

Regional Upwelling as a Major Control in Development of a Miocene Heterozoan-Dominated Carbonate System in a Tropical Setting, Puerto Rico*

Diana Ortega-Ariza¹ and Evan K. Franseen¹

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¹University of Kansas, Lawrence (dianalo@ku.edu)

Abstract

Heterozoan carbonate systems are increasingly being recognized as important petroleum reservoirs in the rock record; yet models for such systems are lacking, especially those that developed in low-latitude settings. A middle-late Miocene carbonate ramp system in Puerto Rico provides ideal outcrops of heterozoan-dominated carbonates that were deposited in a tropical setting. Three sequences (DS1, DS2, and DS3) developed in response to relative sea-level fluctuations. Each sequence is characterized by basal heterozoan-dominated facies (e.g., benthic foraminifera, molluscs, red algae) that grade upward to a mix of heterozoan and photozoan (e.g., cool- and turbid-water corals) facies at the top. DS1 transgressive deposits consist of in-place *Kuphus incrassatus* bivalves within a soritid foraminifera facies, and *Amphistegina* sp. foraminifera packstone interbedded with *Kuphus* and oyster facies. Upper DS1 consists of *Montastrea* sp. coral debris flows followed by in-place *Goniopora* sp. and *Porites* sp. coral reef that can be traced down paleoslope, indicating deposition during highstand and relative sea-level fall. DS2 transgressive deposits consist of soritid and bivalve packstone facies that grade upward to facies containing corals (*Montastrea* sp., *Porites* sp.) deposited during highstand and relative sea-level fall. DS3 transgressive deposits consist of soritid and bivalve packstone facies, which grade upward to red algae boundstones and coral-rich facies (*Montastrea* sp., *Porites* sp., *Agariicid* sp.) deposited during highstand and relative sea-level fall. Upwelling has been documented as a regional process in the Caribbean during the middle and late Miocene. The dominance of heterozoans and local photozoan corals tolerant of cool and turbid conditions in our study is consistent with upwelling of nutrient-rich and cooler water. Although upwelling appears to have been persistent throughout deposition, the presence of photozoans only in the highstand and regressive portions of sequences suggests a relationship of upwelling to relative sea level, with highest intensities during transgressions. Shallow-water heterozoan systems that form in tropical settings require special conditions; in our study upwelling and sea level were the major controls, and their interaction resulted in predictable facies partitioning. These results have application to heterozoan reservoir systems, such as those in offshore Vietnam and Venezuela.

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CARBONATE FACIES TYPES

TROPICAL >22 °C	SUBTROPICAL 22-18 °C	TEMPERATE 18-10°C	COLD 10-5°C	POLAR < 5 °C
Photozoan				
James, 1997		Heterozoan		

