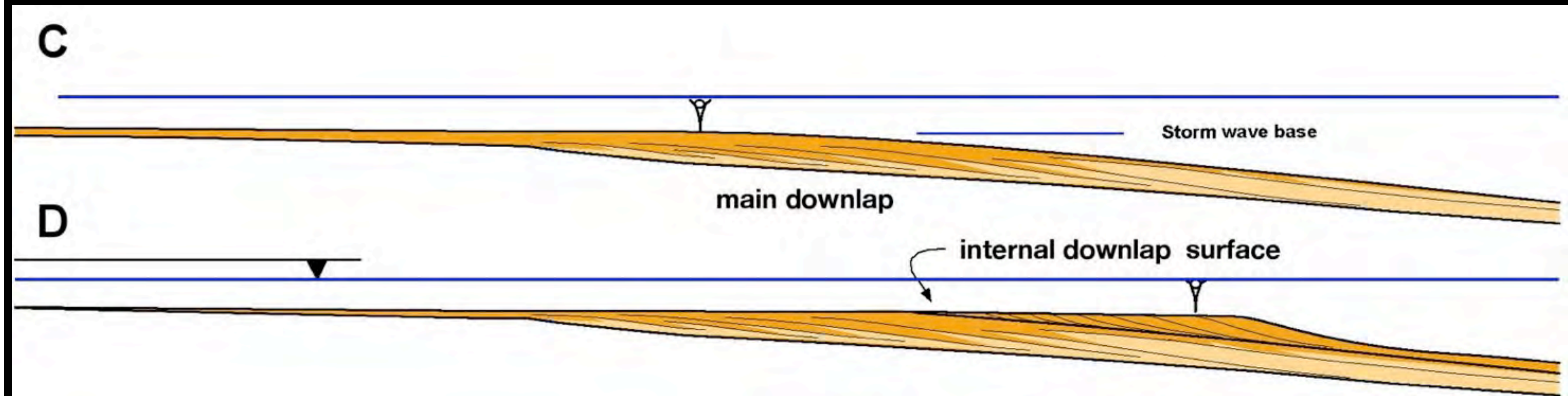
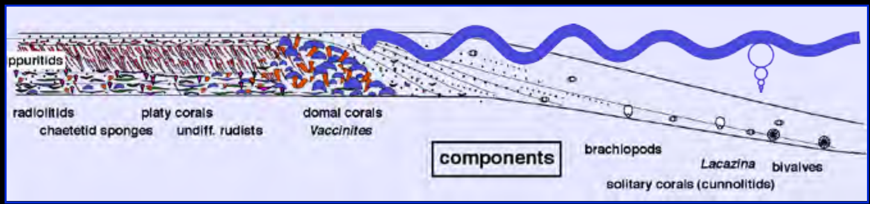


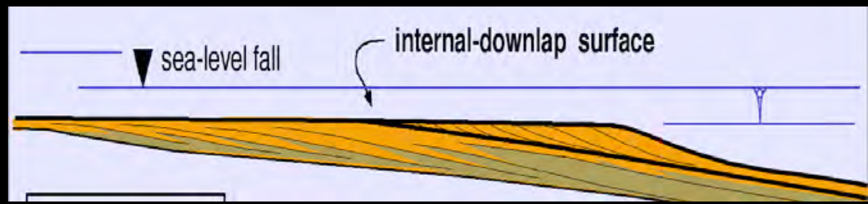
lessons learned from this example

bedding geometries alone cannot provide the solution for sequence interpretation, but components and textures within lithosomes

alternation of production modes suggests alternating periods with water stratification (rudist-coral buildups) and periods with weaker pycnocline

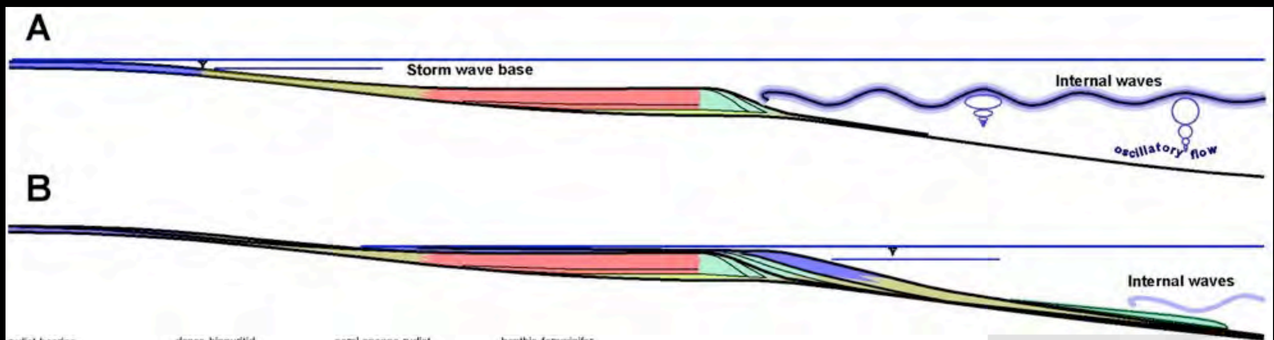


internal waves

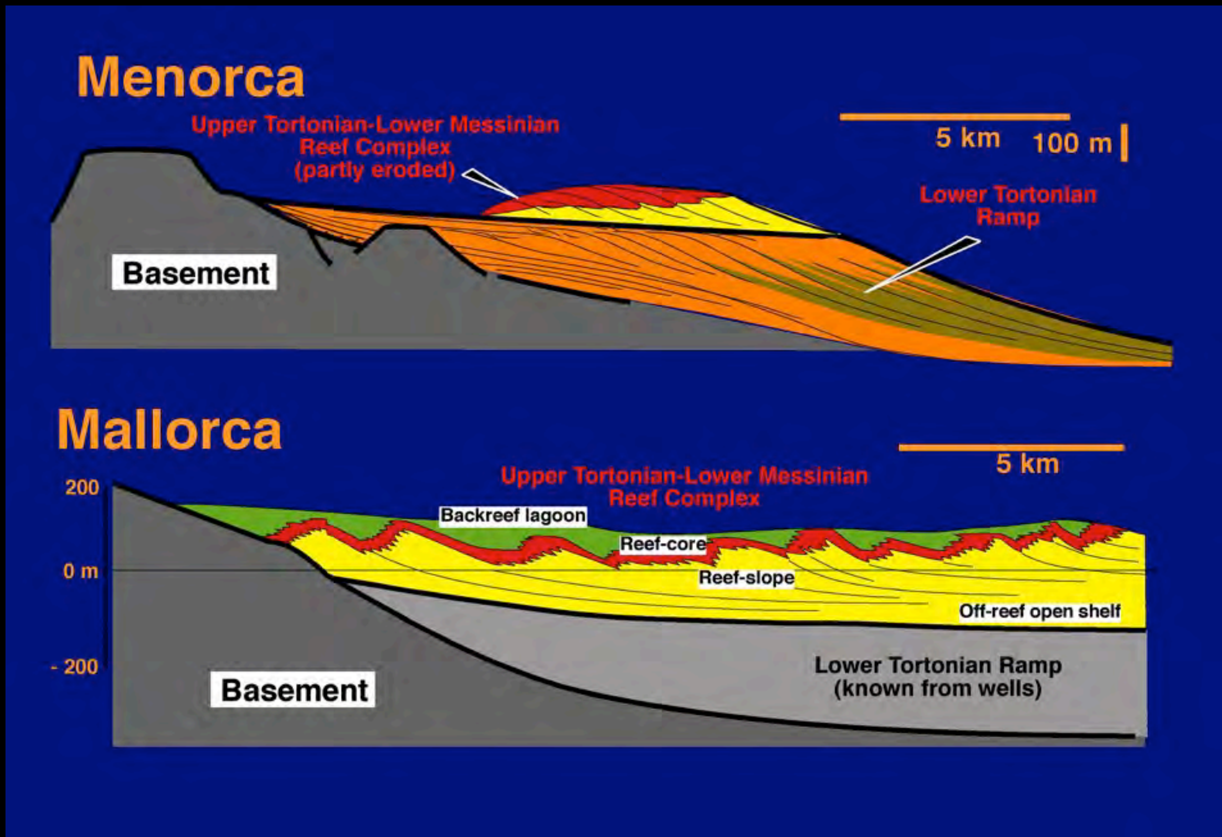


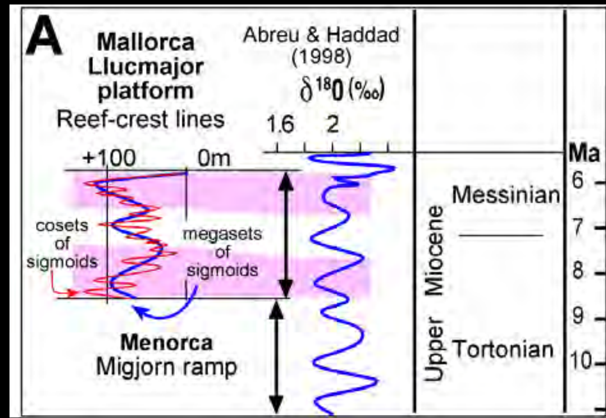
surface storms

Rudist buildups: the position of the forced-regression and lowstand grainstones units, onto the previous highstand, is related to the position of the factories and the occurrence of two base levels



