The Flooding of a Carbonate Platform: The Eastern Yucatán Platform as a Model for Transgressive Carbonates*

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Abstract

The dynamic relationships between marine and freshwater systems on carbonate platforms and their respective responses to sea level rise remain poorly understood. This is surprising given the frequency of platform exposure and flooding events seen in the stratigraphic record, noting also that occurrences first of freshwater and later of brackish water carbonates are typically some of the first indicators of transgression within carbonate platform successions. The Sian Ka'an Wetlands (SKW) of the eastern Yucatán Peninsula, a spectacular and sedimentologically little studied example of a transgressive sedimentary system, comprise a 4,000 km^2 low-relief complex of groundwater-fed freshwater marsh, lake and brackish coastal lagoons. The SKW record a history of Quaternary sea level fall and subsequent rise which is now resulting in the progressive encroachment of freshwater and shallow marine environments onto the platform top. Deep karstification of the platform and the formation of sinkholes (cenotes) and regional cave systems at low sea level have provided effective conduits for extensive recharge from the pediment. Rising groundwater during late Quaternary and Holocene transgression has led to partial flooding and the emergence of groundwater onto the platform top, leading to the formation of extensive palustrine environments in low-lying areas behind the reef and beach, across a vast freshwater carbonate factory which is dynamically linked with the marine carbonate factory offshore. As aquifer levels progressively rise, the marsh areas are shown to flood and migrate successively further landwards. At the coast, breaches of the beach barrier have led to the formation of brackish lagoons. Further sea level rise has locally seen progressive destruction of the barrier and partial marine flooding of coastal palustrine sloughs and lagoons to form seagrass embayments, in which groundwater is still emergent at the seafloor. The deposition and preservation of thick freshwater-brackish and palustrine successions during greenhouse intervals in the Mesozoic and Cenozoic of Iberia, Southern France and Switzerland likely reflect the tectonic creation of accommodation space in extensional and intramontane depocentres developed on regionally extensive carbonate pediments. By contrast, the preservation potential of platform top carbonates is in many cases likely to be low in today's icehouse interval where eustatic sea level rise is relatively rapid in relation to subsidence.

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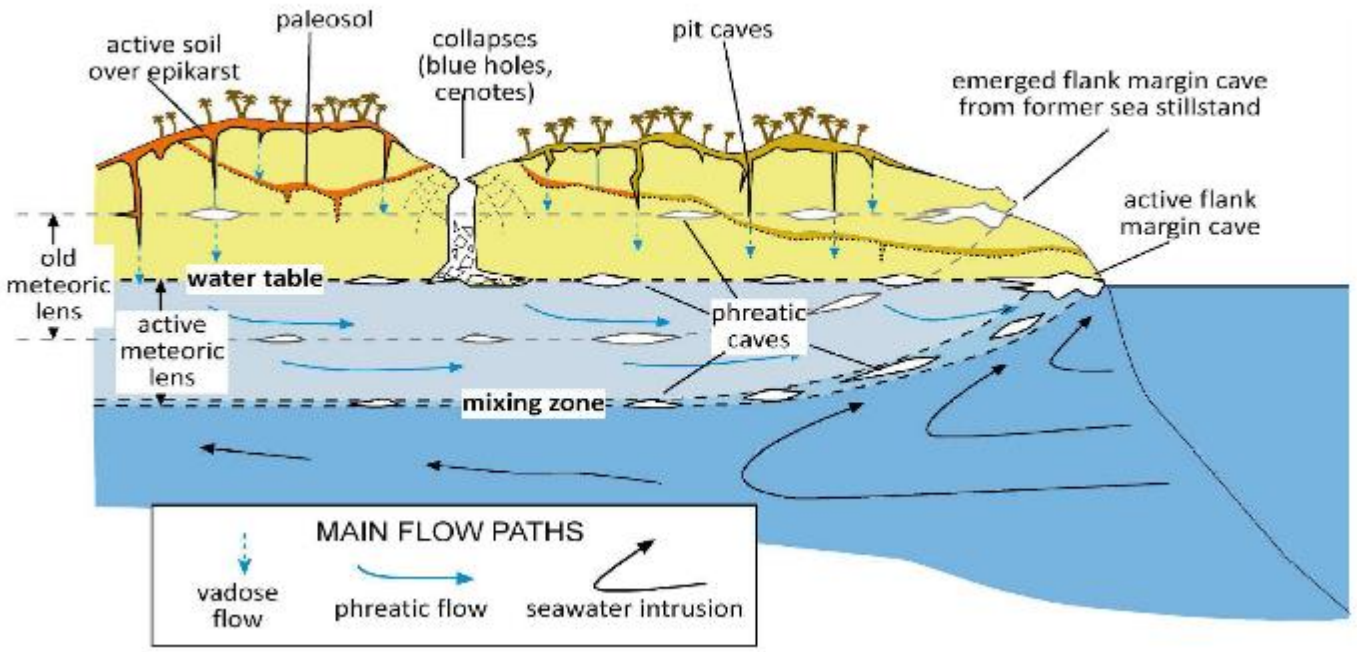
The flooding of a carbonate platform: the eastern Yucatán platform as a model for transgressive carbonates

Nigel H Platt (Edison E&P UK Ltd) V. Paul Wright (National Museum of Wales)

Rationale

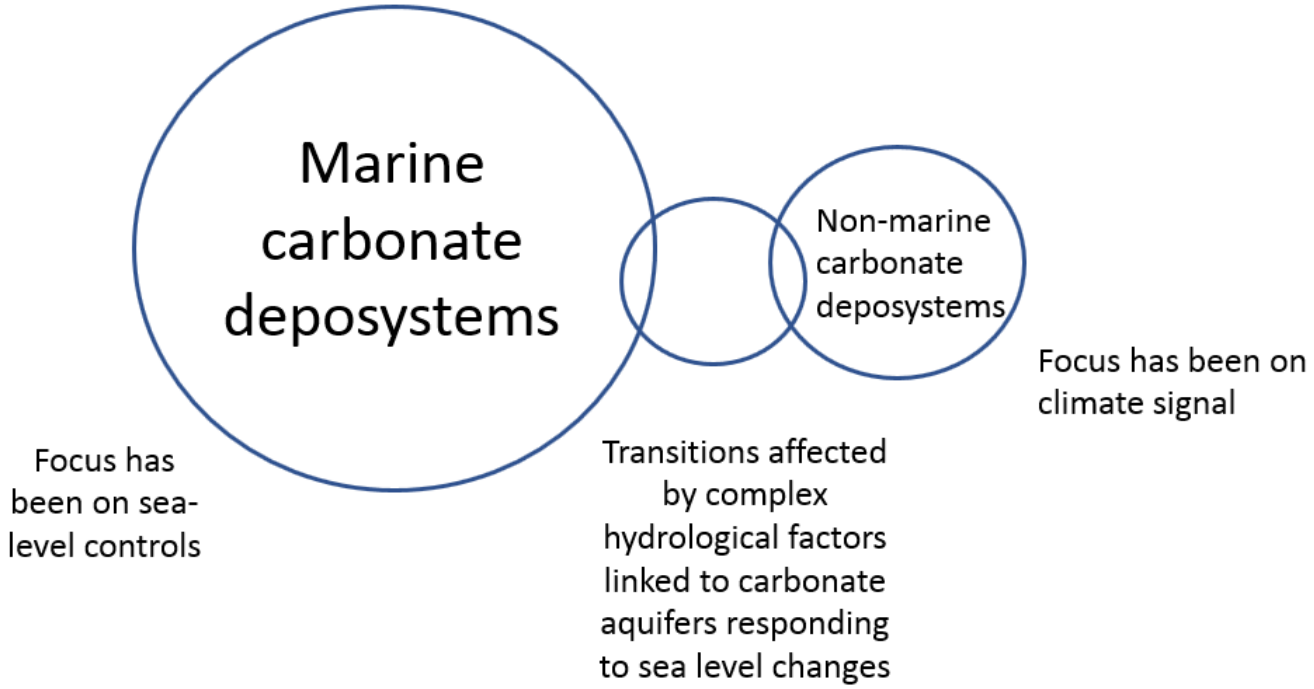


The dynamic relationships between marine and freshwater systems on carbonate platforms, their respective responses to sea-level rise and the associated diagenetic processes have been studied in detail.

This is not surprising given the frequency of platform exposure and flooding events seen in the stratigraphic record.

Based on many sources: From: Wright, V. P. et al. J I 2014. Interpretation, 2, p. SF1-SF16

Rationale



But what about the depositional effects?

A view often cited in the literature is that when carbonate platforms flood the main effect is an initial transgressive lag, but this is simplistic

In fact complex **hydrological and hydrogeological transitions** take place on many flooding platforms, well exemplified by the transgression taking place in east Yucatán today as illustrated here by the Sian Ka'an Wetlands.

Take away points –

Freshwater limestones are typically NOT lowstand deposits.

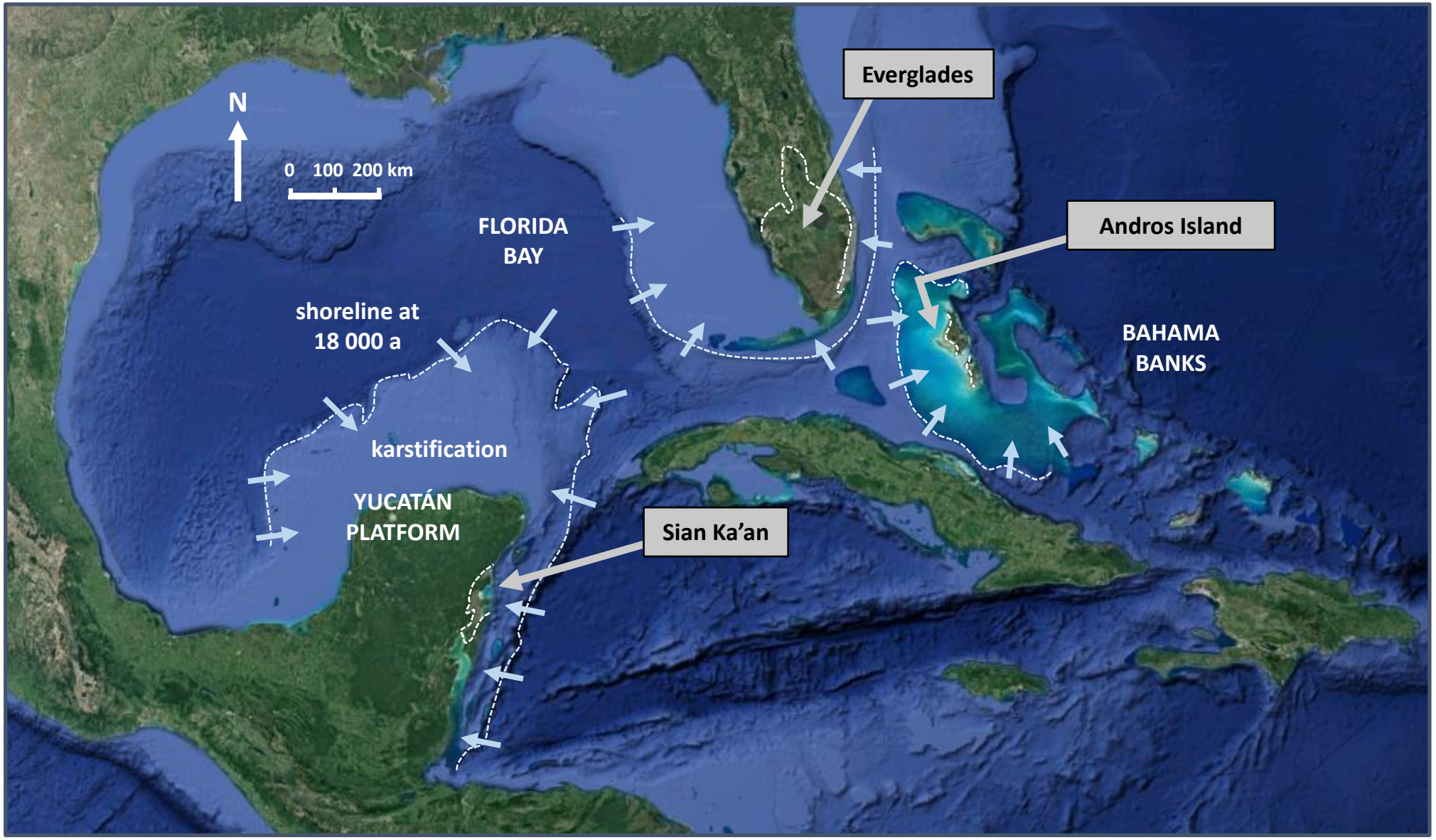
Rising groundwater during late Quaternary and Holocene transgression, as seen in the Sian Ka'an Wetlands of E Yucatán, has led to partial flooding and the emergence of groundwater onto the platform top, leading to the formation of **extensive palustrine environments** in low-lying areas behind the reef and beach, across a **vast freshwater carbonate factory,** which is **dynamically linked** with the marine carbonate factory offshore.