Heterozoans



Bryozoans



Red algae



Echinoderms



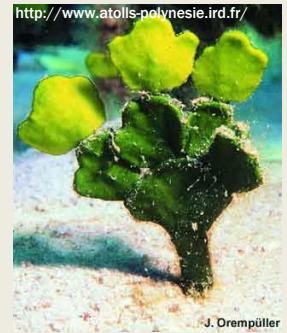
Molluscs

ramp

Photozoans



Corals



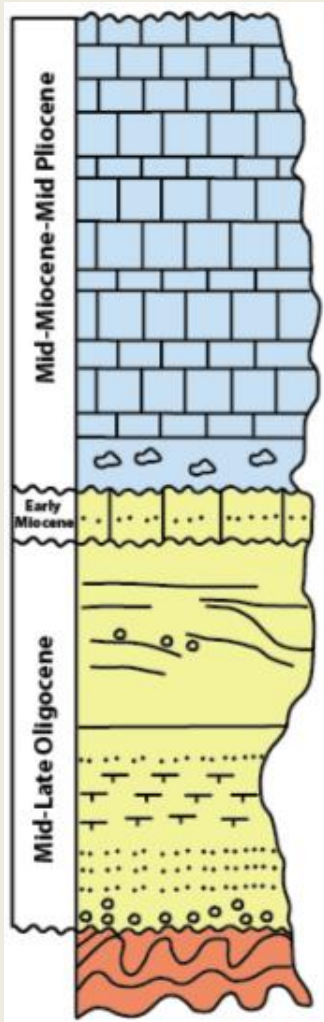
Green algae



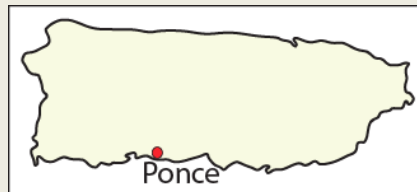
Large Benthic Foraminifera

rimmed platform

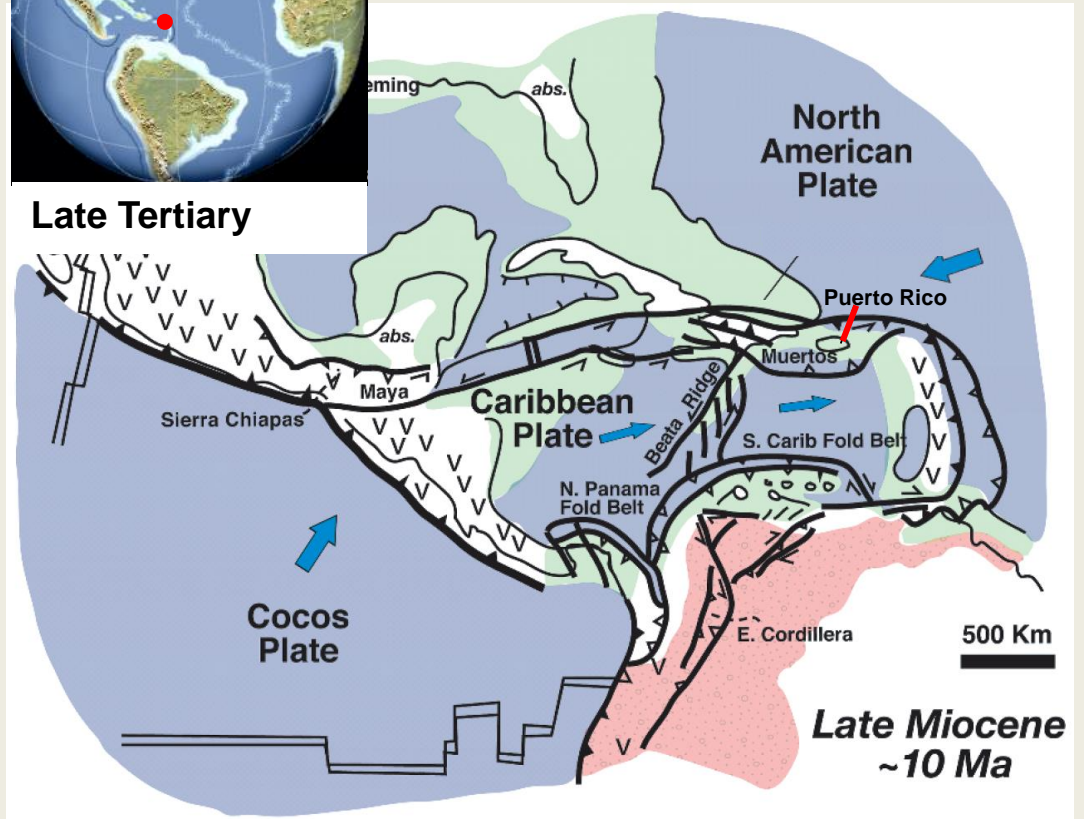
LOCATION

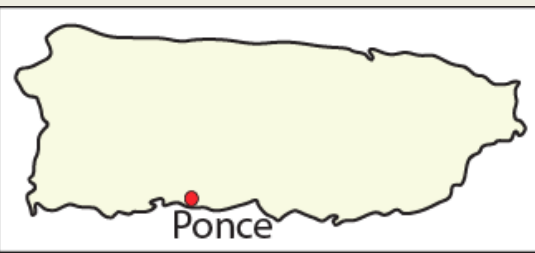


← **Ponce Ls**
Carbonate
embayment
with patch reefs



Late Tertiary





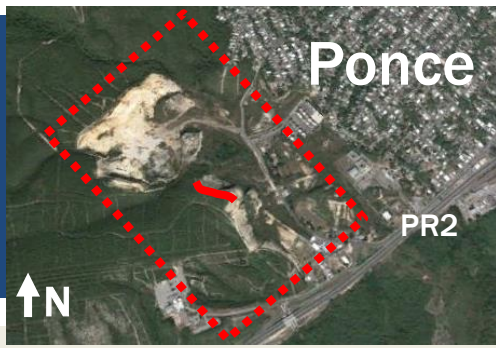