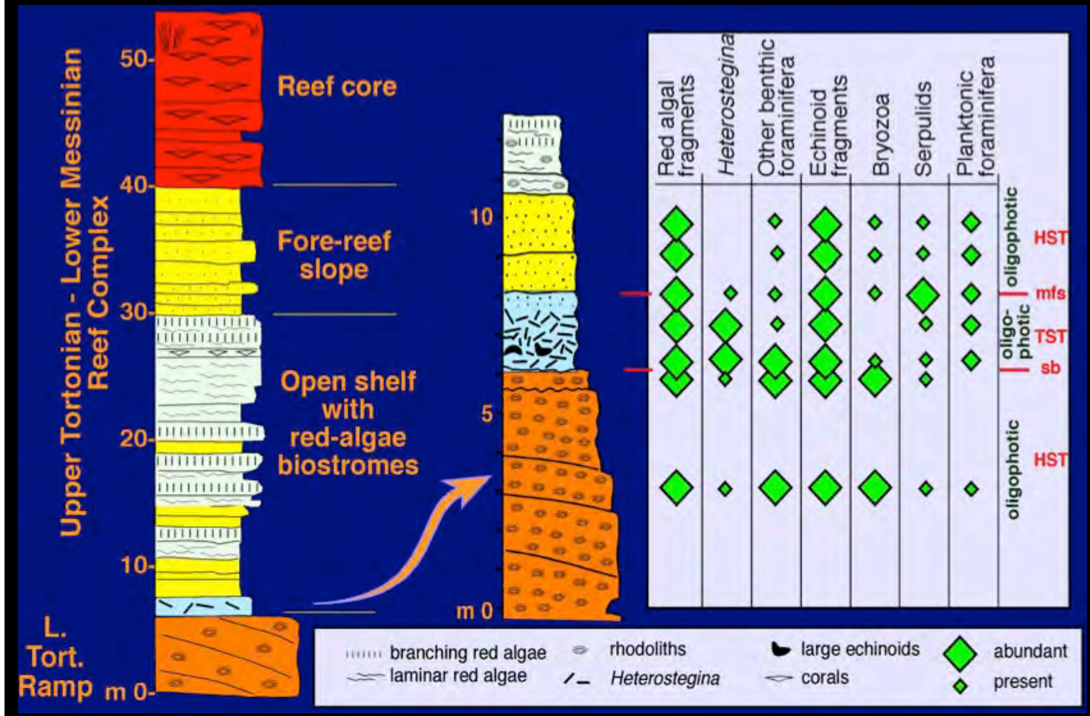
The raising sink: ecological accommodation



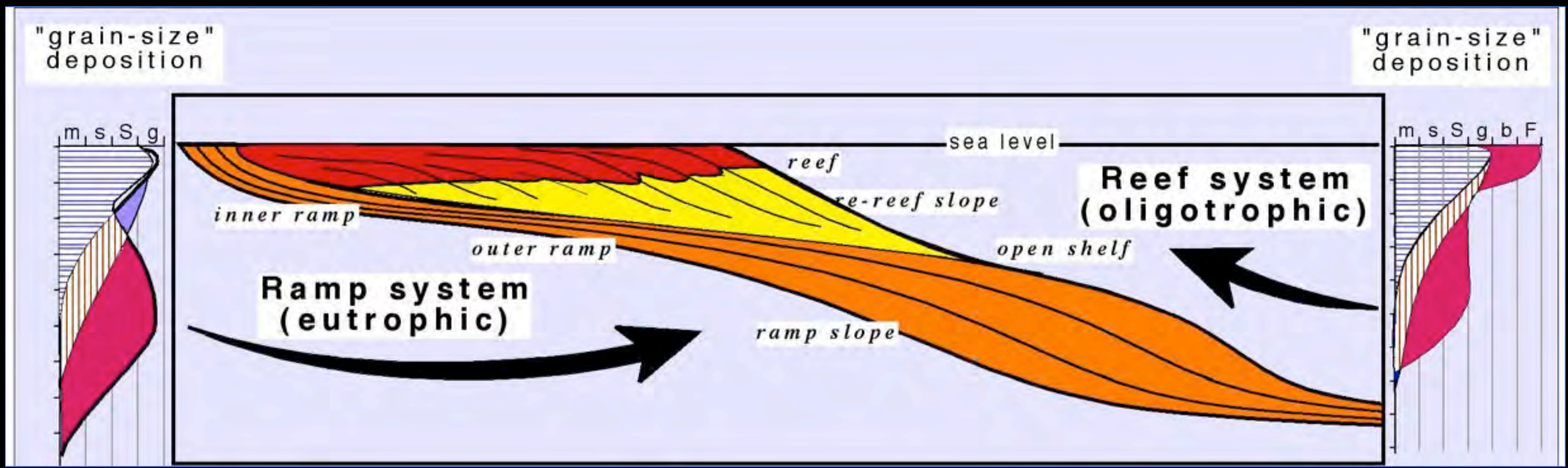


Pomar, 2001 b

The raising sink: ecological accommodation



Pomar, 2001 b



lessons learned from this example

- the increase in effective accommodation space resulted from an ecological change rather than significant relative sea-level rise
- The change of biota, determined a change of base level for sediment to accumulate,
    - RAMP: loose-grains production (base level = wavebase level)
    - REEF: framework production (base level = sea level)

Base level for sediment accumulation (accommodation) depends on both:

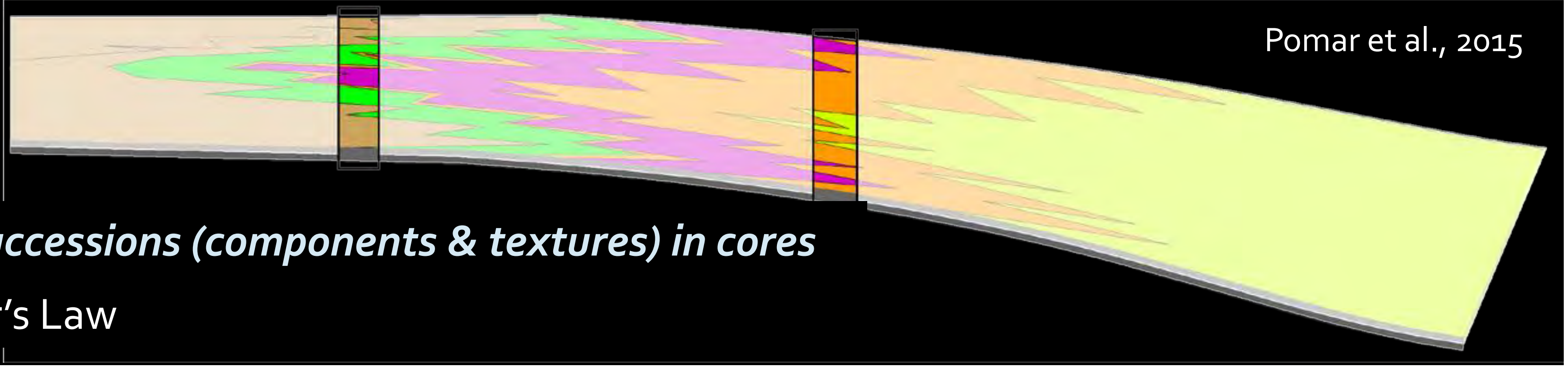
physical accommodation (hydrodynamic conditions at accumulation loci)

ecological accommodation (buildup competence):

type and amount of sediment being produced,
production loci and
processes controlling sediment dispersal