As aquifer levels progressively rise, the marsh areas flood and migrate successively further landwards.

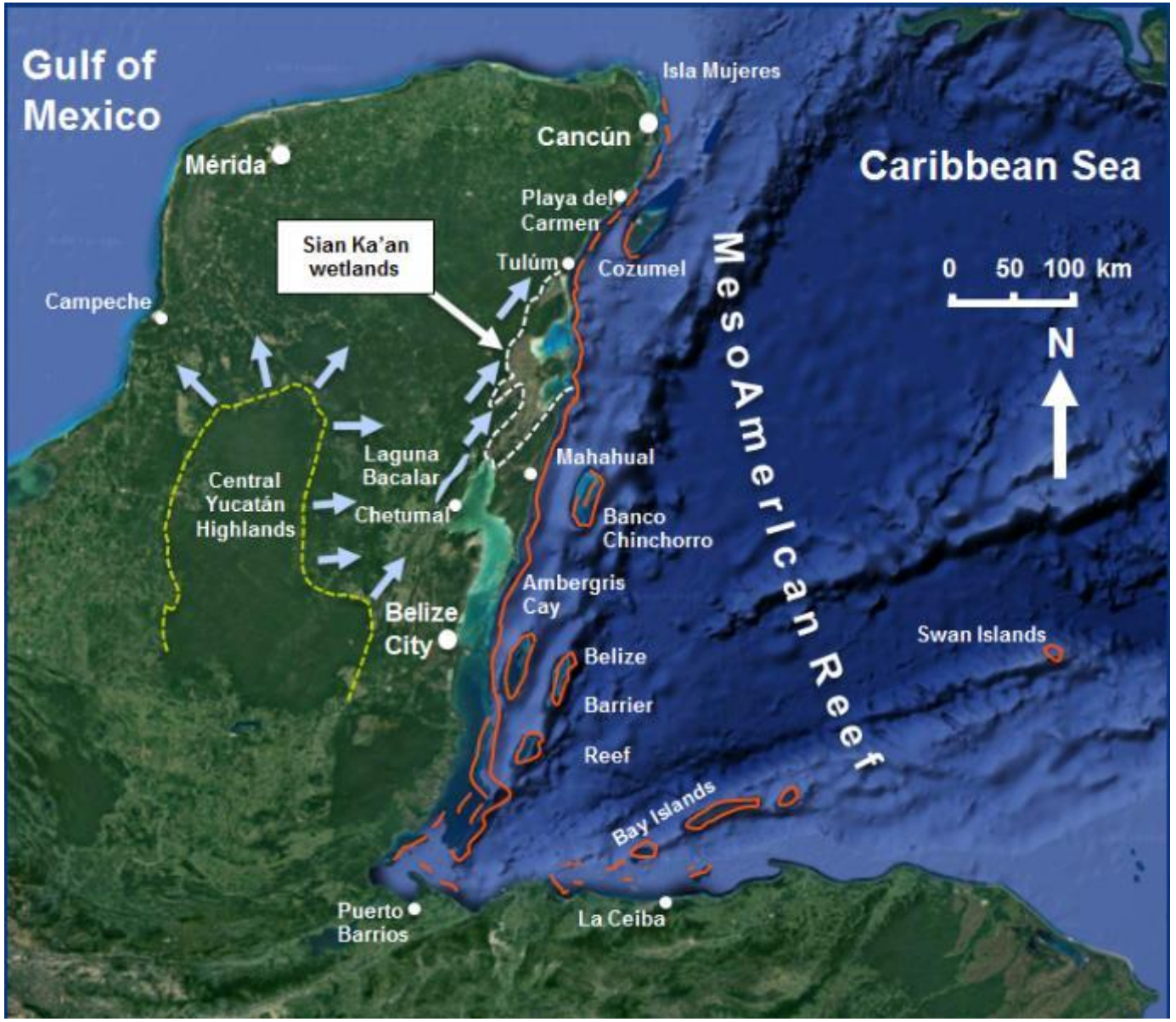
These groundwater-influenced carbonate systems reflect the role of karstic discharge and carbonate aquifers.

As expected, preservational effects play a critical role in controlling how such carbonates enter the stratigraphic record: they are identified in **ice-house and greenhouse** systems but appear to have developed more extensively under greenhouse conditions when rates of sea-level rise were reduced, favouring increased residence times of the transitional hydrologies?

We identify ancient analogues from throughout the Phanerozoic.



Freshwater wetlands cover significant areas of the Bahamas-Caribbean carbonate province



The Yucatán Peninsula comprises a stable carbonate platform covering 400,000 km^2

To the east is the MesoAmerican Reef – the second longest barrier reef in the world

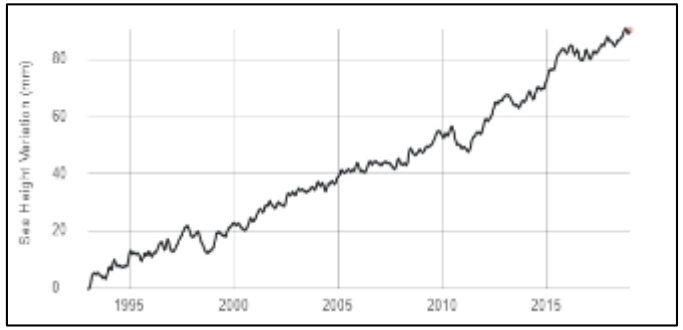
The area includes the longest linked cave systems in the world. These are dry in the north, and flooded in the south

There is regional aquifer drive across the area from the Yucatán Highlands to the coast

We can examine the effects of a marine transgression on the east Yucatán coast of the Sian Ka'an Biosphere Reserve, a 5,280 km^2 wilderness roughly equally divided between tropical forest, marshes & mangrove and coastal lagoons and adjacent marine habitats

Calibrating sea level rise:

Reef and lagoon backstepping



Satellite data
3.3 mm/year (1993-)

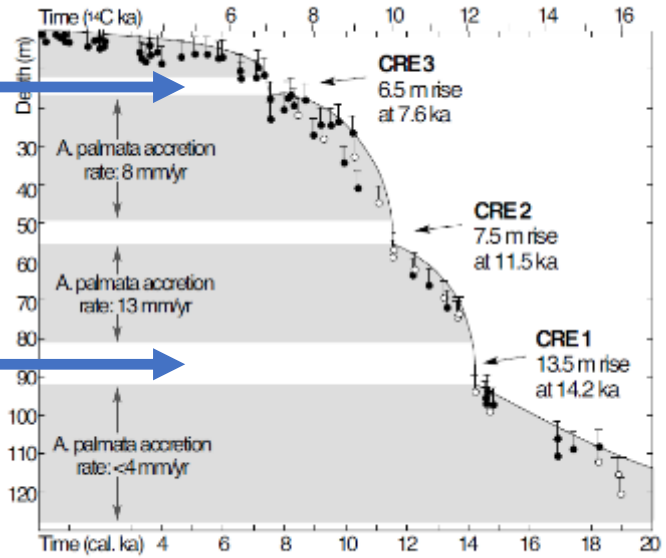
NASA 2019

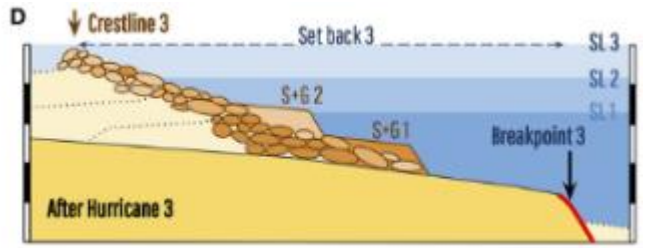
A

MesoAmerican Reef
6.0 mm/year (14 200 – 0 BP)