Ponce

PR2

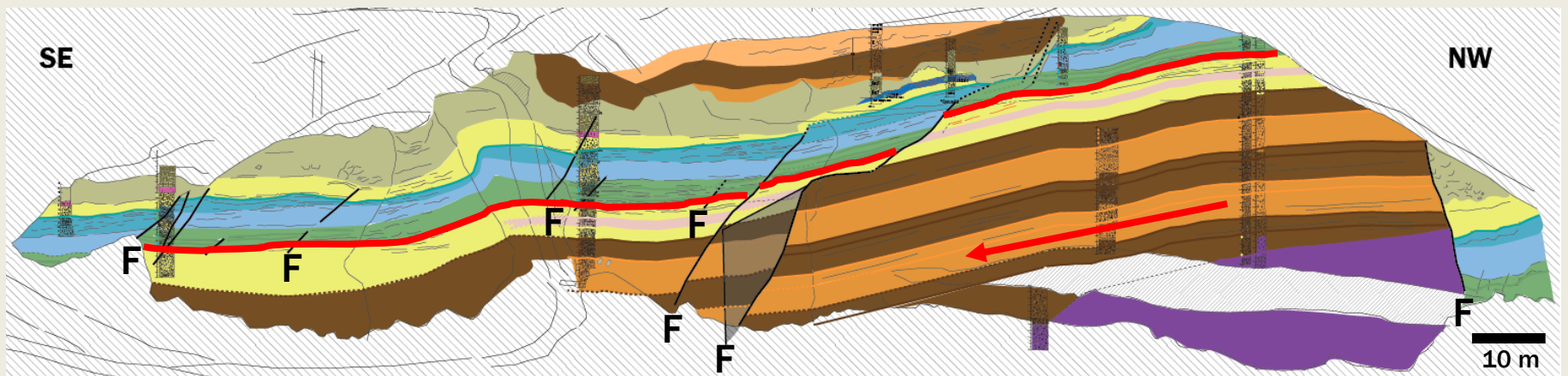
Salina
Lagoon

Caribbean Sea

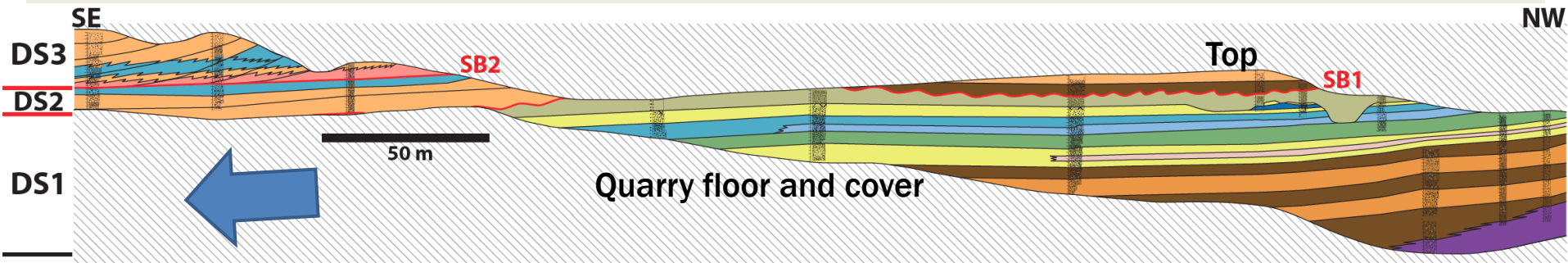




PONCE LIMESTONE



HETEROZOAN-DOMINATED RAMP SYSTEM

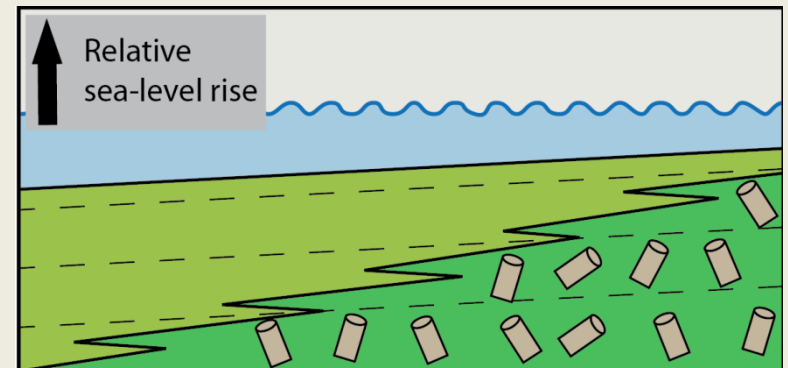
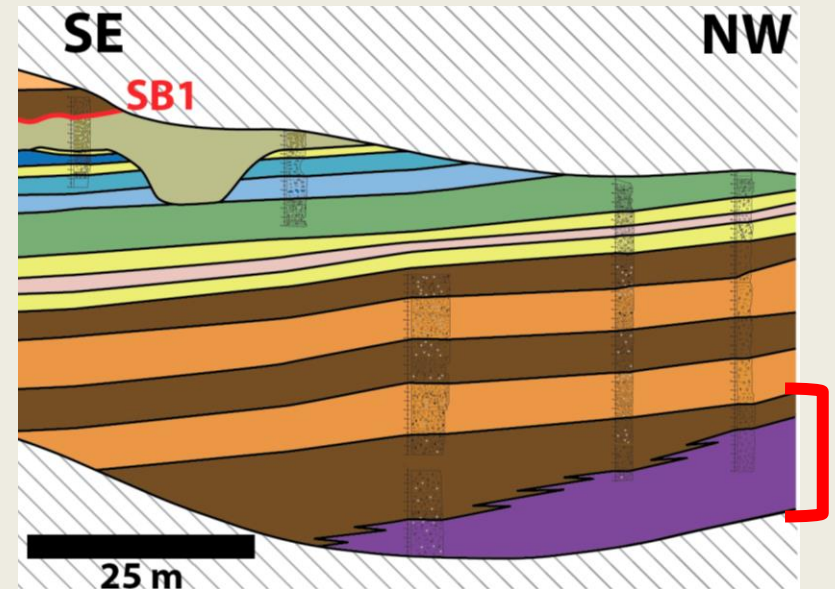


- Gently dipping ($\sim 3^\circ$) ramp
- Three Depositional Sequences



BASAL DS1

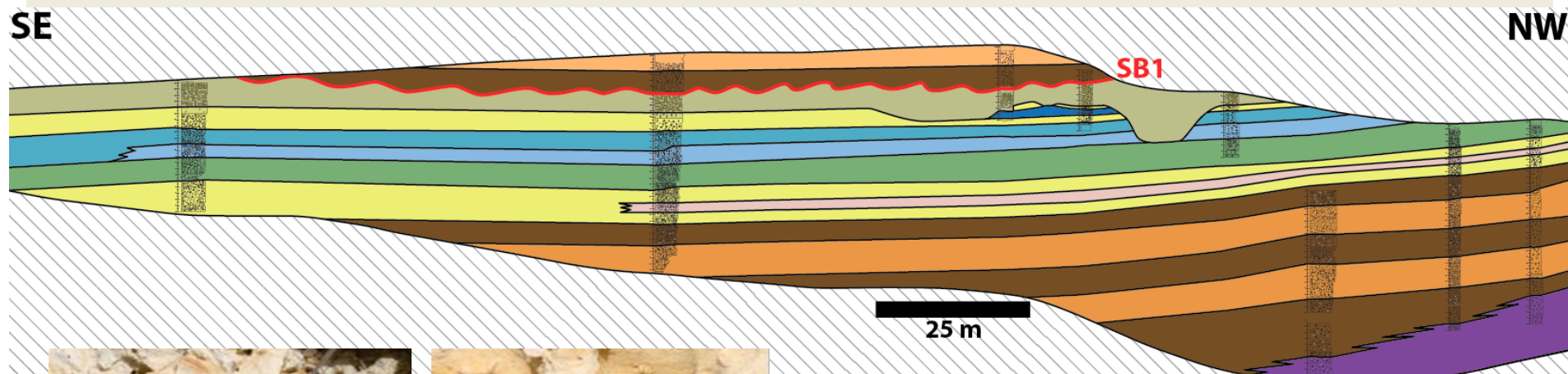
In-place *Kuphus* backstepping, interfingering and progressively changing to BF Facies