Oligo-Miocene, Perla Field, Offshore Venezuela

applicability: a sub-surface example



Pomar et al., 2015

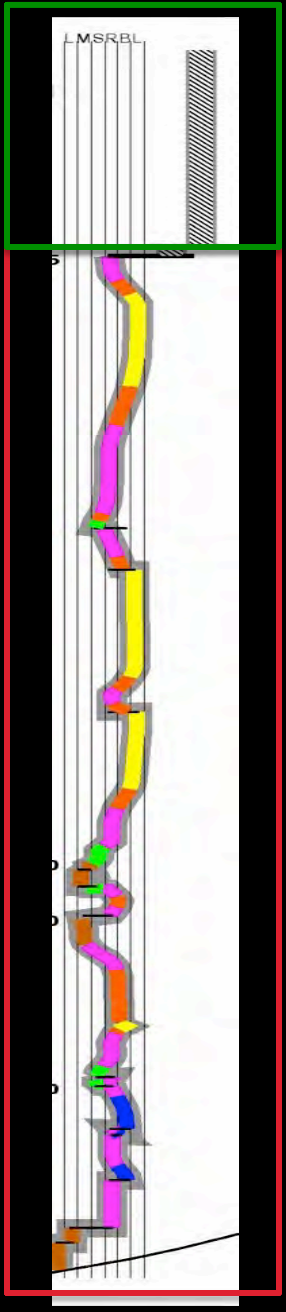
facies successions (components & textures) in cores

& Walter's Law

Oligo-Miocene, Perla Field, Offshore Venezuela

2 types of facies succession

P4



upper interval, Type 2

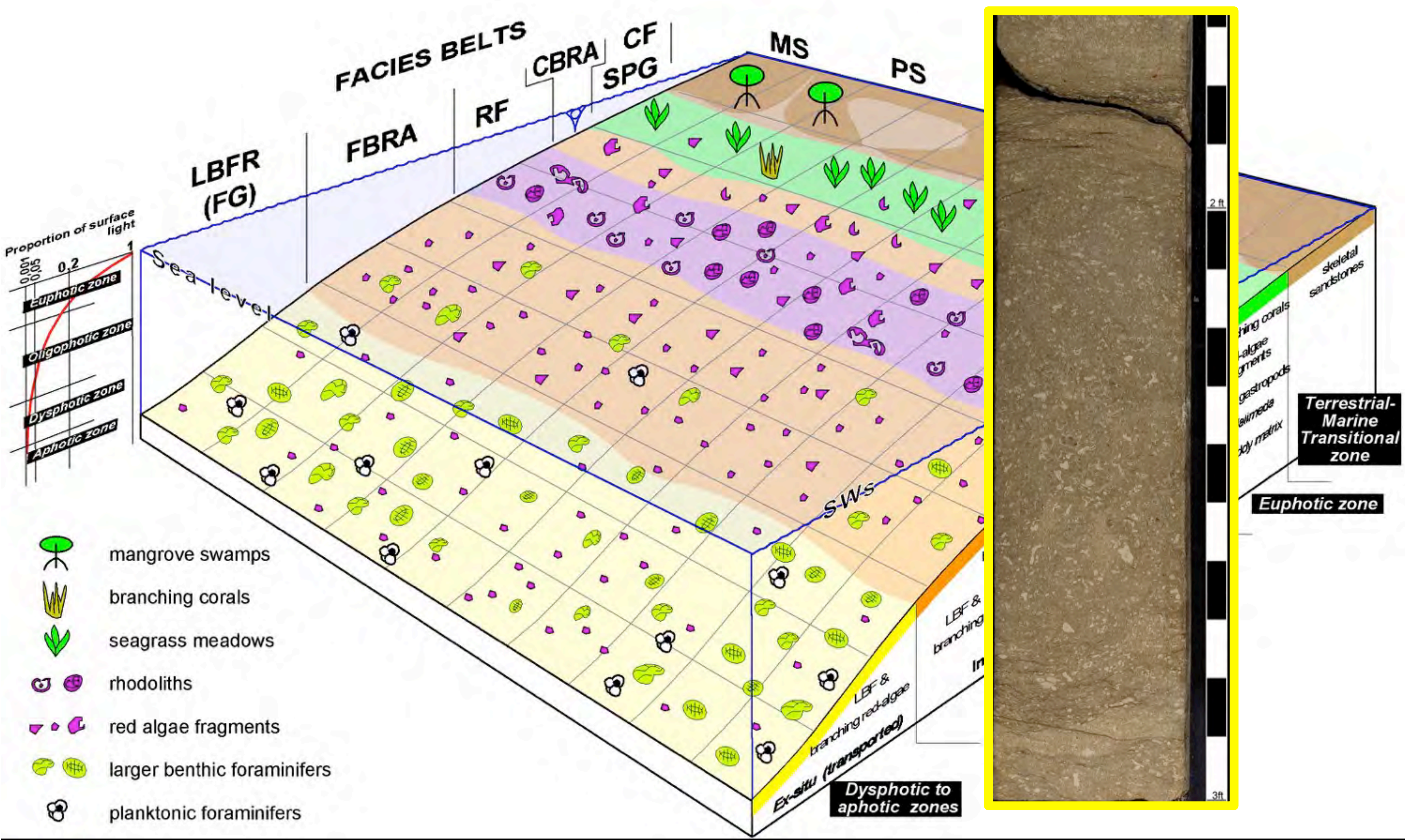
- rhodolithic rudstone in thick layers predominant
- commonly in fining-upward sets
- abundant planktonic foraminifers and nannofossils
- abundant gray-black skeletal grainstone commonly associated to pyrite, phosphate, and glauconite
- dark-gray marls and shales interbedded

lower interval, Type 1

- volumetrically the most important
- repeated order in the appearance of facies
- bounded by erosional surfaces, commonly associated with terrigenous (above and/or below)

Pomar et al., 2015

Oligo-Miocene, Perla Field, Offshore Venezuela



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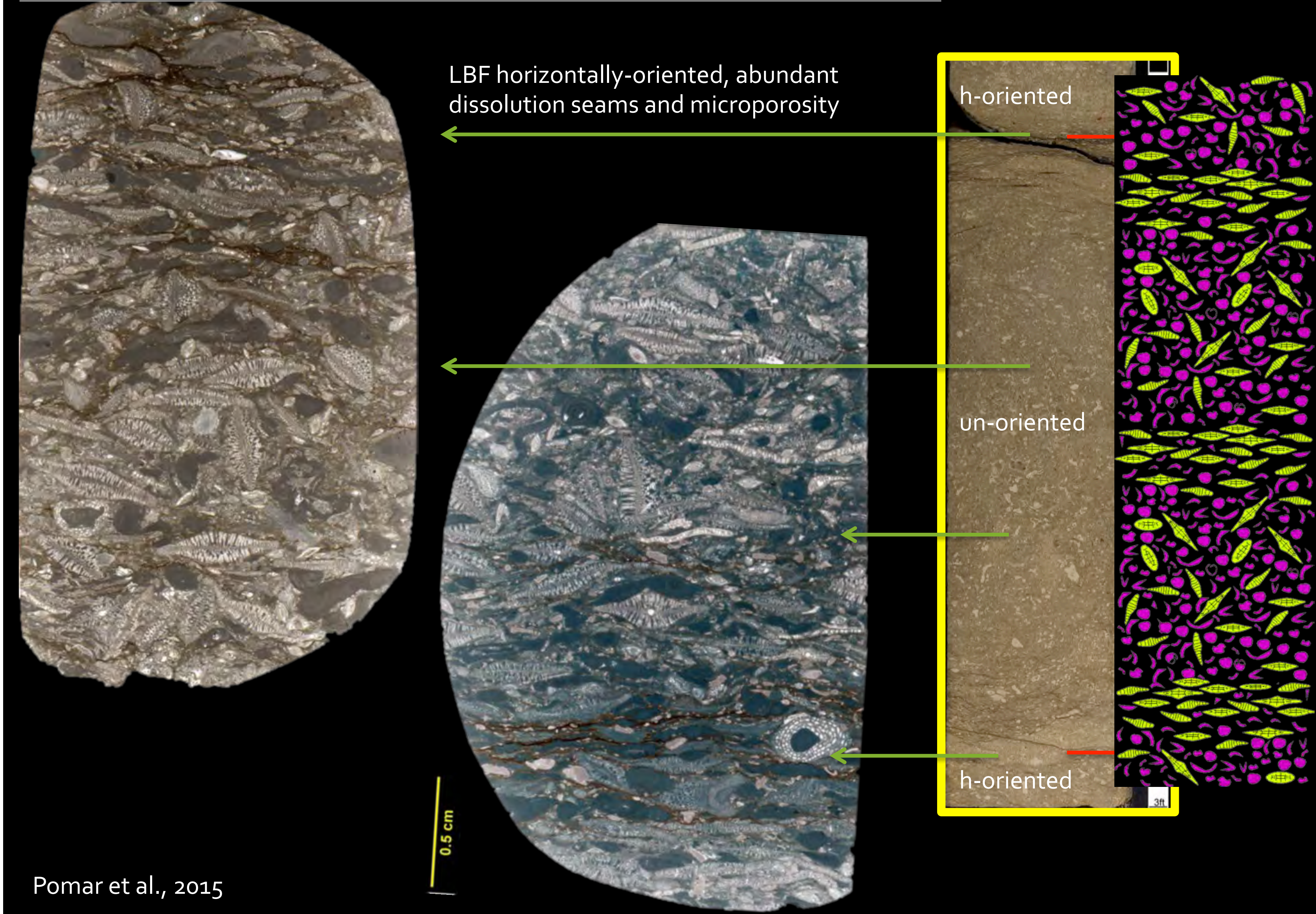