Yucatán, Everglades Yucatan -7,600a

Florida Bay -14,200a

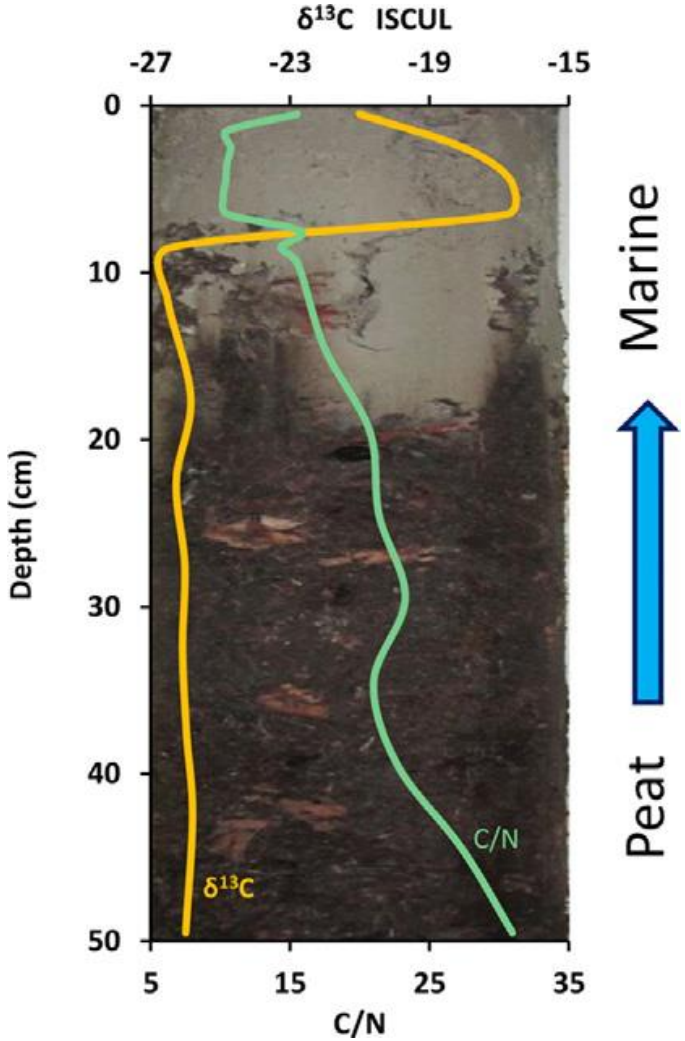




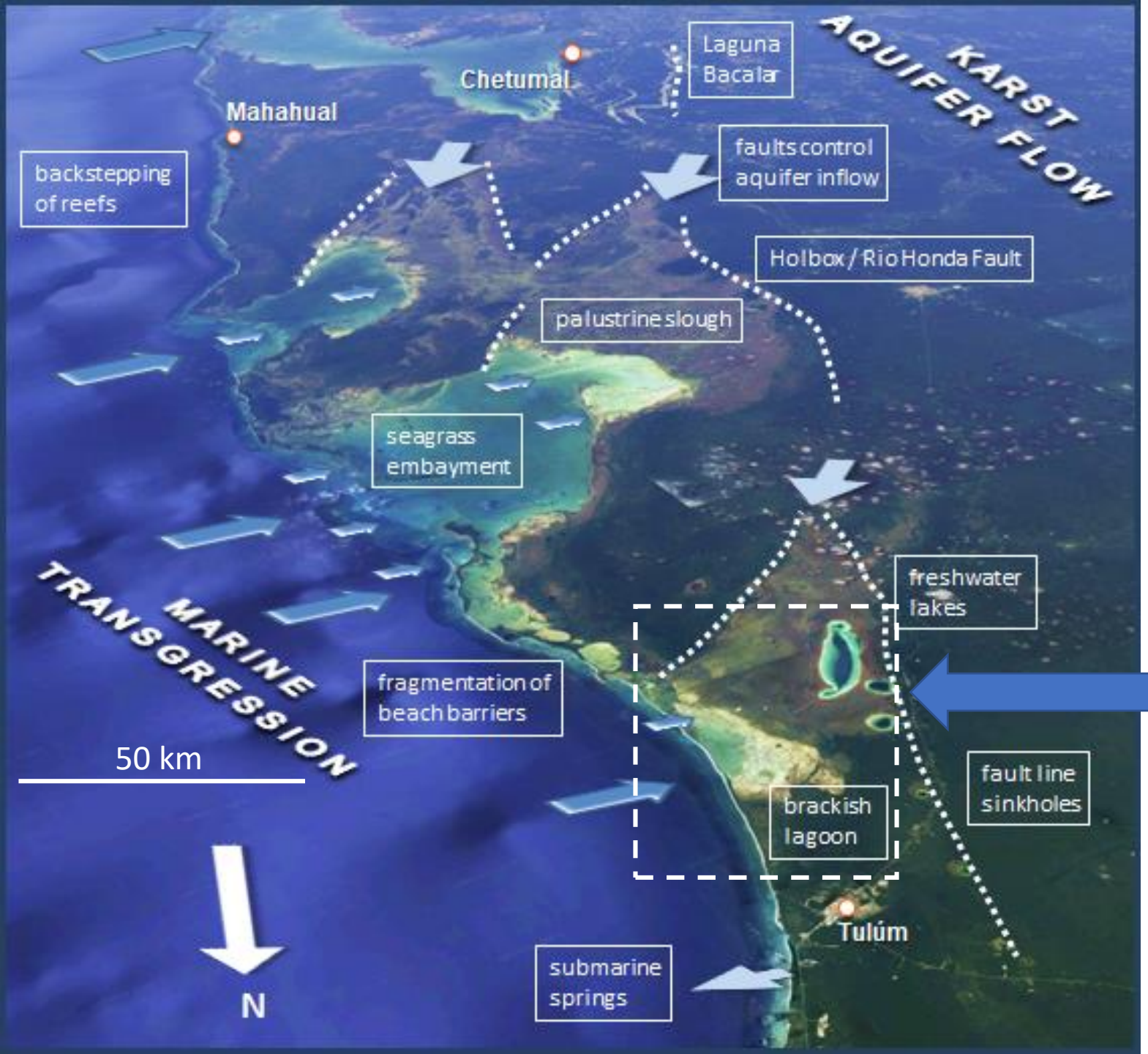
Blanchon & Shaw, Nature 1995
Blanchon, Frontiers in Earth Sci 2017

B

Bahia de la Ascensión
3.5 mm/year (1947-1999)



Carnero-Bravo et al.,
Science of the Total Env. 2016



We will examine a transect through the wetlands from the tropical forest to the coast, comparing with large embayments to the south

Study area

Muyil – an ancient Mayan settlement, with access to fresh water and a canal to the sea

KARST AND CENOTES

Tulúm

A

LAKES

BEACH BARRIER

Muyil

MANGROVE SWAMP

REEFS

SAWGRASS MARSH

LAGOON

0 5 km

N

Sian Ka'an

Mérida

Cancún

Playa del Carmen

YUCATAN

Campeche

CAMPECHE

QUINTANA ROO

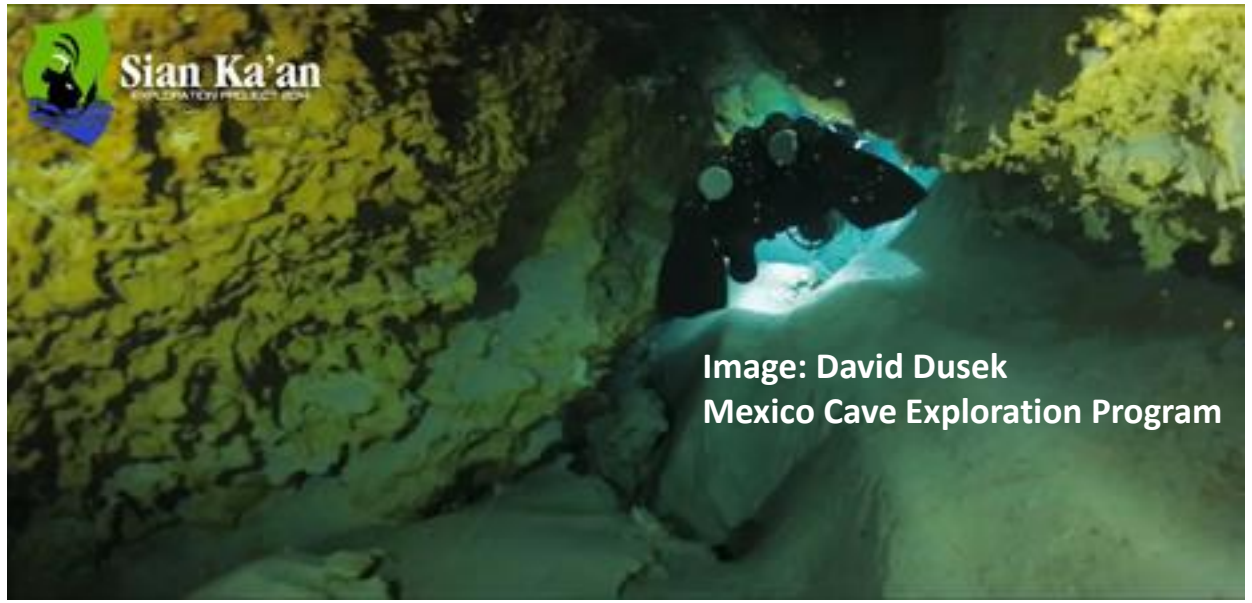
Chetumal

Belmopan

Belize

Sian Ka'an Wetlands: W to E traverse

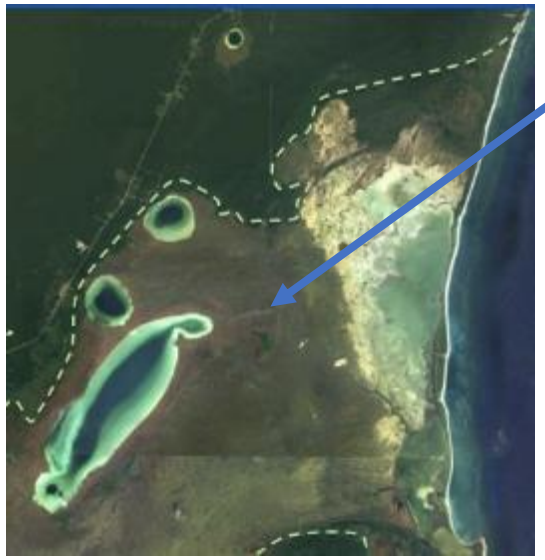
Inland forest with cenotes and caves



Freshwater lakes with recharge from cenotes

Sawgrass marsh with periphyton – seasonally flooded and desiccated, carbonate muds: palustrine wetland

Marshes are cut by channels with dwarf mangrove fringes, oncoids and microbial heads

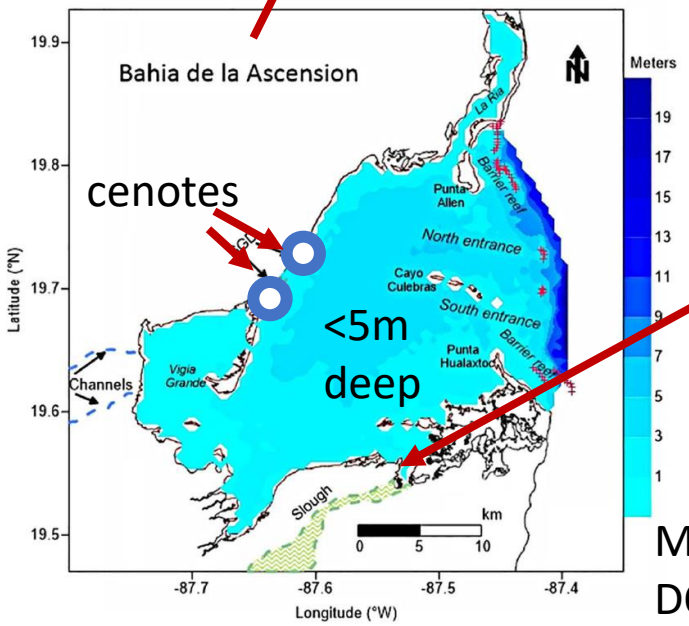


Seawards there are extensive red mangroves, replaced by black mangroves, then passing into brackish lagoon with freshwater cenotes