Heterozoan-dominated facies

BASAL DS1

Alternating packages of benthic foraminifera facies



Benthic foraminifera



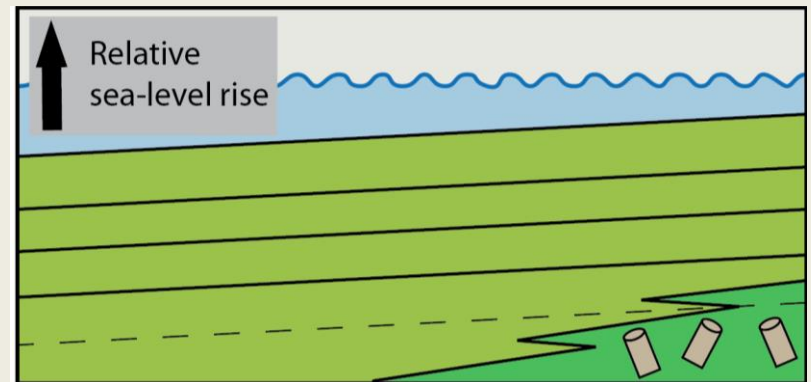
Bivalve



Gastropod



Solitary coral



Heterozoan-dominated facies

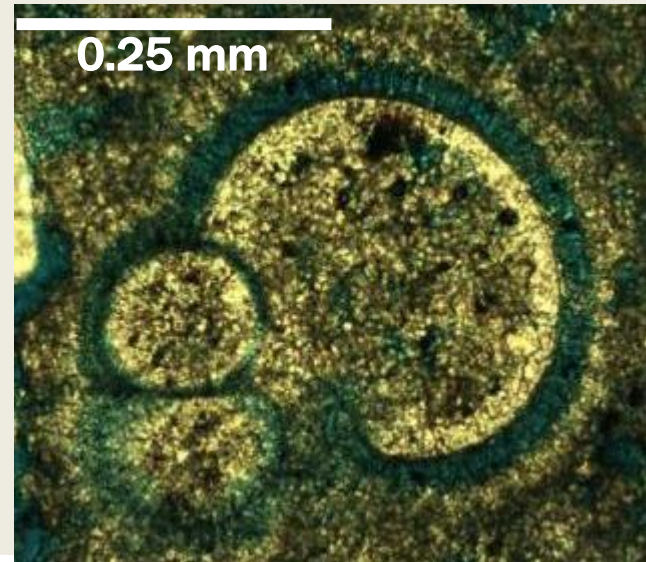
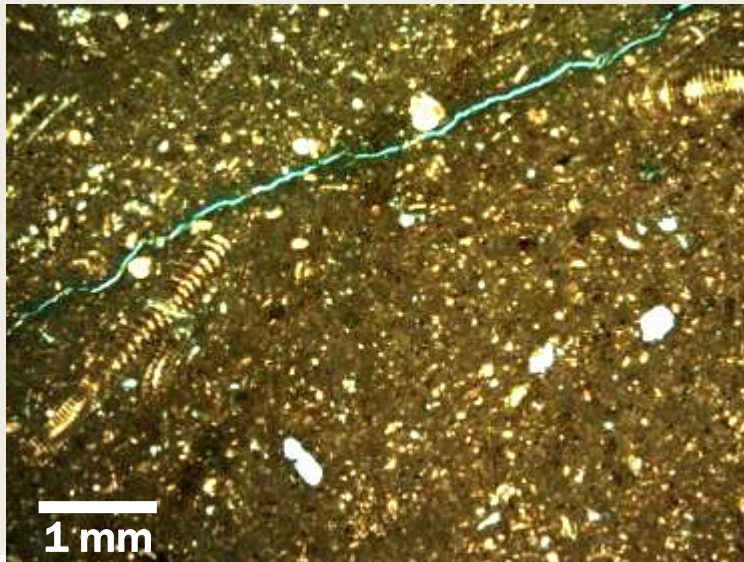
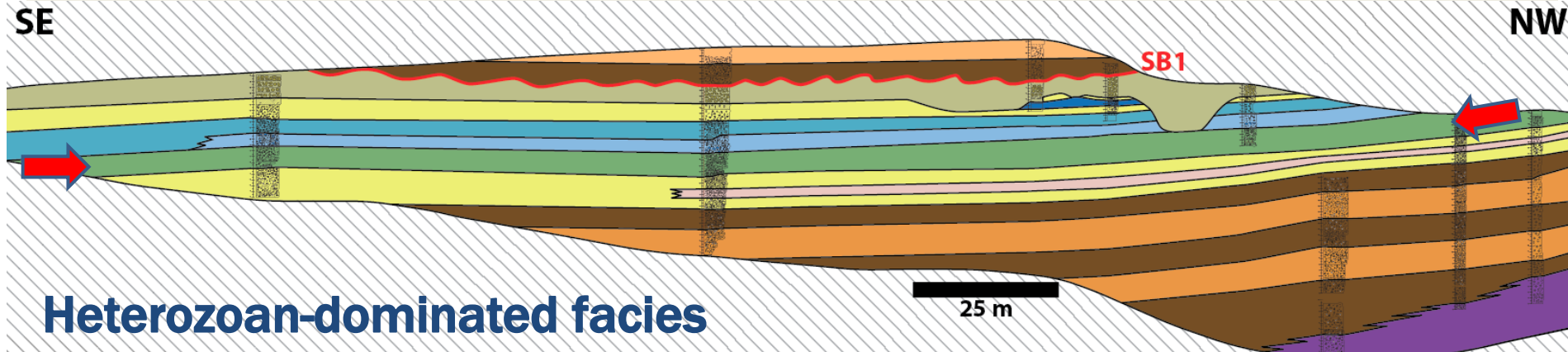
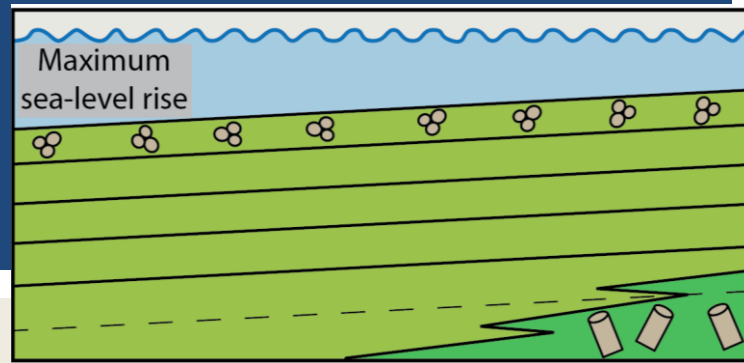
***Ostrea, Kuphus, Clypeaster* layers**
(Bivalves) (Echinoids)