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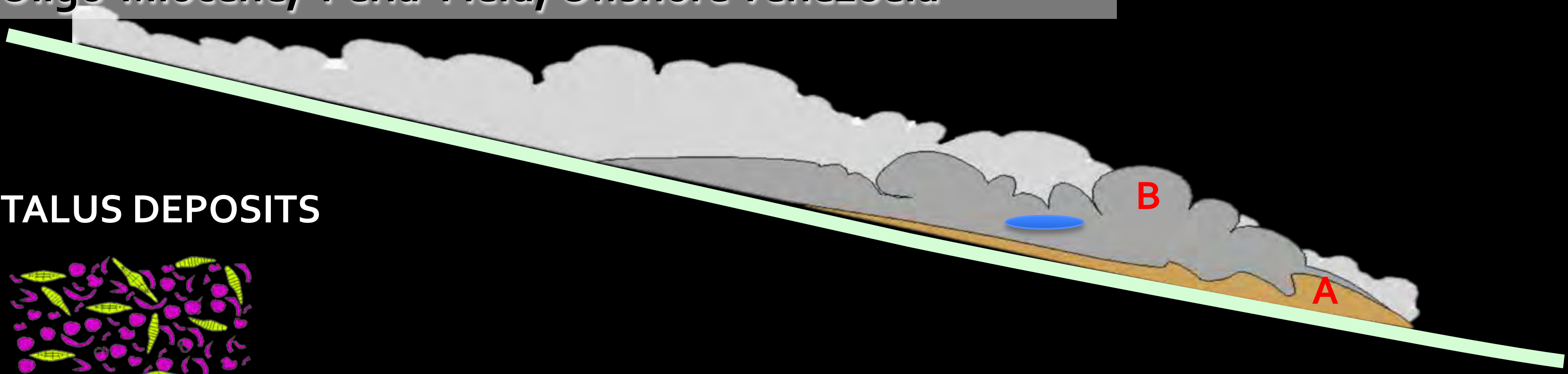


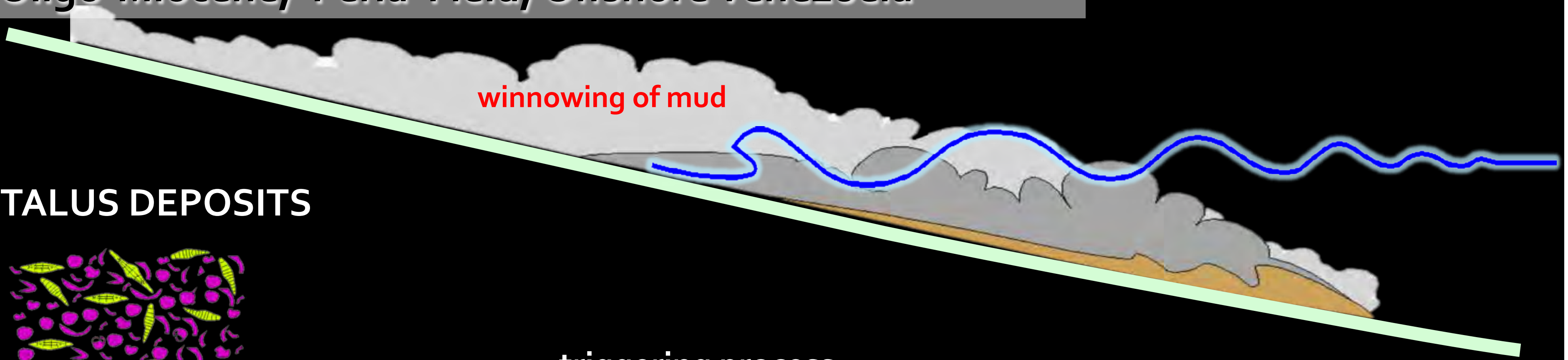
TALUS DEPOSITS

B — LBF predominantly horizontal
last settling of flat, low-density test LBF

A — non-oriented red algae fragments and LBF
main density flow

Pomar et al., 2015

Oligo-Miocene, Perla Field, Offshore Venezuela



TALUS DEPOSITS

Pomar et al., 2015

triggering process

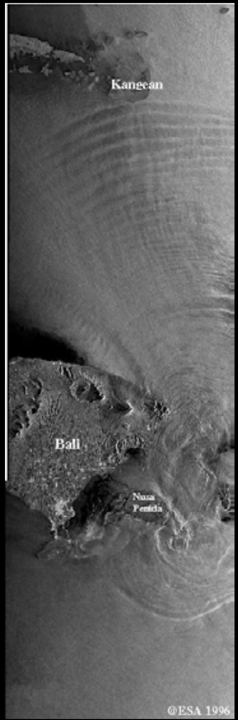
components reworking from the middle-outer ramp