cenotes

Beach barrier, seagrass lagoon and MesoAmerican reef

reef



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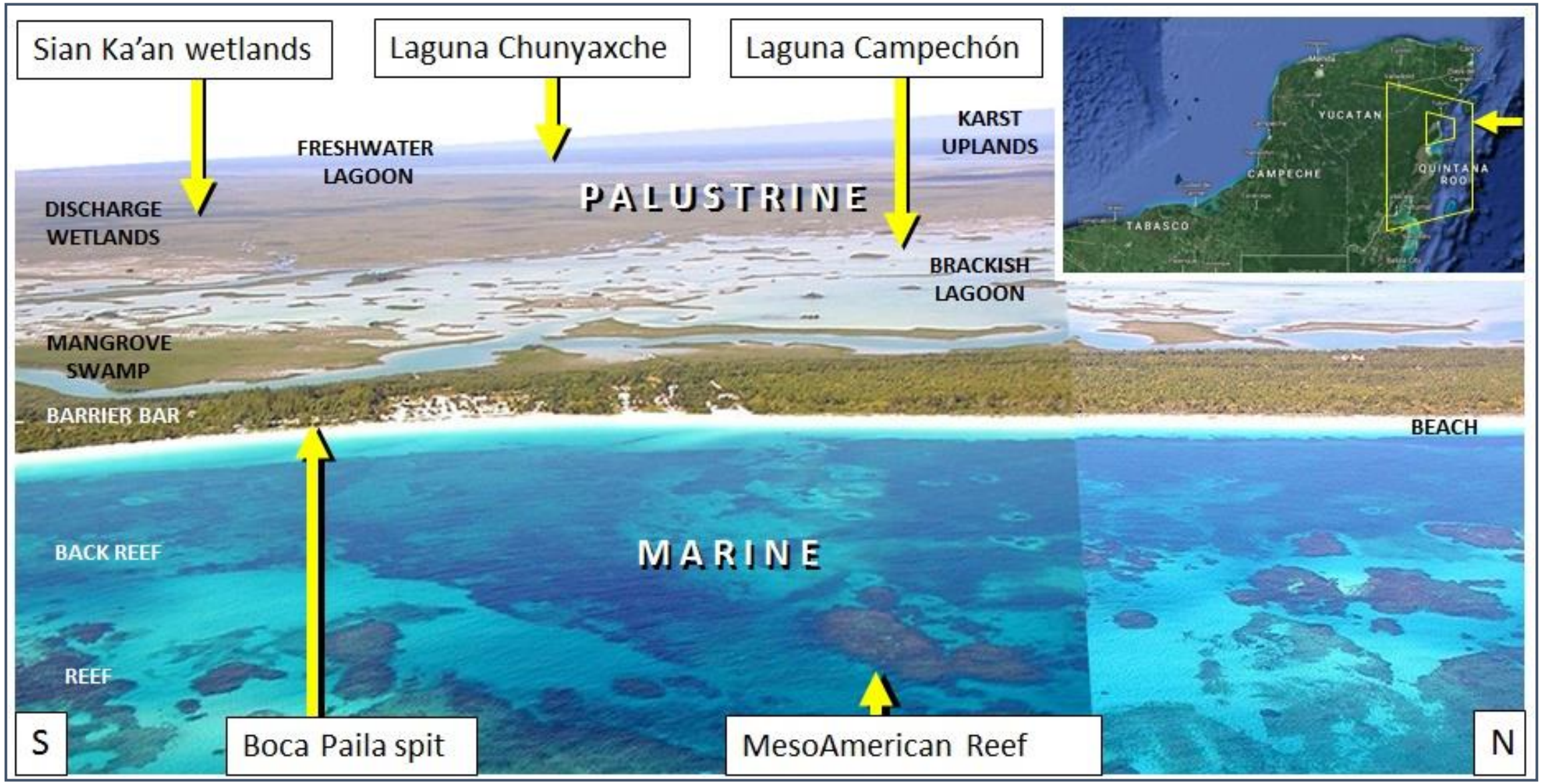
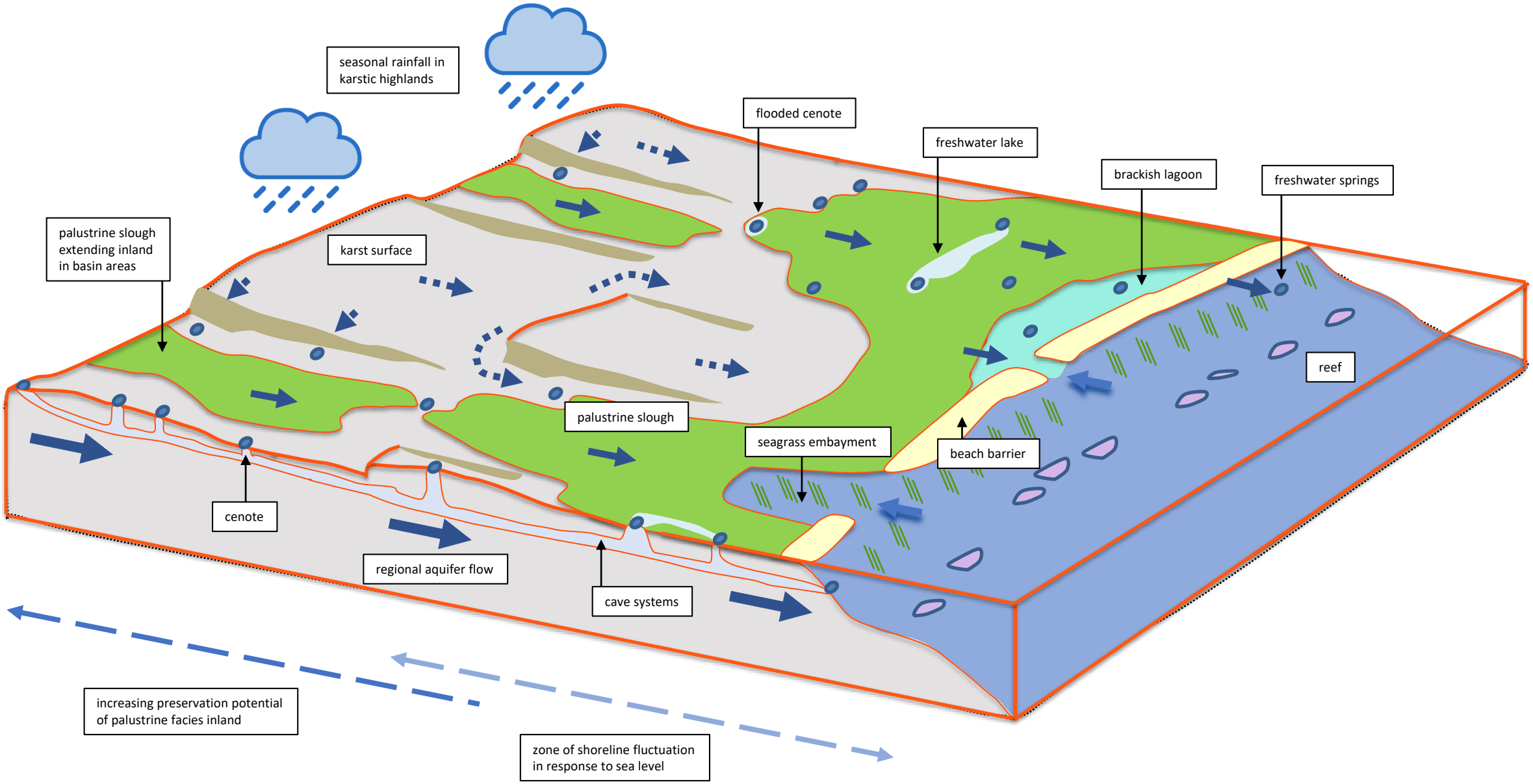