***Kuphus* backstepping**

UPPER DS1

Globigerinid sp. planktonic foraminifera



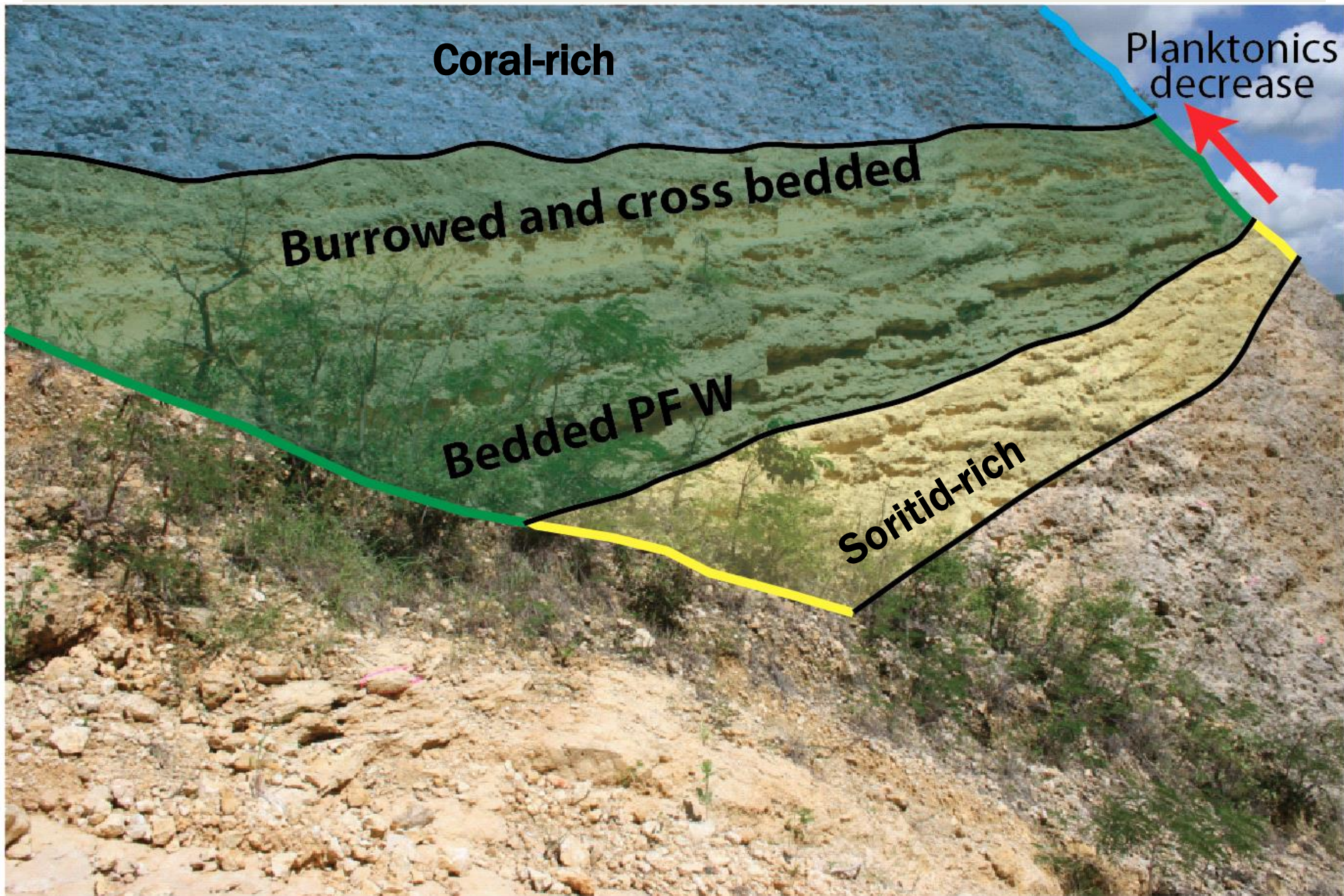
Coral-rich

**Planktonics
decrease**

Burrowed and cross bedded

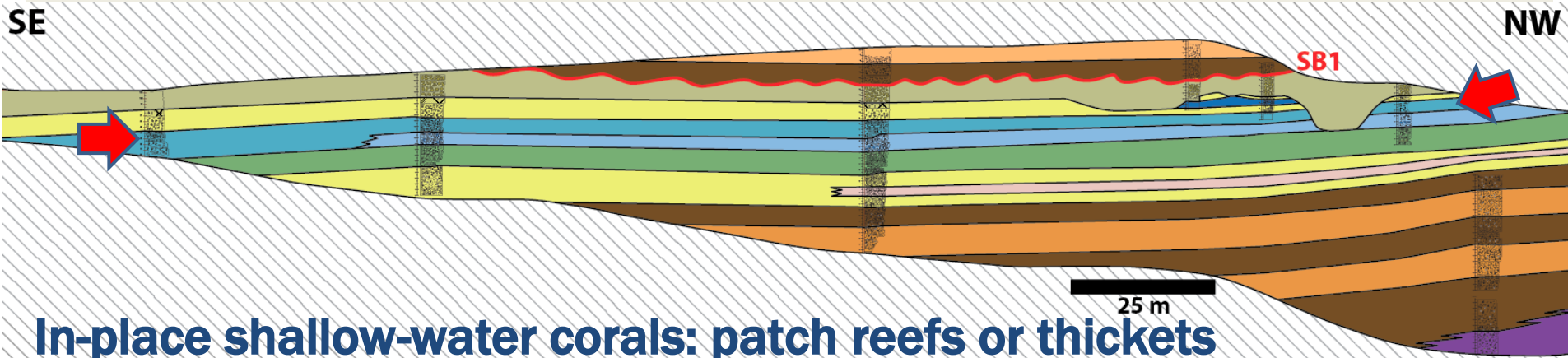
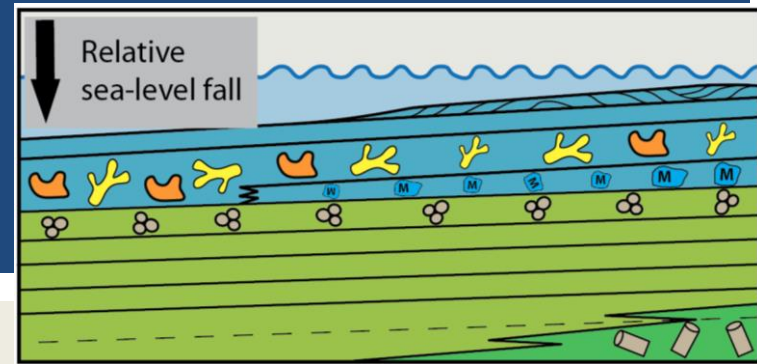
Bedded PF W