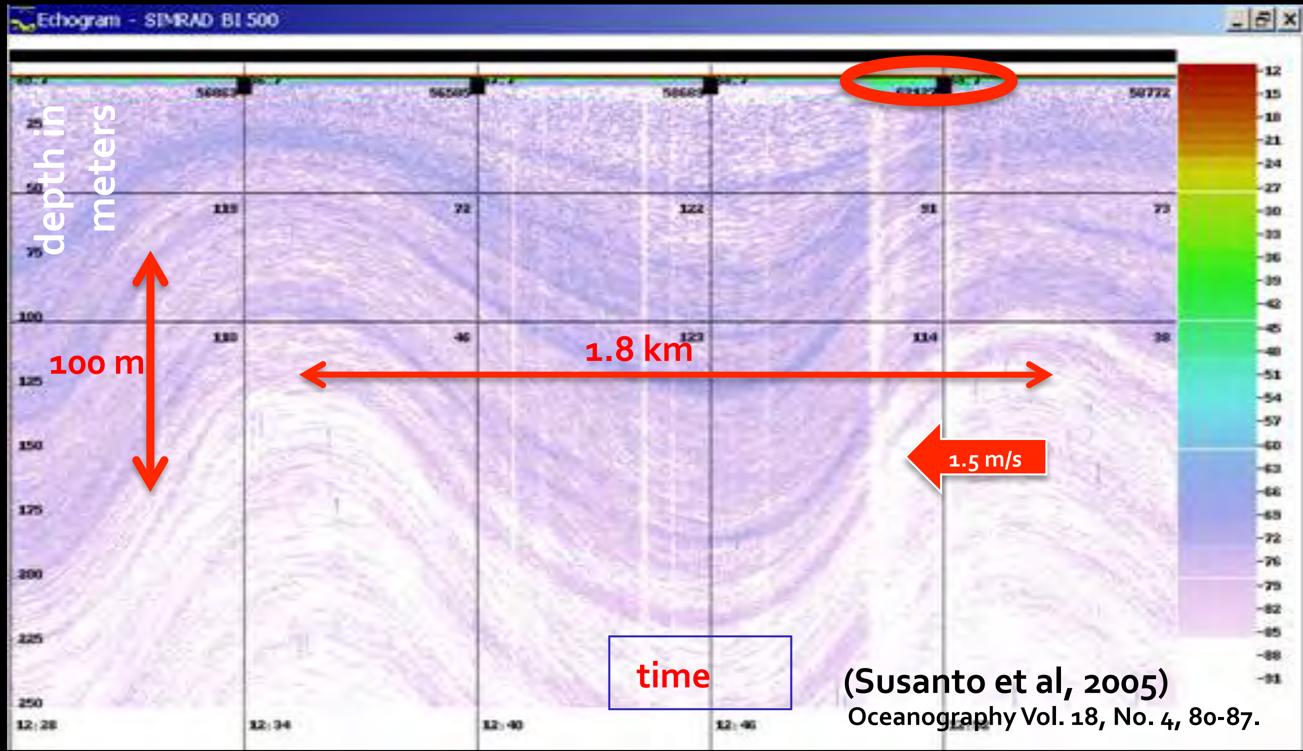
↓

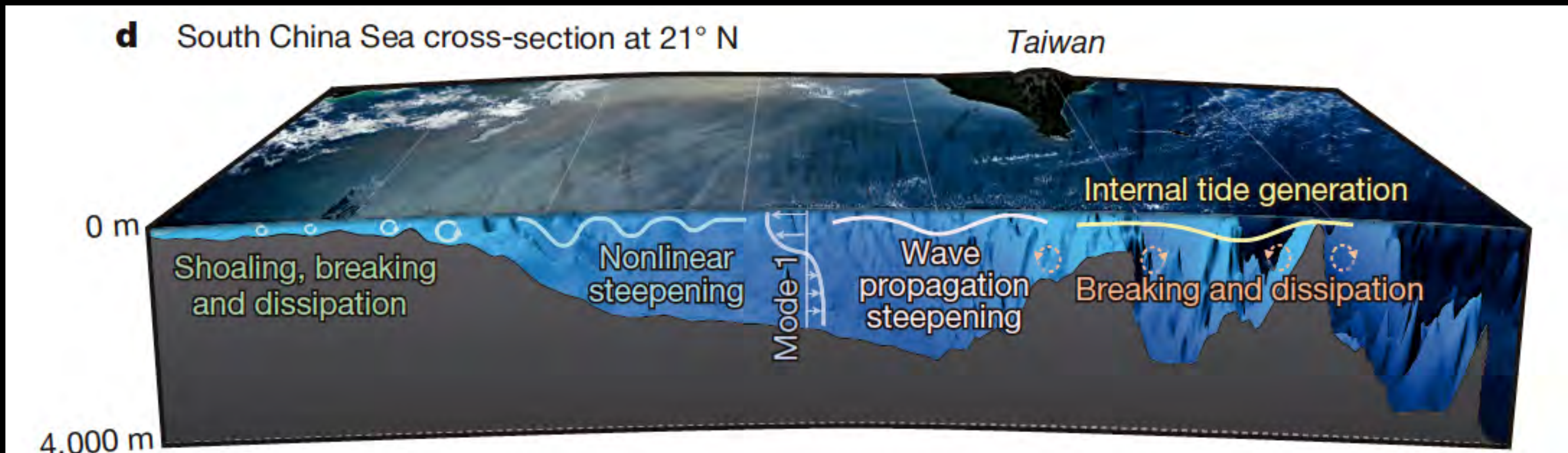
turbulence in the deep

↓

internal waves

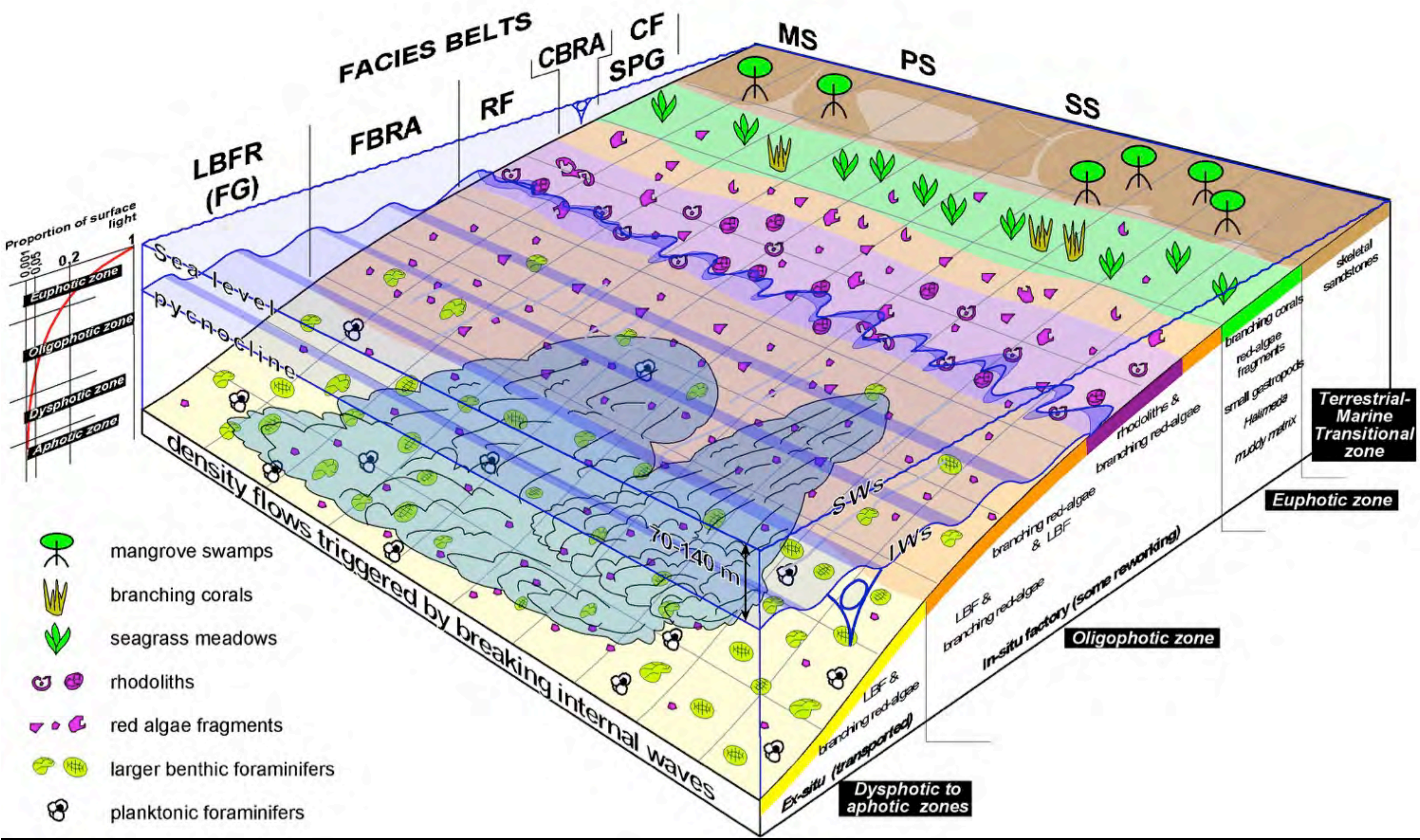




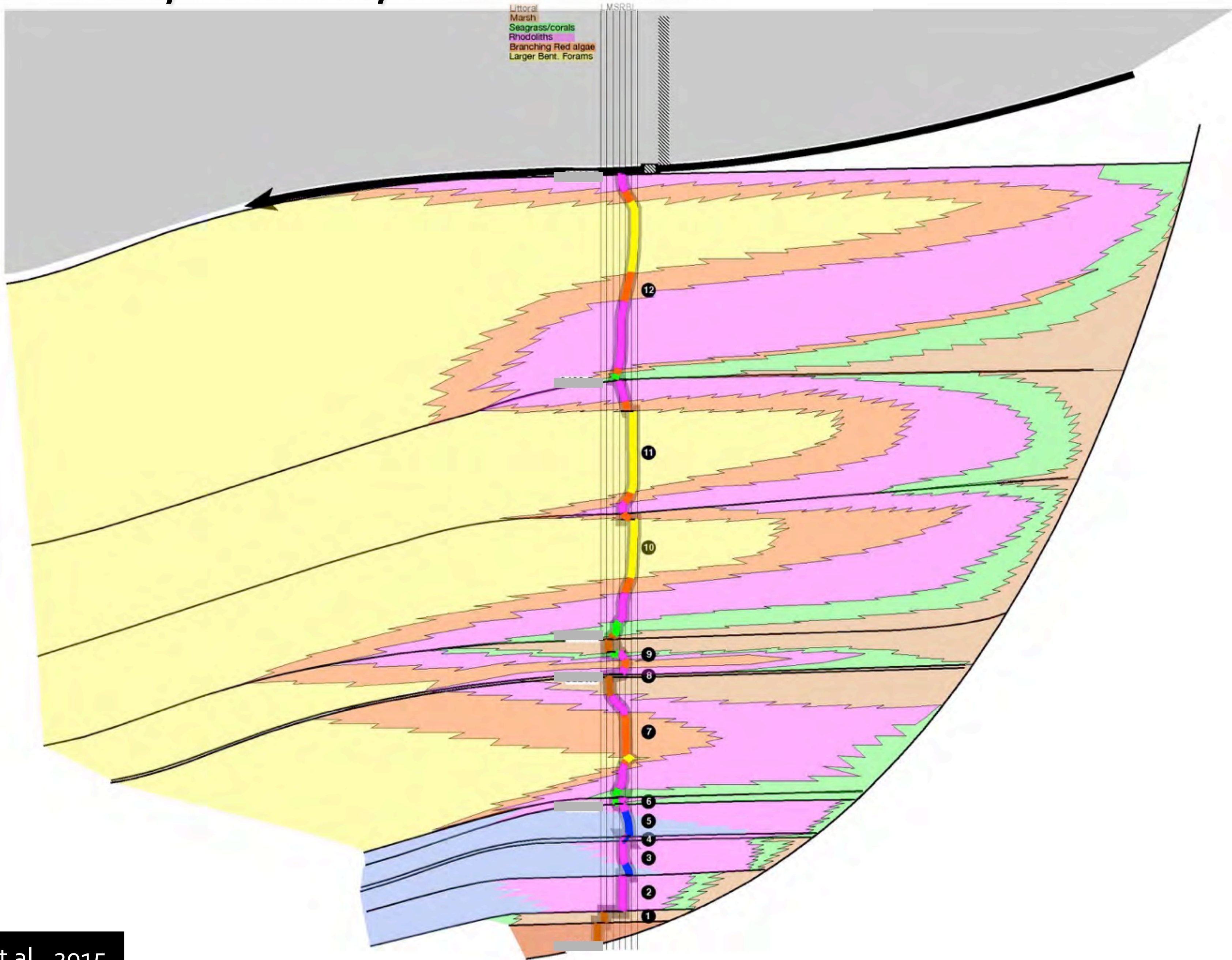


Alford et al., 2015: Nature, v. 521, p. 65-69.