Environments – contextual overview

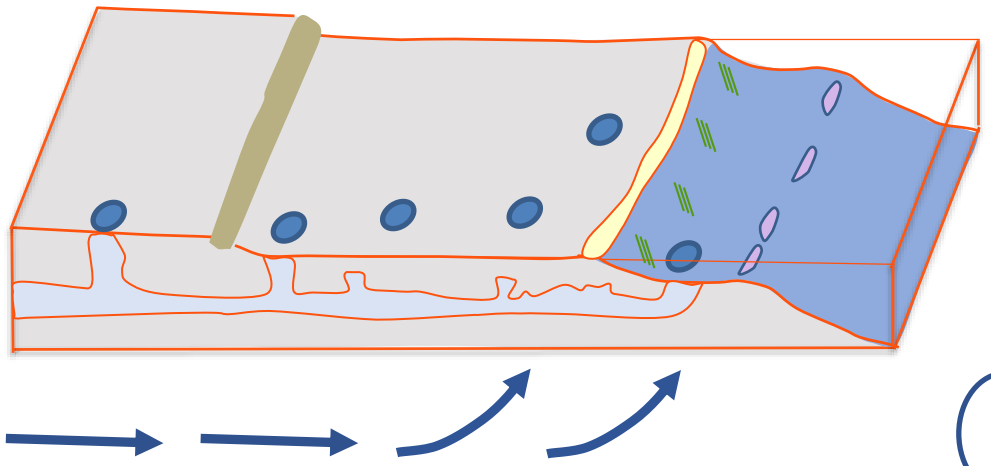


Palustrine wetlands: Geological model based on Sian Ka'an

karst surface

cenotes

freshwater springs

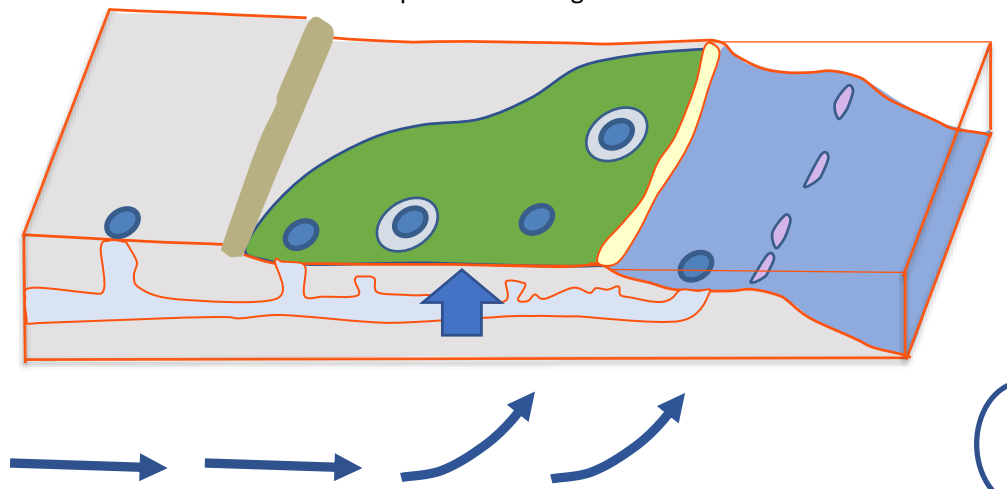


1

palustrine slough

rising water table → cenotes flooded

palustrine slough forms on inundated karst surface



2

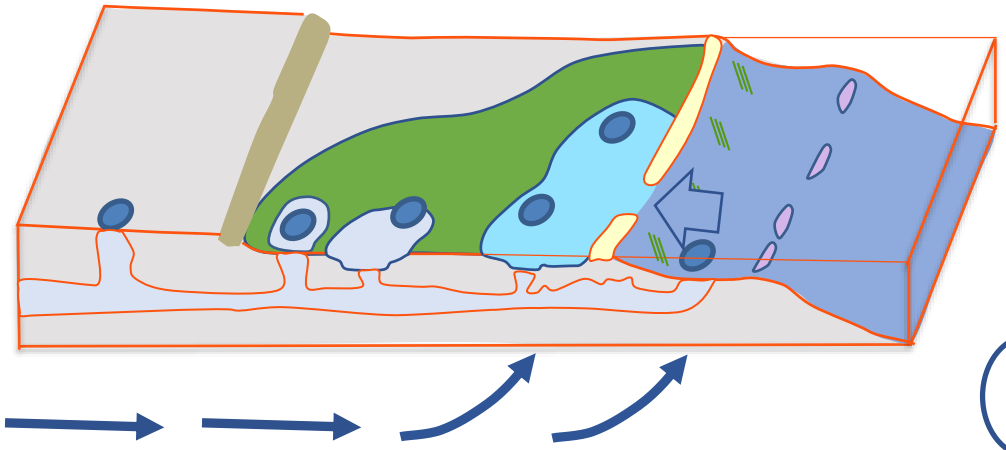
coastal lagoon

brackish lagoon forms at coast

fresh groundwater feed from below

beach barrier

locally breached



3

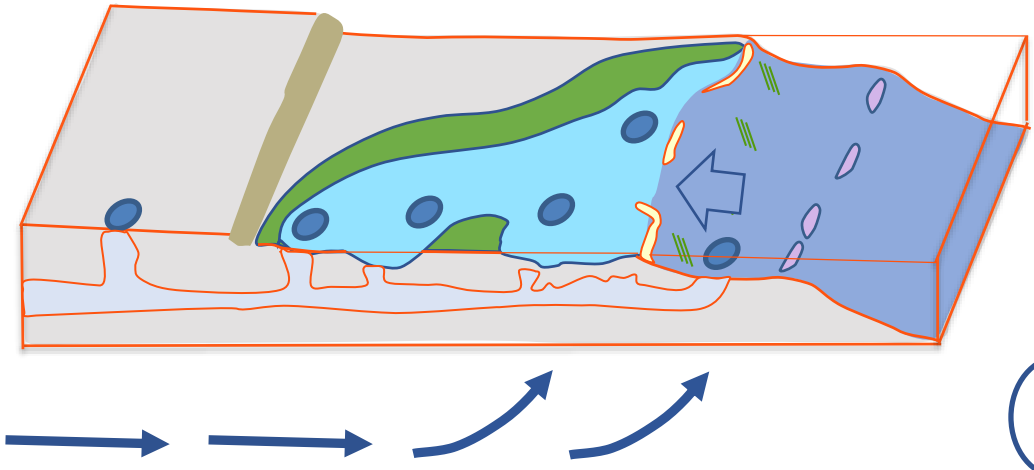
brackish embayment

brackish lagoon expands

across palustrine slough

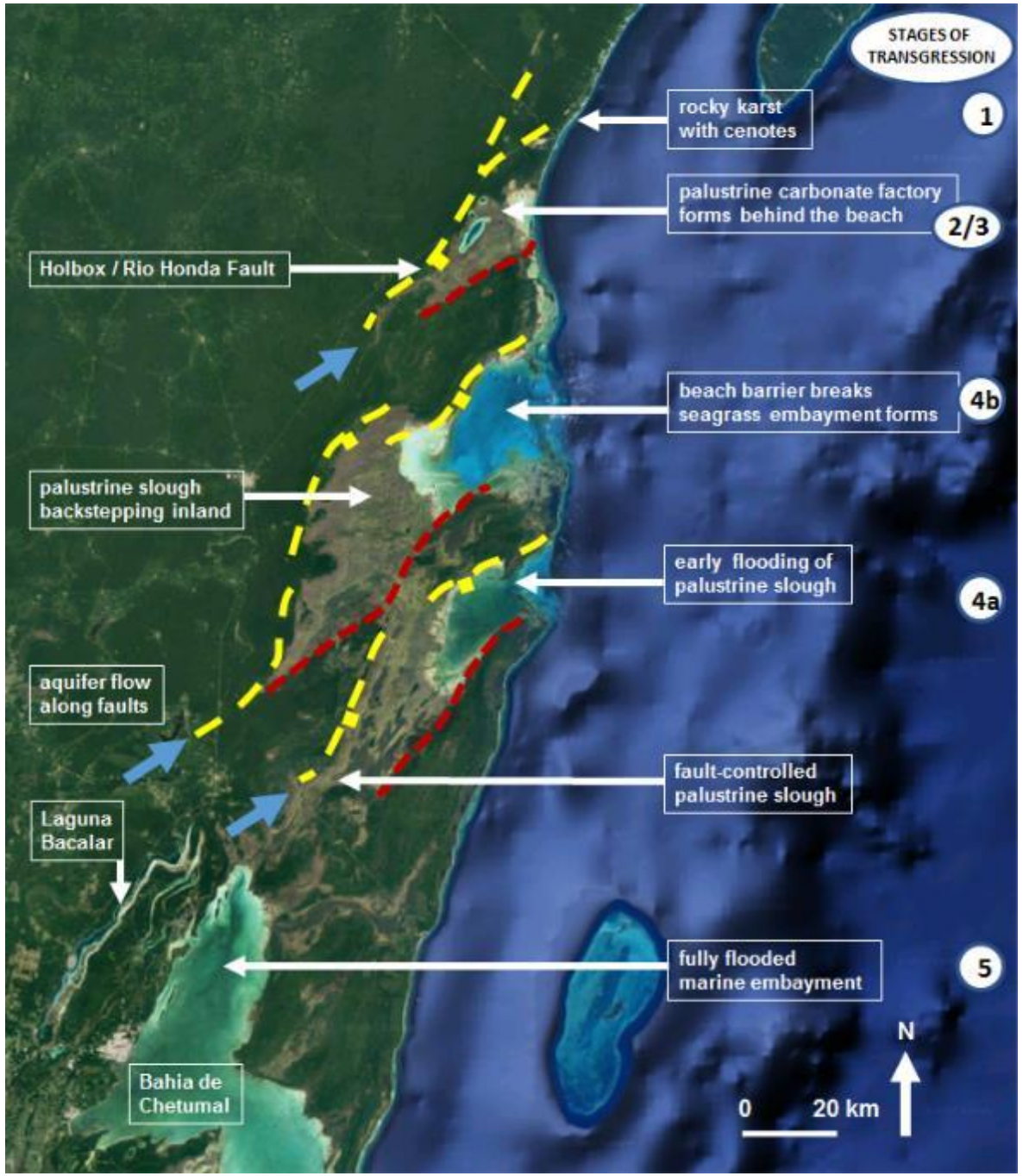
vestigial

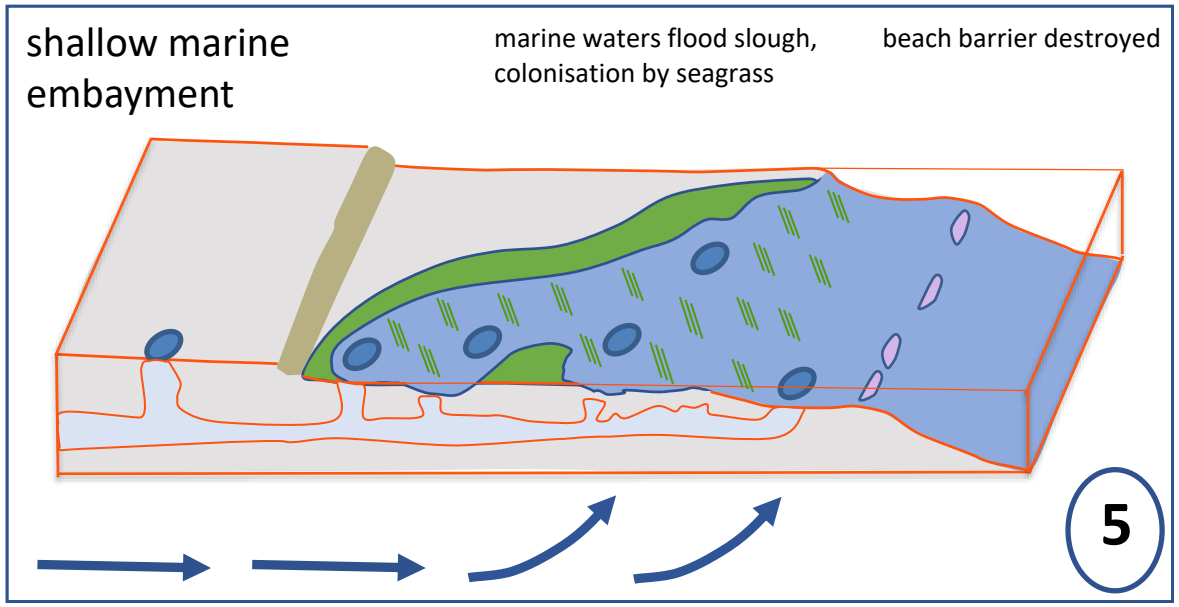
beach barrier only



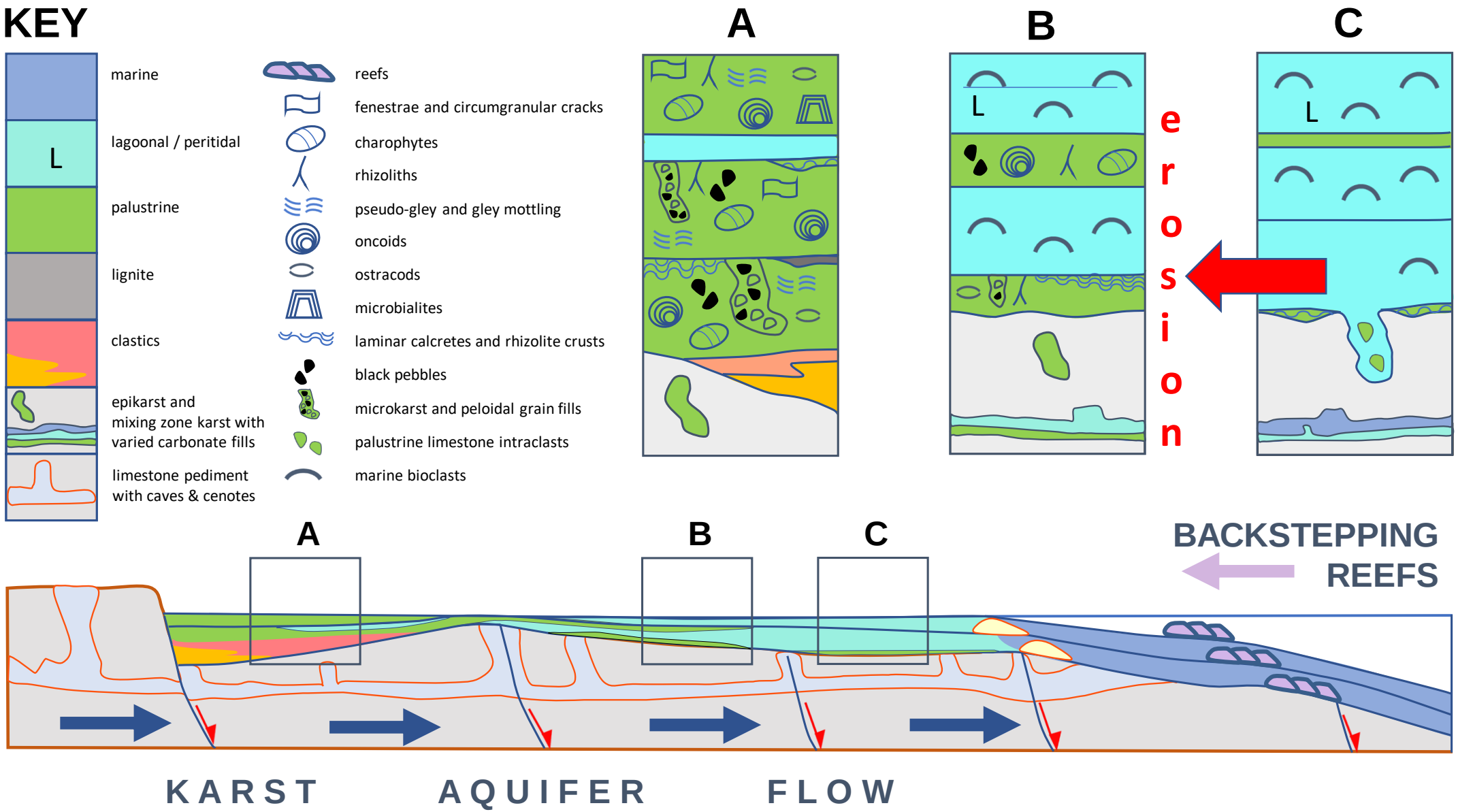
4

Transgressive model, in action

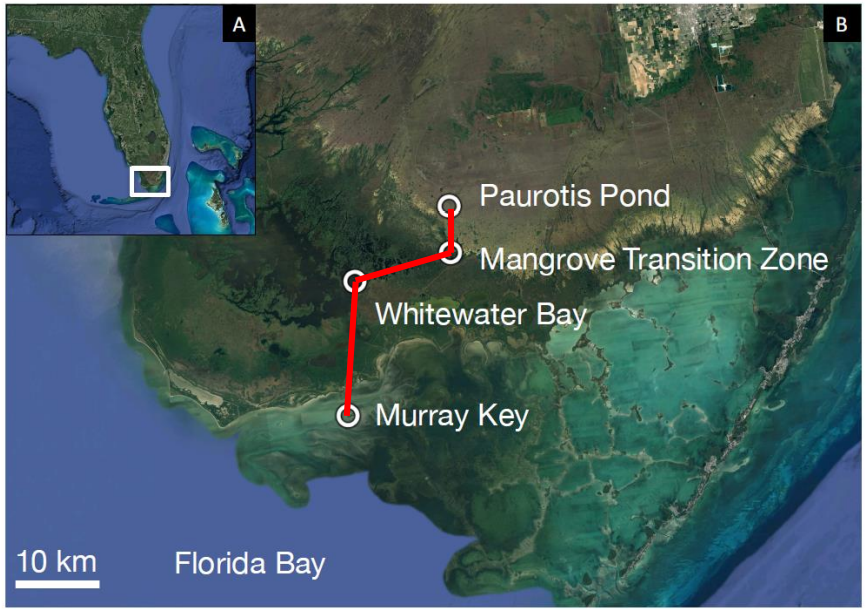


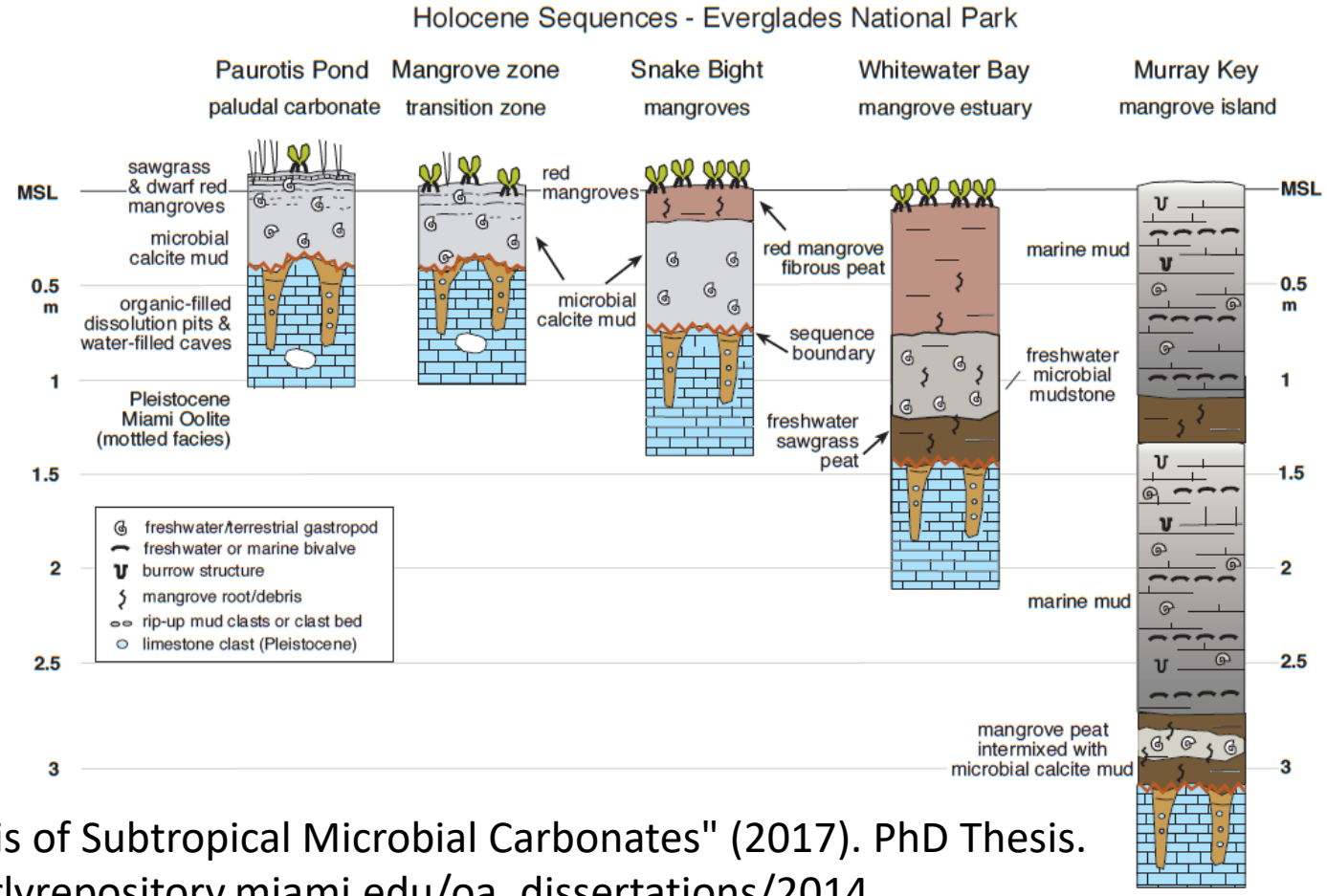