Soritid-rich



UPPER DS1

Photozoan-dominated facies



In-place shallow-water corals: patch reefs or thickets

M. imperatoris

G. imperatoris

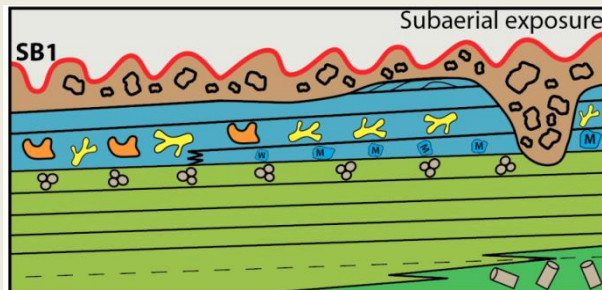
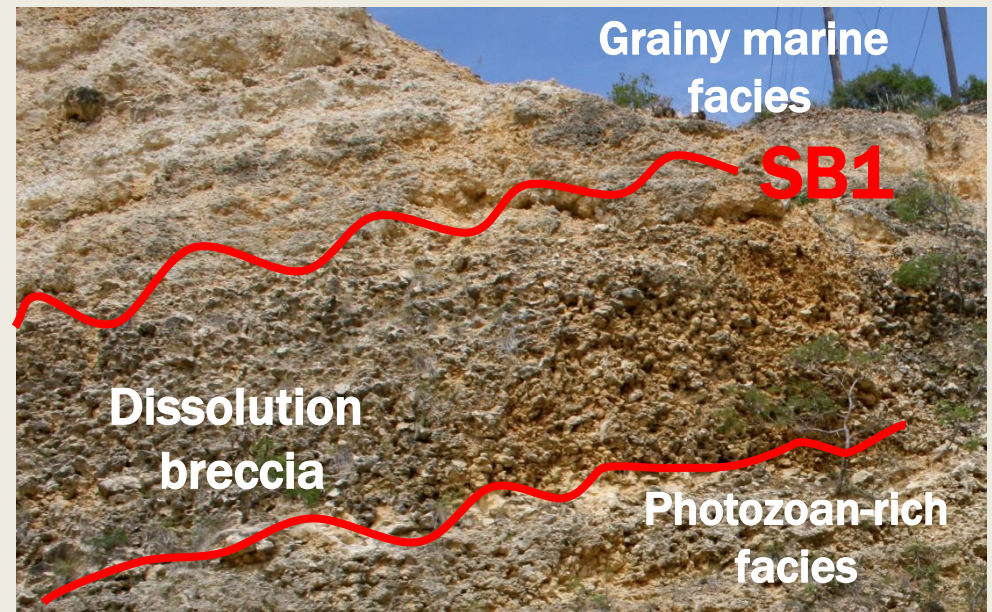
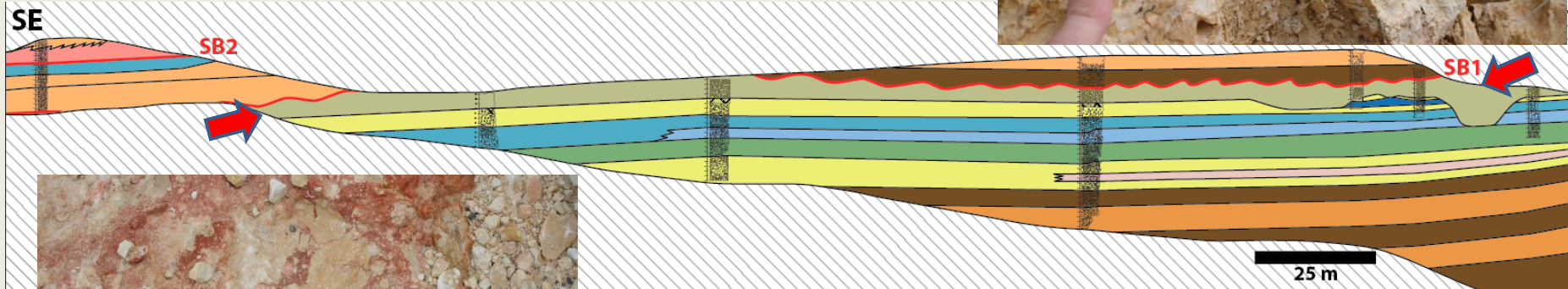
P. baracoensis