Oligo-Miocene, Perla Field, Offshore Venezuela

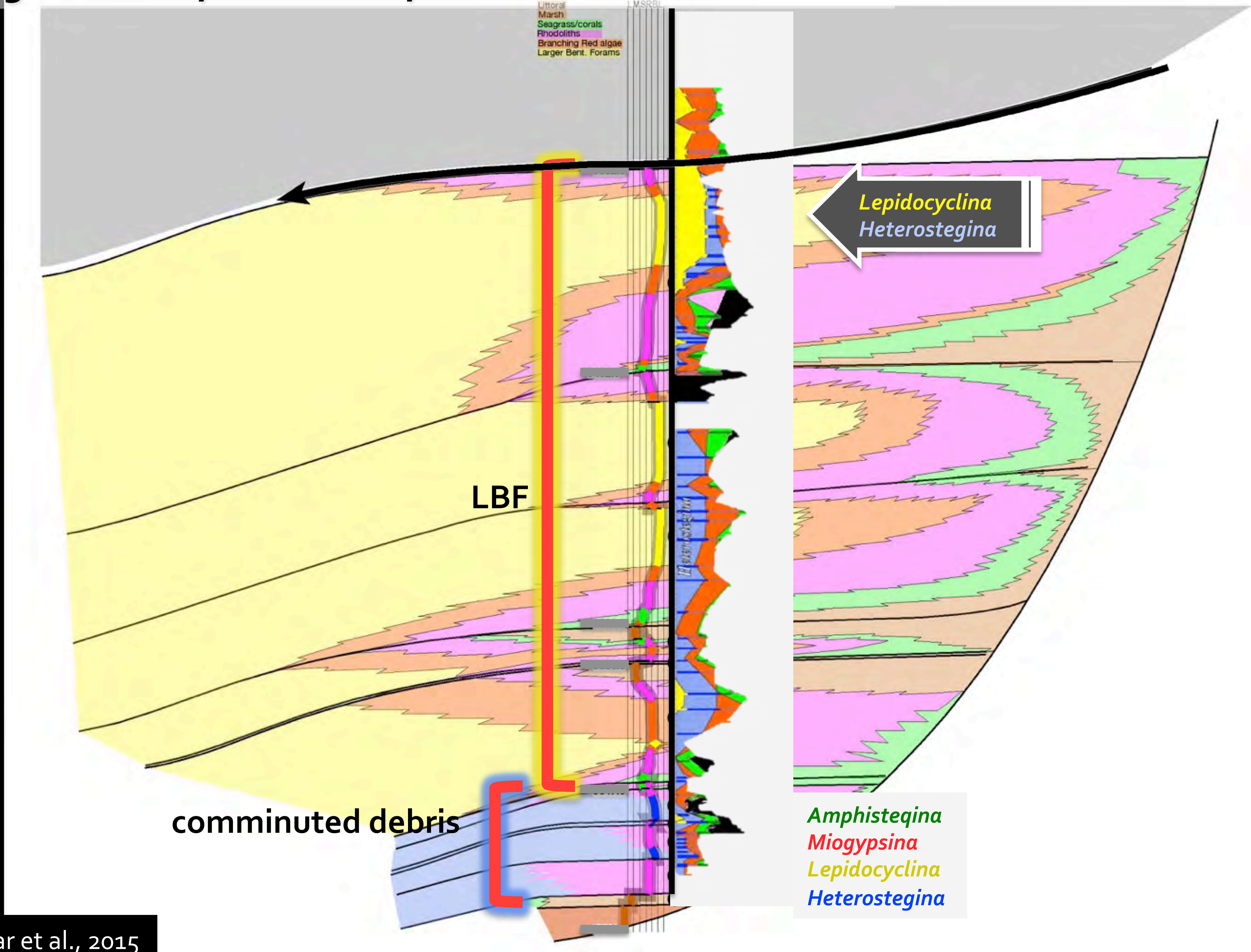


Oligo-Miocene, Perla Field, Offshore Venezuela



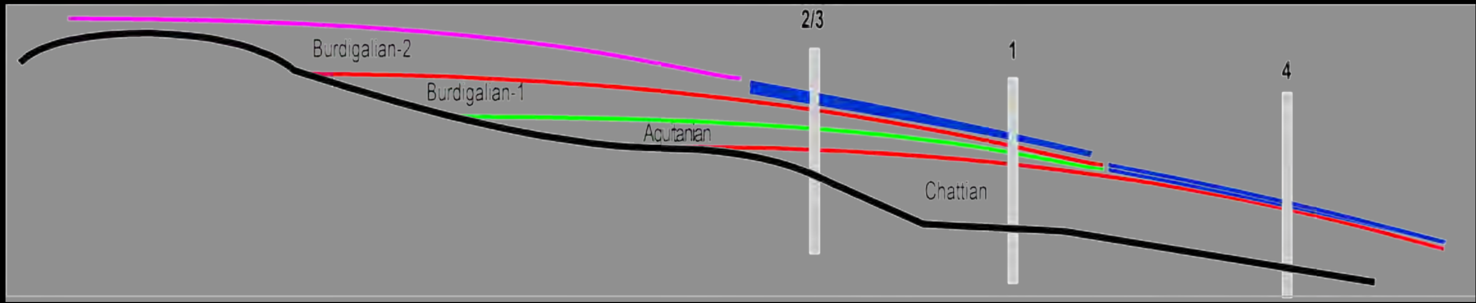
Pomar et al., 2015

Oligo-Miocene, Perla Field, Offshore Venezuela

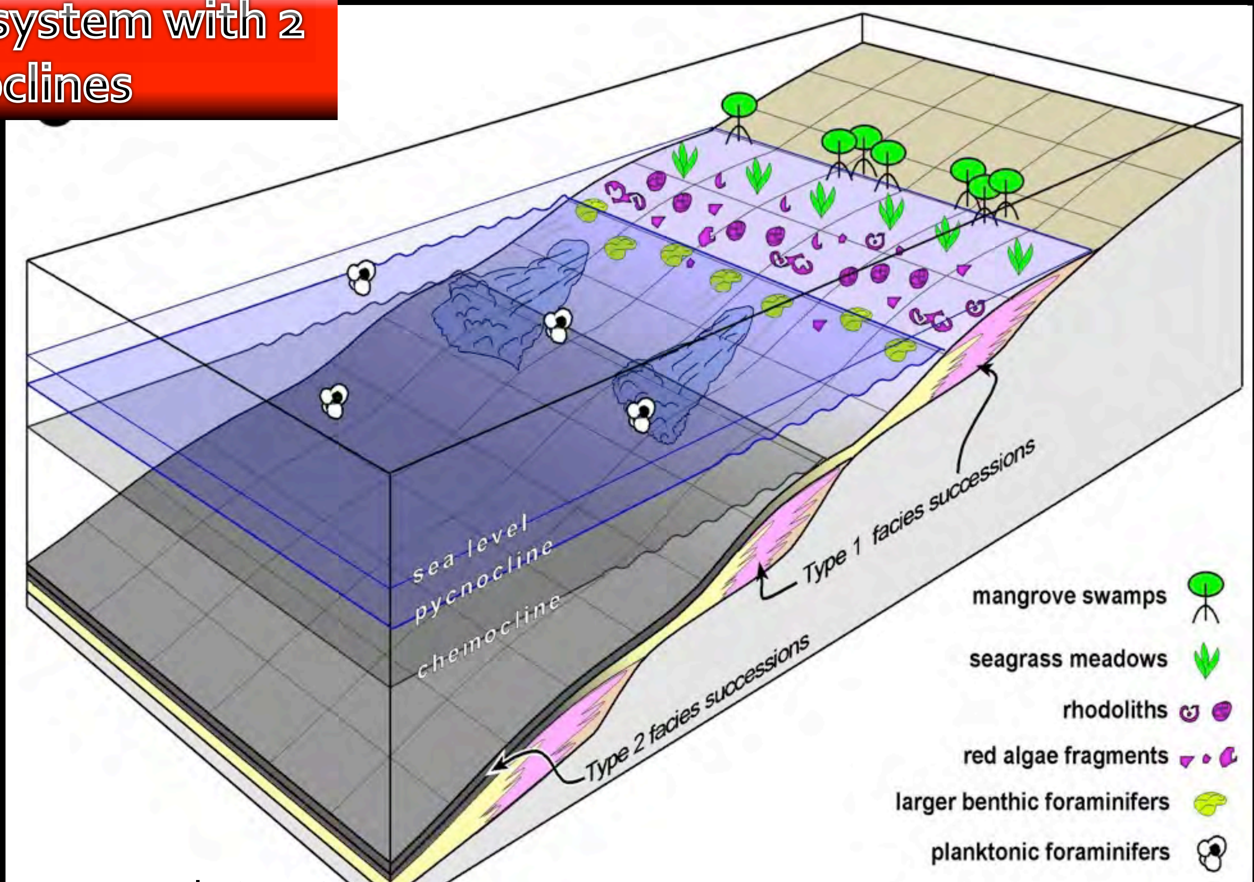


Pomar et al., 2015

Perla Field, offshore Venezuela; Oligo-Miocene

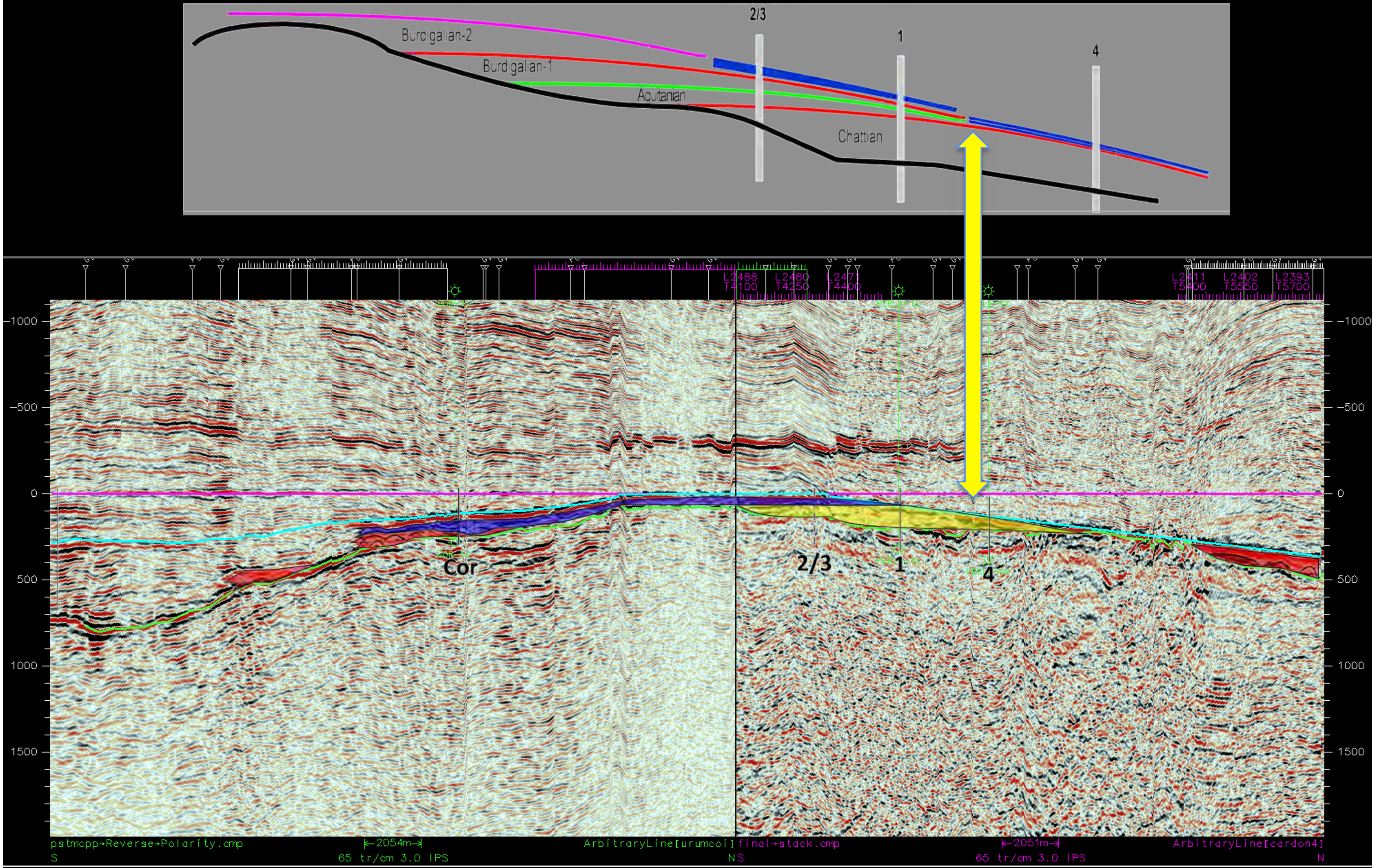


depositional system with 2 pycnoclines