What might we expect in terms of facies?



South Florida analogue: freshwater (Paurotis Pond) to marine (Murray Key)





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Stratigraphic Occurrence: Transgressive and regressive preservation

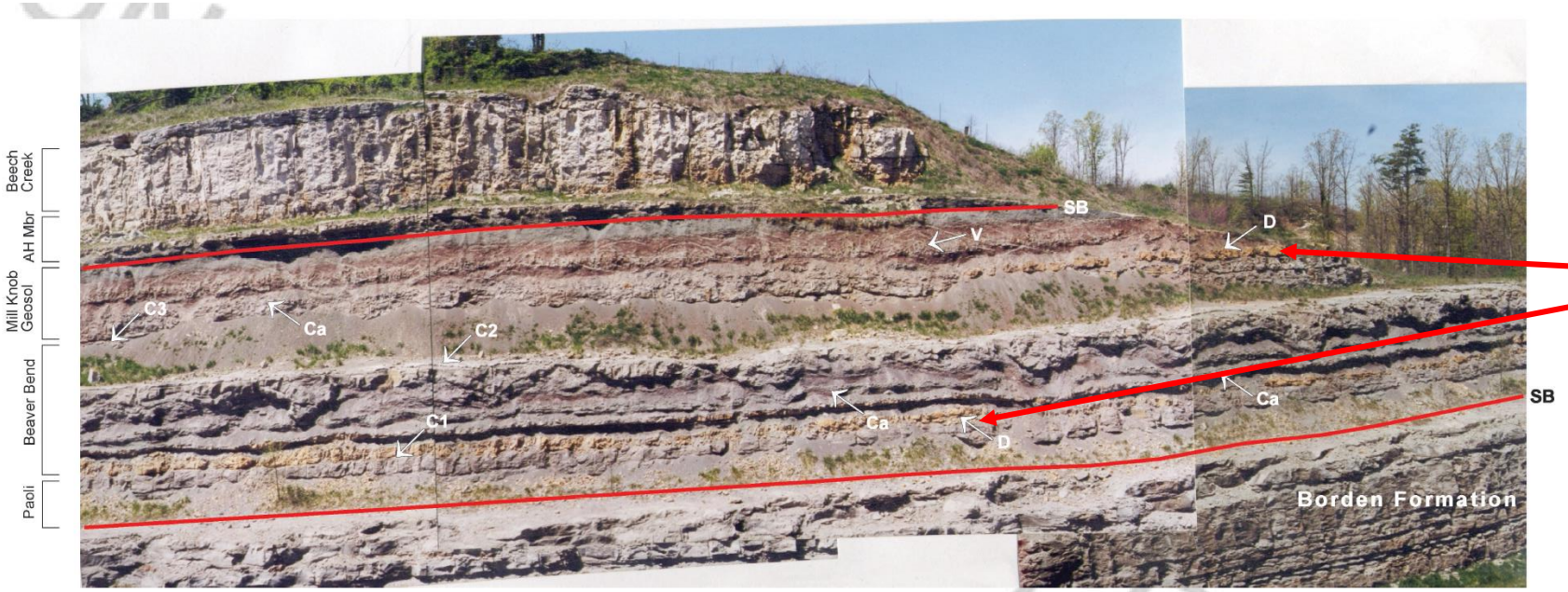
Regressive

Ancient wetland deposits can form either as progradational packages or as a result of minor sea-level falls, but it seems likely such deposits would have a low preservation potential especially if water tables fell and extensive pedogenesis and/or karst developed

Transgressive

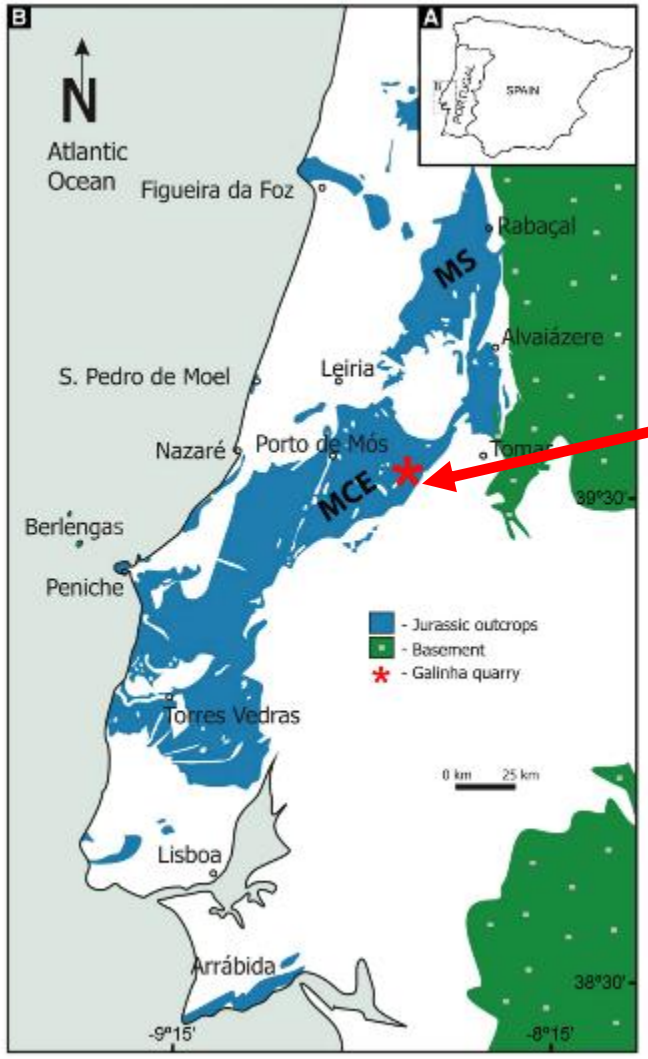
During transgressions such deposits are readily eroded

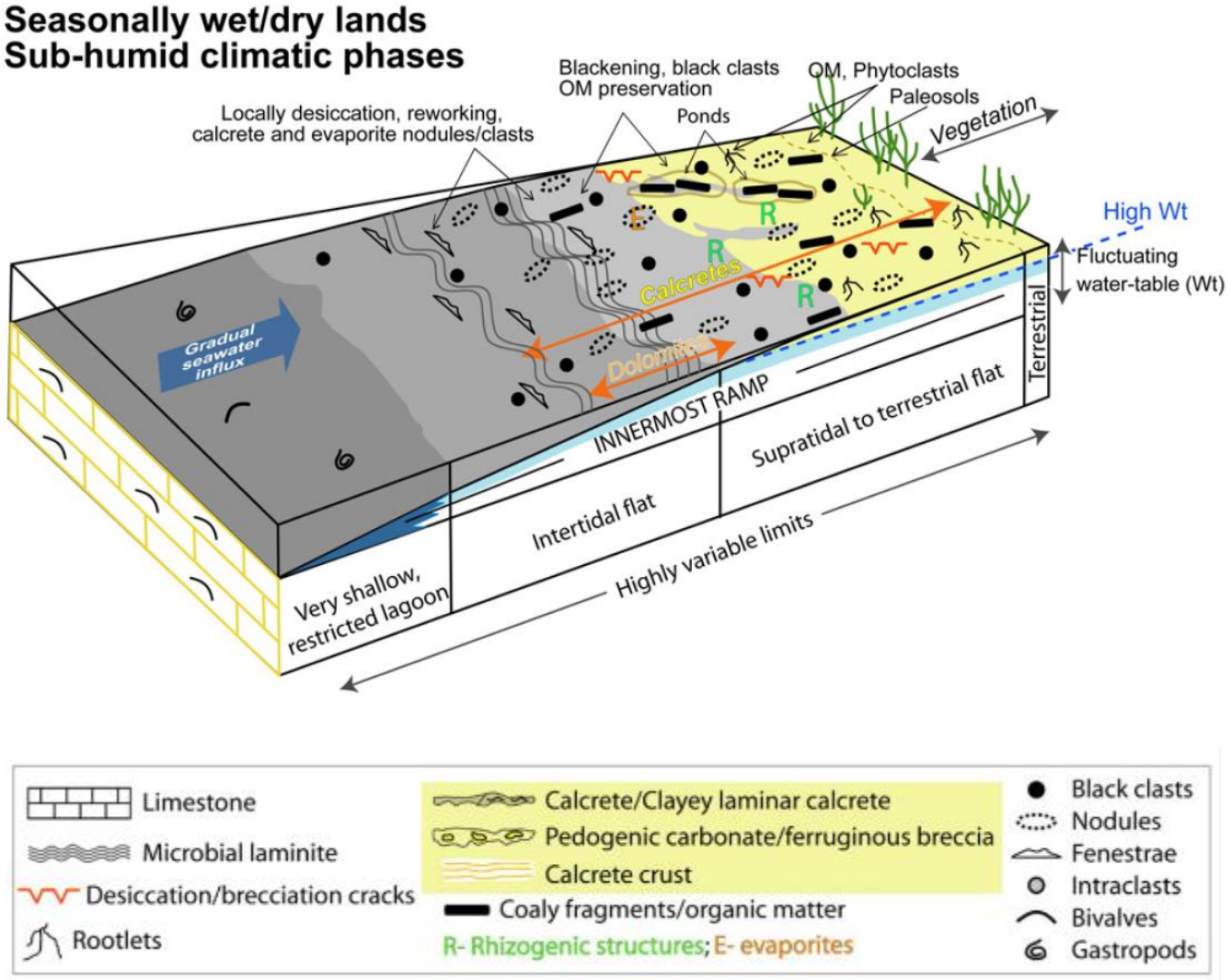
Thin transgressive brackish marsh dolomites are known from the Mississippian of Europe and USA and the Devonian of Canada in **greenhouse and ice house** intervals.