P. macdonaldi

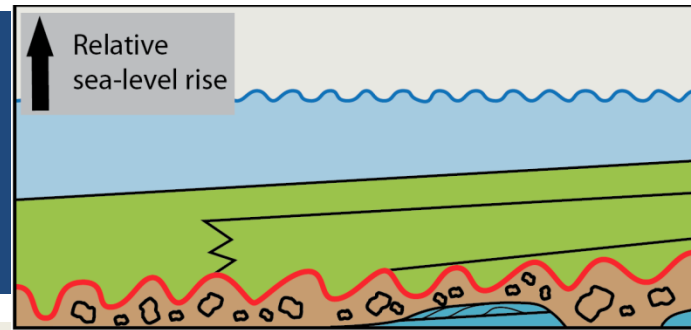


UPPER DS1 – SB1

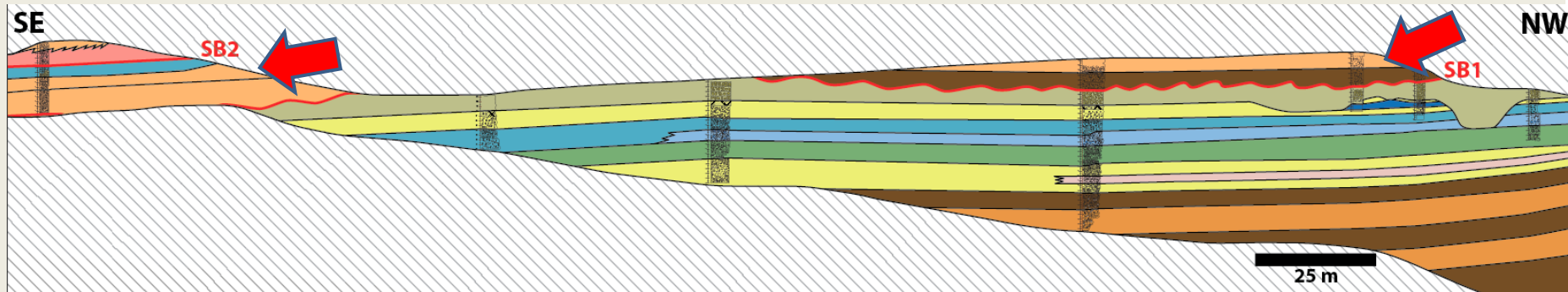
Recrystallized dissolutional breccia



BASAL DS2



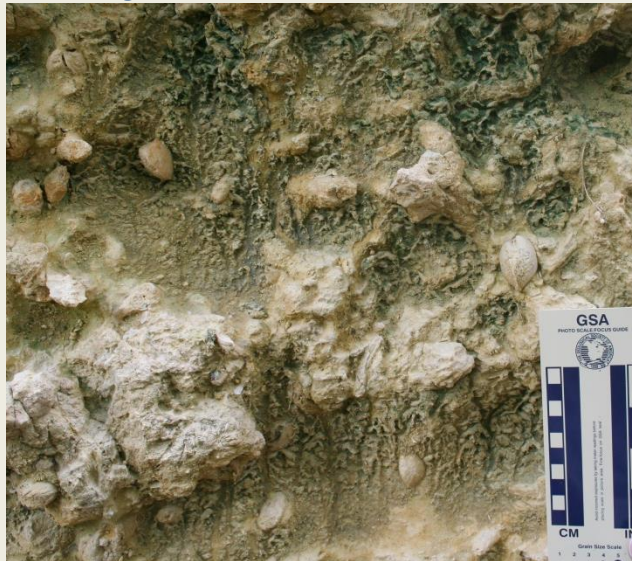
Heterozoan-dominated facies



Burrows and cross beds



Myrtaea sp. bivalve

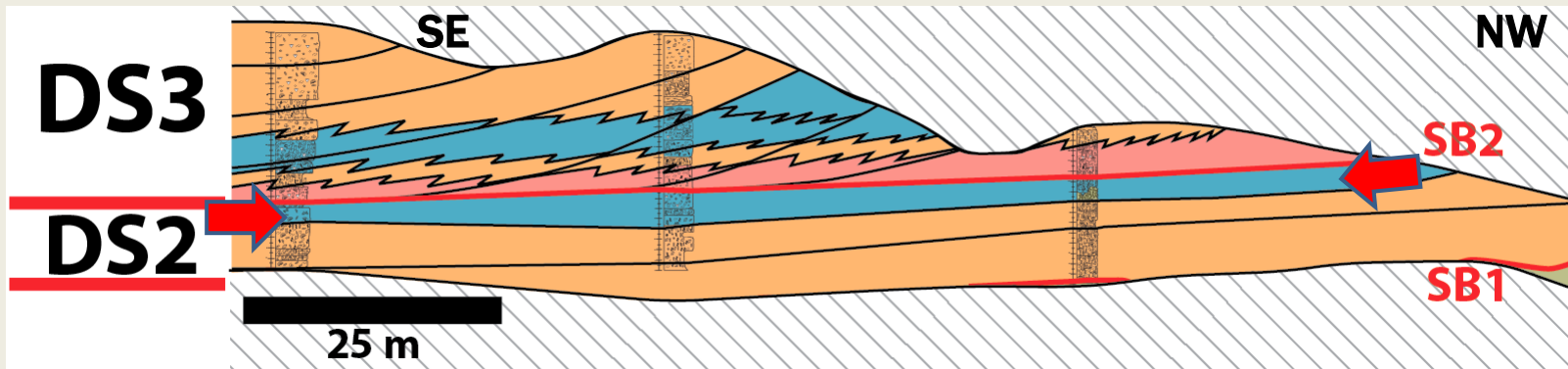


Soritids

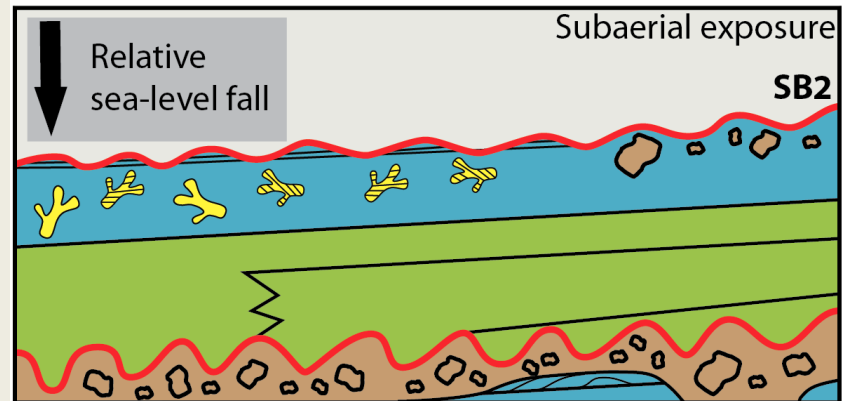
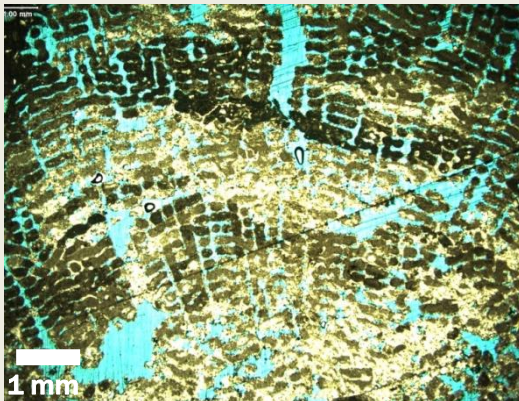


UPPER DS2

Photozoan-dominated facies

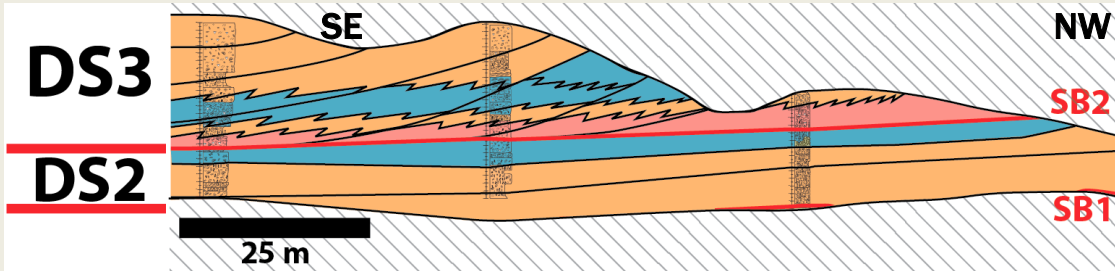


- Base: In-place shallow-water *Porites* sp. corals
- Top: Recrystallized grains, oxidation, alteration, local brecciation



UPPER DS3

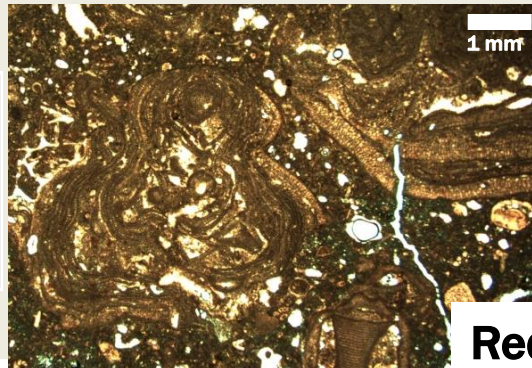
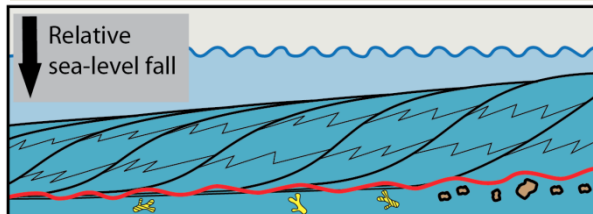
Photozoan-dominated facies