Pomar et al., (2015)

seismic interpretation



Pinto et al., 2015

lessons learned from this example

component and texture analysis allowed to:

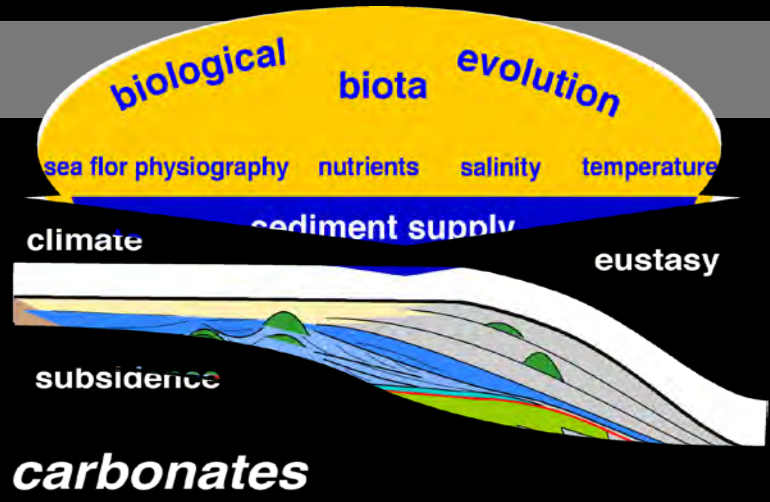
1) break the sedimentary succession into basic accretional units

2) recognize the cycles of relative sea level

3) distinguishing a very-coarse, mud-lean, very specific, outer ramp lithofacies, induced by the turbulence of breaking internal waves.