Morehead section SE Kentucky – Mississippian brackish ferroan dolomites. Barnett A J et al 2012 Int. Assoc. Sedimentol. Spec. Publ. 45, 477–500

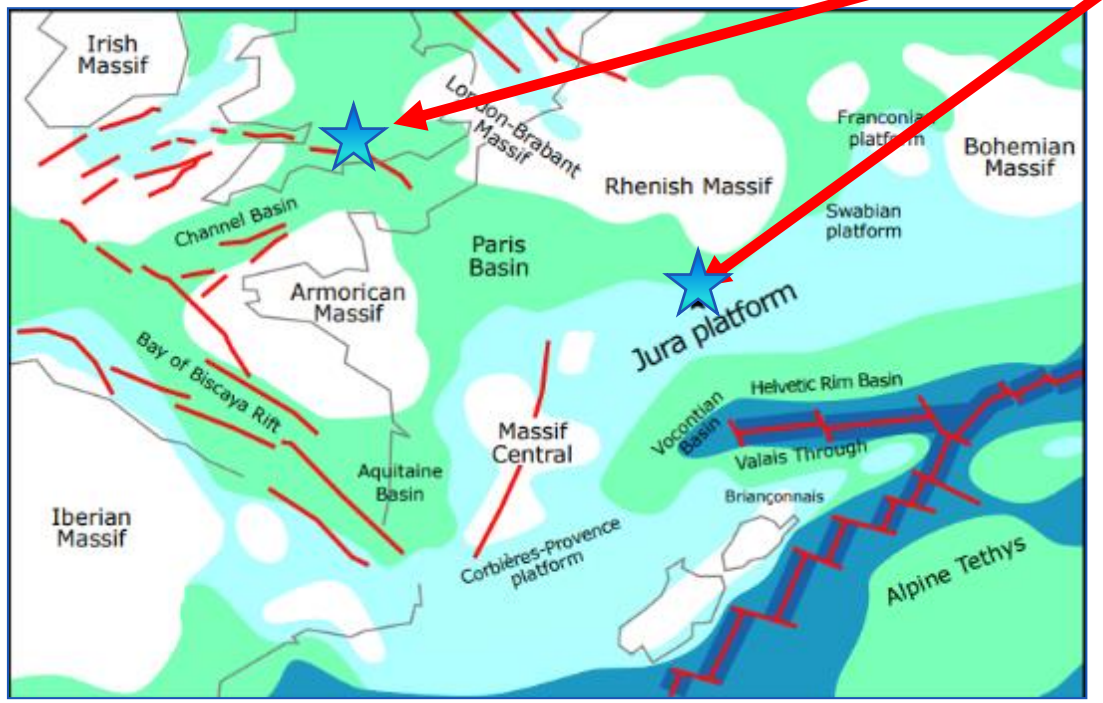
Middle Jurassic (Lower Bathonian) of Portugal: thin and highly varied transgressive palimpsest mix of marine-brackish, freshwater pond and terrestrial facies

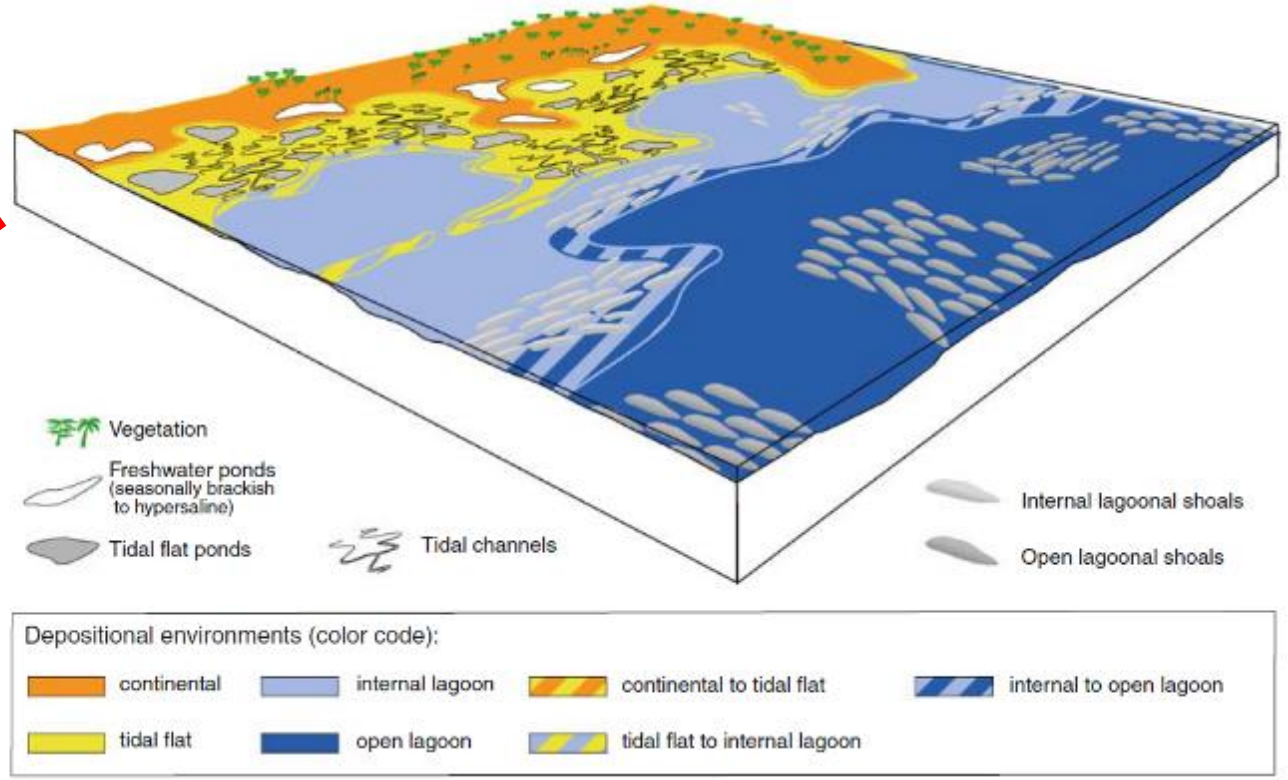




From: Azerêdo et al. 2015. Sedimentary Geology 323, 66–91

Thicker, more widespread examples may exist: The mixed peritidal-brackish-freshwater Purbeckian (Oxfordian-Lower Berriasian) of the Swiss & French Jura (Goldberg Fm.), and similar facies associations in UK, Normandy, Spain, Croatia etc.

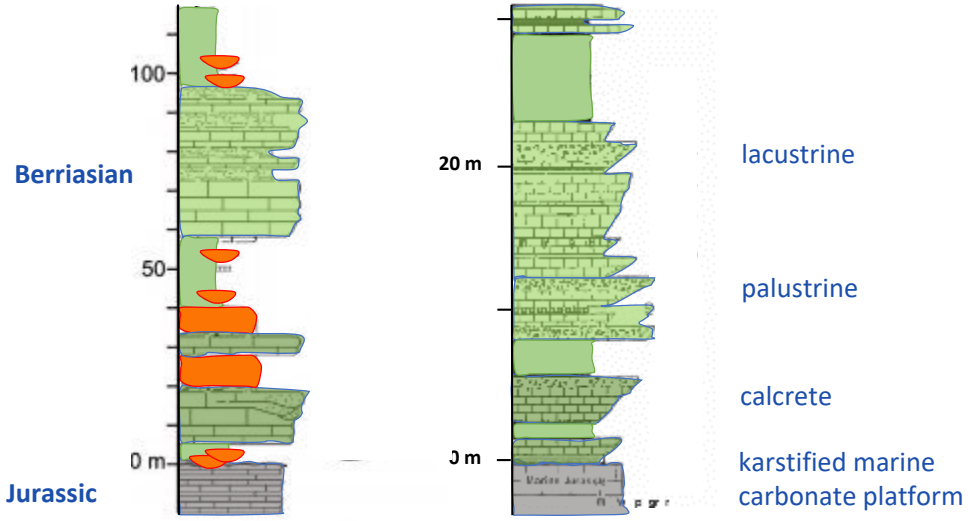


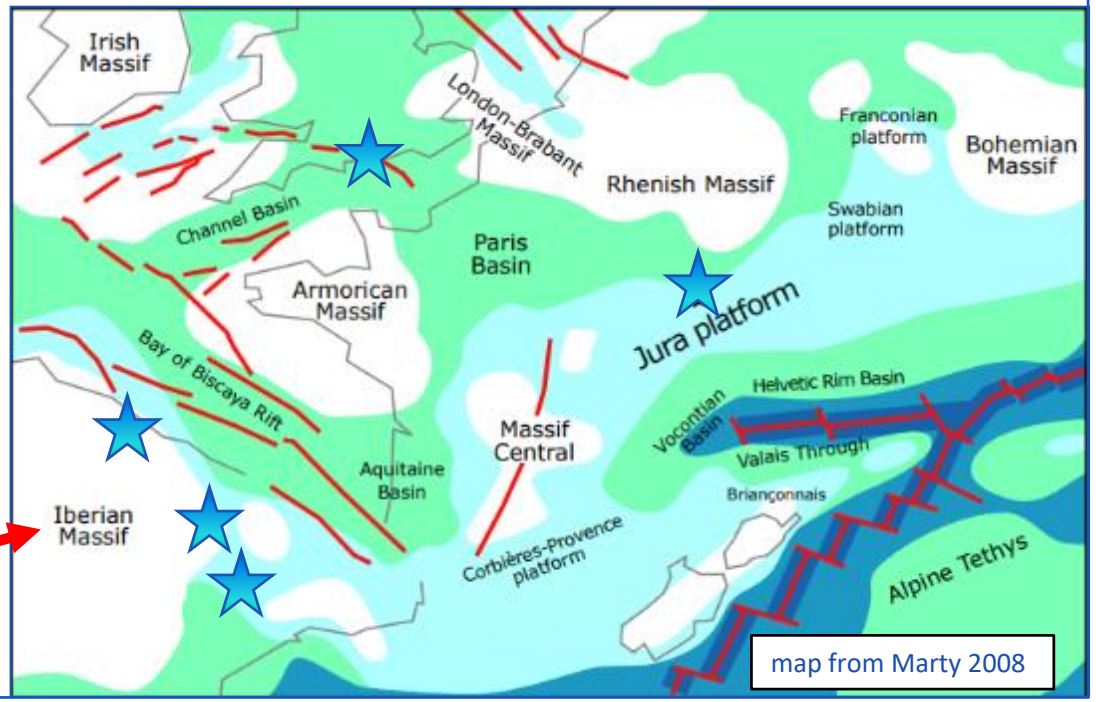


Tresch J. & Strasser, A. 2010 Intern. J. Earth Sci. 99, 139-163,

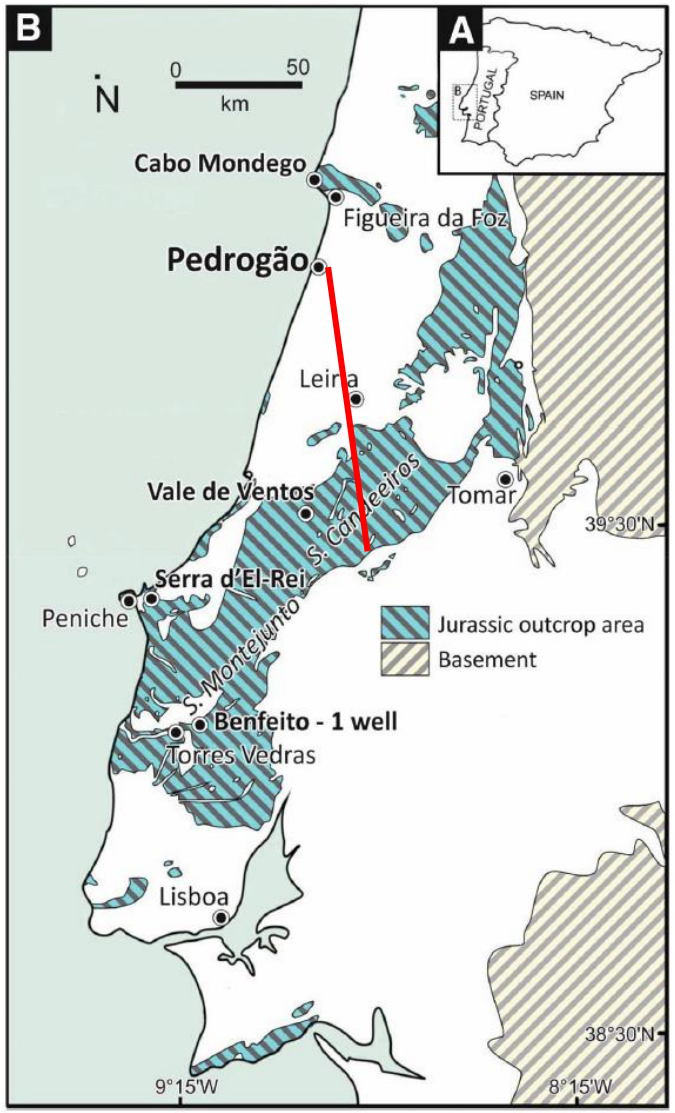
Coeval marine transgression in the Berriasian of NE Spain may have controlled palustrine and lacustrine deposition in proximal interior rifts (Basco-Cantabrian and Cameros basins)