Agaricia undata



Clinoforms



Red algae





MIOCENE PONCE RAMP SEQUENCES

Heterozoan-Dominated Facies



Red Algae



Bivalve



Gastropod



Solitary coral



Bryozoan



Echinoid

Cold-water, Turbidity-tolerant Corals



P. baracoensis



P. macdonaldi



A. undata



M. imperatoris



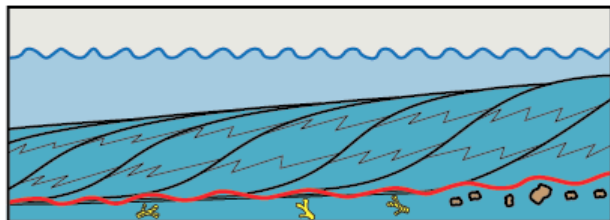
G. imperatoris



P. portoricensis



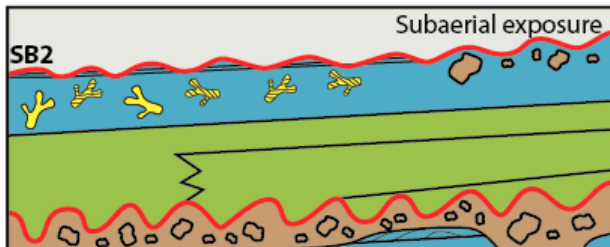
5



DS3

SB2

4



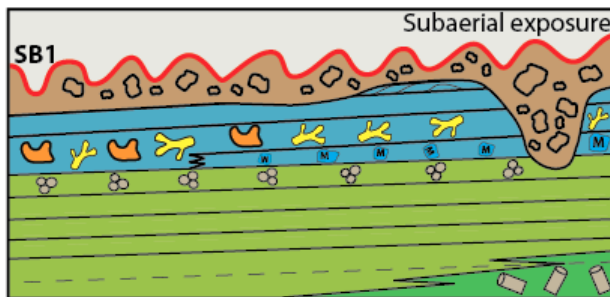
DS2

3



SB1

2



DS1

1



R T



P

H?

P

H

P

H



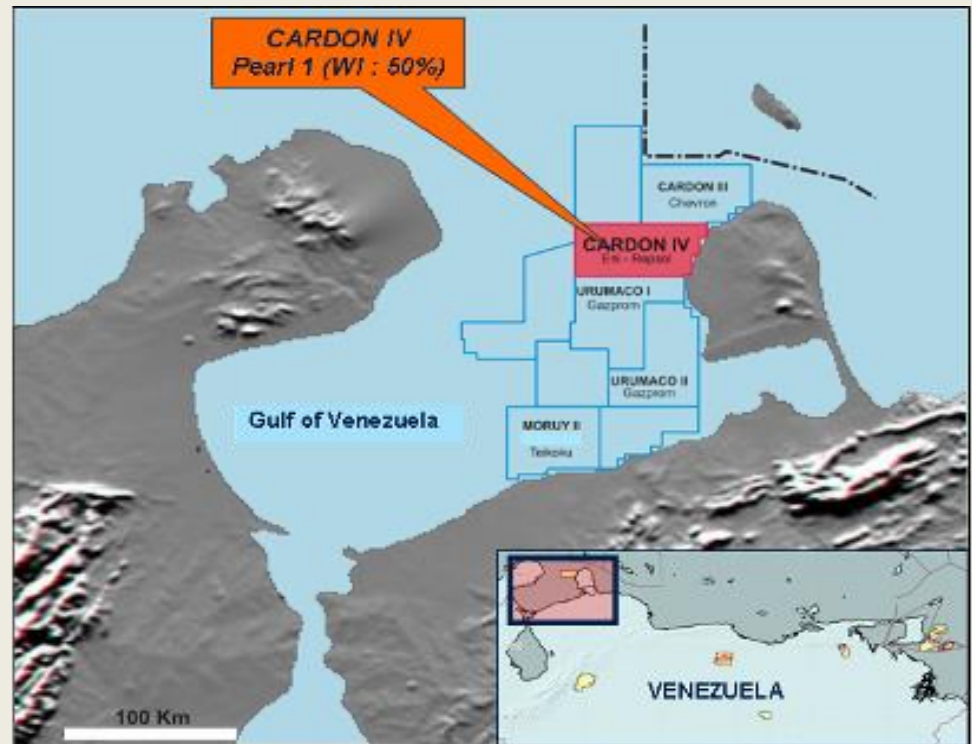
- **Three Depositional Sequences**
- **Alternation of Heterozoan (transgressions) and Photozoan (regressions) facies**

PERLA GIANT GAS FIELD

- Oligocene – Miocene Heterozoan
- Distally steepened ramp
- Facies distribution controlled by physical & biological processes

- **Constituents:**

- Dominant: Branching red algae, rhodoliths, large benthic forams
- Common: Molluscs, barnacles, bryozoans, planktonic forams, finger corals, green algae



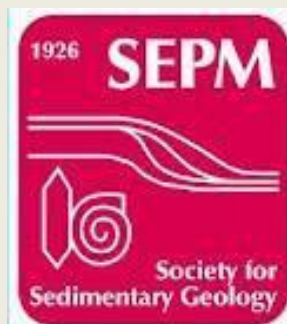
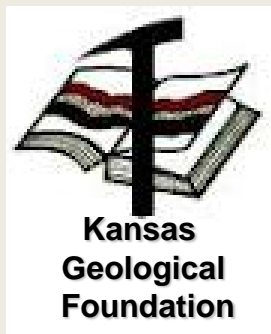
KEY FINDINGS

- **Three Middle-Late Miocene (~13-10 My) carbonate sequences (Ponce Ls, PR)**
 - Alternations of Heterozoan (transgressions) and Photozoan (regressions) facies
- **Controls**
 - Upwelling
 - Evidence of Miocene upwelling in Puerto Rico
 - Heterozoans abundant
 - Coral genera tolerant of cold-water and turbidity
 - Relative sea-level fluctuations
 - Appear to have affected upwelling intensity and resulted in important and predictable facies changes
- **Outcrop studies can aid in development of heterozoan models applicable to reservoir systems**
 - Perla Giant Gas Field – Venezuela

ACKNOWLEDGMENTS

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- Dr. Ann Budd - University of Iowa
- Dr. Marcelle Boudagher-Fadel - University College London



THANKS!