4) to identify the synsedimentary tectonic subsidence, and the context of water stratification

Epilogue



The complexity of reality is never to be fully understood, and the analysis here presented is not an exception

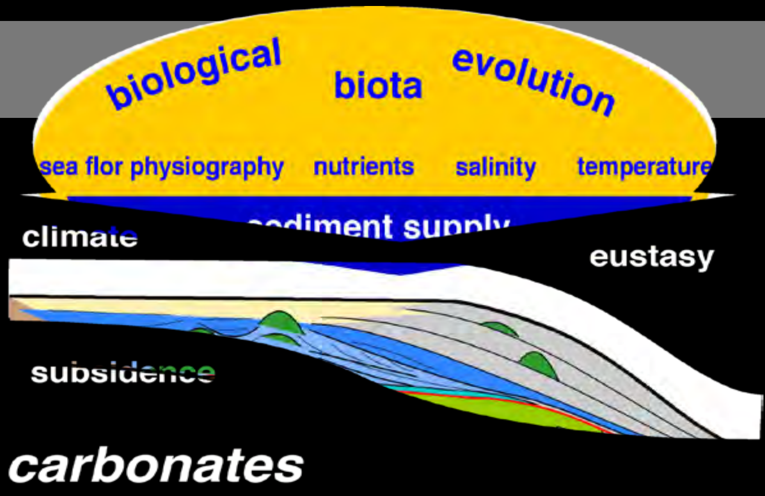
the "physical stratigraphic" concepts applied to siliciclastics does not work in carbonate systems

biofacies are the most important think in understanding carbonate reservoirs

the limit to this analytical strategy is tied to the knowledge of the ecology of ancient biota

but the advantage is that it will become a fully predictive tool.

Epilogue



the analytical strategy involves:

processes analysis, rather than identification of bedding patterns/bounding surfaces

each case is singular and unique,

"the efficacy is in using the changes of biotic components" to infer the:

- production modes,
- the depositional model/s,
- the stacking patterns of the basic accretional units,
- the sea-level trajectory

Alford, M.H., Peacock, T., MacKinnon, J.A. et al. 2015. The formation and fate of internal waves in the South China Sea. Nature, 521, 65-69, doi: 10.1038/nature14399.

Alnazghah, M.H., Bádenas, B., Pomar, L., Aurell, M. & Morsilli, M. 2013. Facies heterogeneity at interwell-scale in a carbonate ramp, Upper Jurassic, NE Spain. Marine and Petroleum Geology, 44, 140-163, doi: 10.1016/j.marpetgeo.2013.03.004.

Ball, M.M. 1967. Carbonate sand bodies of Florida and the Bahamas. J. Sed. Petrol., 37, 556–591.

Handford, C.R. & Baria, L.R. 2007. Geometry and seismic geomorphology of carbonate shoreface clinoforms, Jurassic Smackover Formation, north Louisiana. Geological Society, London, Special Publications, 277, 171-185, doi: 10.1144/gsl.sp. 2007.277.01.10.

Hernández-Molina, F.J., Fernández-Salas, L.M., Lobo, F., Somoza, L., Díaz-del-Rio, V. & Alveirinho Dias, J.M. 2000. The infralittoral prograding wedge: a new large-scale progradational sedimentary body in shallow marine environments. Geo-Marine Letters, 20, 109-117.

Pinto, D., Diaz, N., Tang, G., Arends, A., Ramírez, R., Pomar, L. & Padrón, V. 2014, Interpretación de rampas carbonáticas asociadas a paleoislas durante el Oligoceno-Mioceno en el Golfo de Venezuela. Caso de Estudio: Campo Perla. Memorias del I Congreso Venezolano de Gas Natural (ICVGAS), Porlamar, Venezuela,.

Pomar, L. 1991. Reef geometries, erosion surfaces and high-frequency sea-level changes, upper Miocene reef complex, Mallorca, Spain. Sedimentology, 38, 243-270, doi: DOI: 10.1111/j.1365-3091.1991.tb01259.x.

Pomar, L. 1993. High-resolution sequence stratigraphy in prograding carbonates: application to seismic interpretation. In: Louks, B. & Sarg, R.J. (eds.) Carbonate Sequence Stratigraphy: Recent Developments and Applications. A. A. P. G. Memoir No. 57, 389-407.

Pomar, L. 2001 a. Types of carbonate platforms, a genetic approach. Basin Research, 13, 313-334, doi: 10.1046/j.0950-091x. 2001.00152.x.Pomar & Tropeano, 2001

Pomar, L. 2001 b. Ecological control of sedimentary accommodation: evolution from a carbonate ramp to rimmed shelf, Upper Miocene, Balearic Islands. Palaeogeography, Palaeoclimatology, Palaeoecology, 175, 249-272

Pomar, L. & Kendall, C.G.S.C. 2008. Architecture of carbonate platforms: A response to hydrodynamics and evolving ecology. In: Lukasik, J. & Simo, A. (eds.) Controls on Carbonate Platform and Reef Development, SEPM Special Publication, 187-216.Pomar, L. & Tropeano, M. 2001.

The "Calcarenite di Gravina" Fm. In Matera (Southern Italy): new insights for large-scale cross-bedded sandbodies encased in offshore deposits. American Association of Petroleum Geologists Bulletin, 84, 661-689.

Pomar, L. & Ward, W.C. 1994. Response of a Late Miocene Mediterranean reef platform to high-frequency eustasy. Geology, 22, 131-134, doi: doi: 10.1130/0091-7613(1994)022<0131:ROALMM>2.3.CO;2.

Pomar, L. & Ward, W.C. 1995. Sea-level changes, carbonate production and platform architecture: the Llucmajor Platform, Mallorca, Spain. In: Haq, B.U. (ed.) Sequence Stratigraphy and Depositional Response to Eustatic, Tectonic and Climatic Forcing. Kluwer Academic Press, 87-112.

Pomar, L. & Ward, W.C. 1999. Reservoir-scale heterogeneity in depositional packages and diagenetic patterns on a reef-rimmed platform, Upper Miocene, Mallorca, Spain. AAPG Bulletin, 83, 1759-1773.

Pomar, L., Obrador, A. & Westphal, H. 2002. Sub-wavebase cross-bedded grainstones on a distally steepened carbonate ramp, upper Miocene, Menorca, Spain. Sedimentology, 49, 139-169, doi: 10.1046/j.1365-3091.2002.00436.x.

Pomar, L., Gili, E., Obrador, A. & Ward, W.C. 2005. Facies architecture and high-resolution sequence stratigraphy of an upper Cretaceous platform margin succession, Southern Central Pyrenees, Spain. Sedimentary Geology, 175, 339–365, doi: 10.1016/j.sedgeo.2004.11.009.

Pomar, L., Esteban, M., Martinez, W., Espino, D., Castillo de Ott, V. & Benkovics, L. 2015. Oligocene-Miocene carbonates of the Perla Field, offshore Venezuela: depositional model and facies architecture. In: Bartolini, C. & Mann, P. (eds.) A.A.P.G. Memoir 108, "Petroleum Geology and Hydrocarbon Potential of Colombia Caribbean Margin, 647–674.

Susanto, R.D., Mitnik, L. & Zheng, Q. 2005. Ocean internal waves observed in the Lombok Strait. Oceanography, 18, 80-87.

Tropeano, M., Pieri, P., Pomar, L. & Sabato, L. 2002. The Offlap Break Position Vs Sea Level: A Discussion. EGS XXVII General Assembly, Nice.

Cátedra Guillem Colom Casasnovas

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