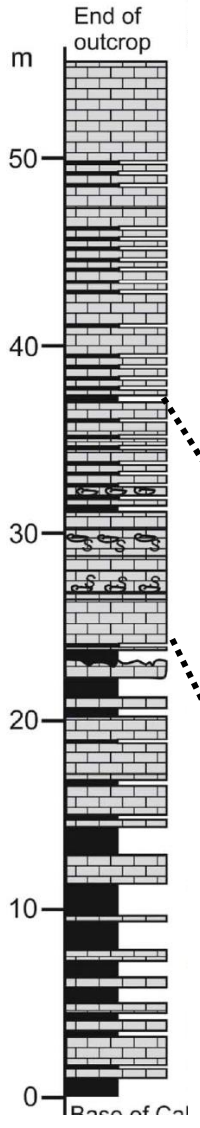
Platt, N.H. 1995. Intern Assoc Sedimentol Spec Publ, 22, 219–236;
Diéguez, C. et al. 2009, J Iberian Geol. *35*, 127–140;
Mas R et al. 2019 J Iberian Geol., 45, 1–27

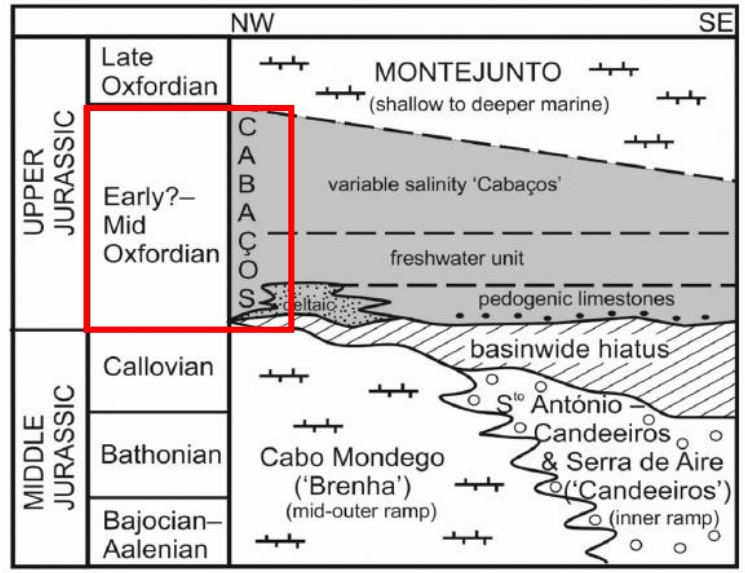




Oxfordian Cabacos Fm of W Portugal: transgressive lacustrine-brackish-marine succession associated with a thicker freshwater interval atop a major unconformity and karsted terrain







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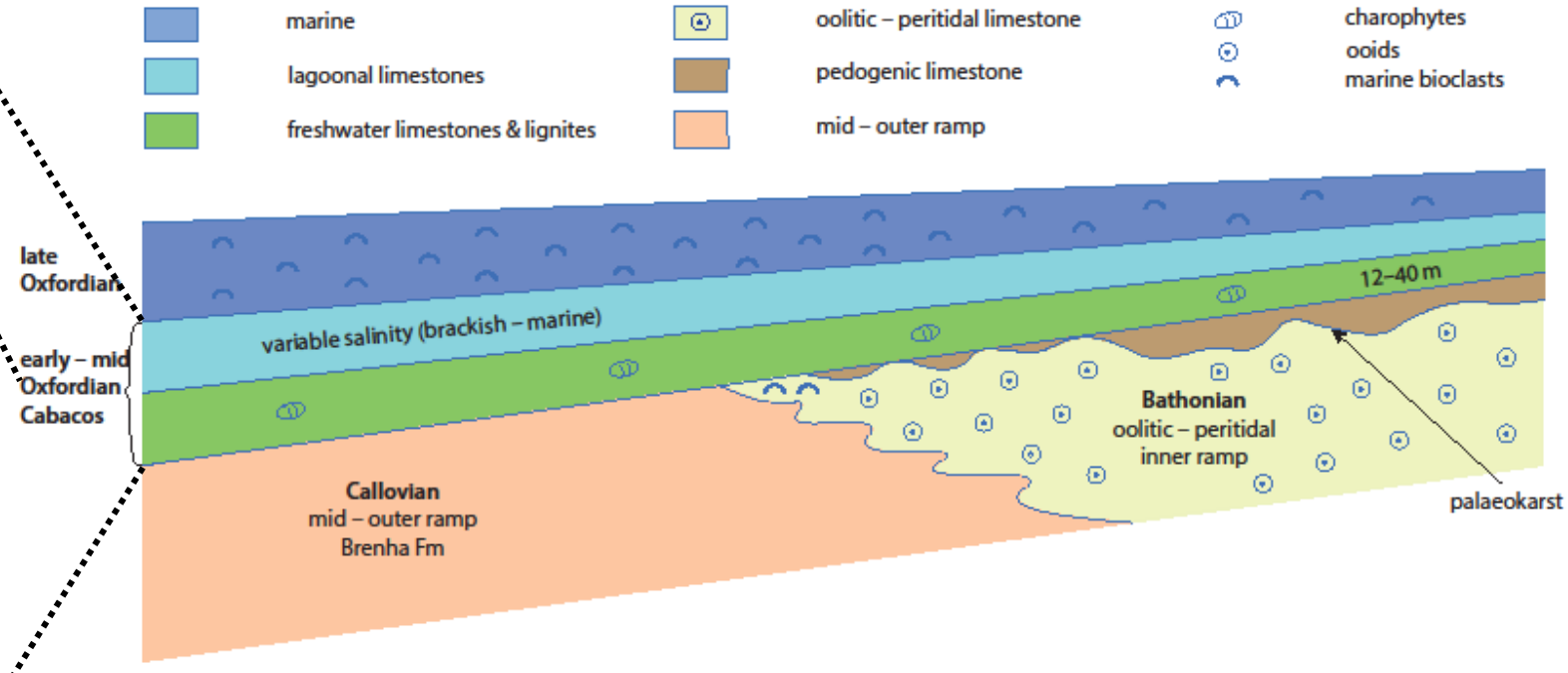

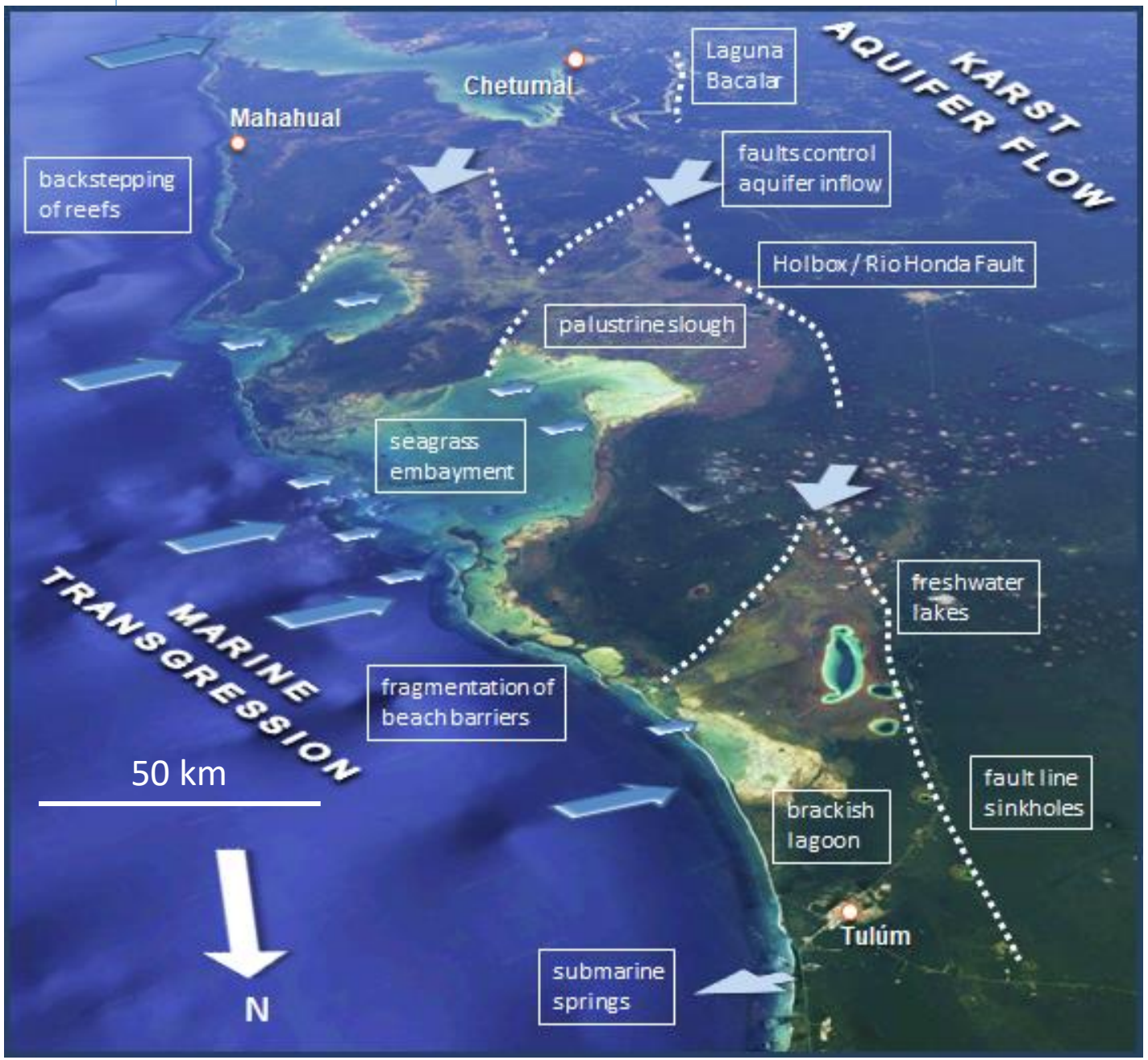

Conclusions

- The classic view that carbonate platform flooding results in transgressive lags is simplistic
- Complex **hydrological and hydrogeological** transitions take place on many flooding platforms – the Sian Ka'an Wetlands of Yucatán, Mexico and the Florida Everglades are examples
- Karstic aquifer discharge is a fundamental control
- Rise of the meteoric lens in transgression creates extensive coastal wetland systems, comprising a **freshwater-brackish carbonate factory**, which is dynamically linked with marine systems offshore
- During icehouse conditions, when sea-level rise is rapid, the freshwater factory may be short lived
- Slower sea-level changes in the greenhouse world facilitated many examples in coastal environments, and also in interior rifts and foreland basins where accommodation space permitted preservation