Deep-Water Resedimented Carbonate Exploration Play Types: Controls and Models*

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Abstract

Deep water, resedimented deposits have been recognized and described in modern and ancient carbonate sequences, many with good reservoir potential, for example the giant Cretaceous Poza Rica field in Mexico (~40 MMBoe), the Mississippian Tangiz field in Kazakhstan, and several fields in the U.S. Permian basin (several Tcf gas). Nevertheless, carbonate slope and basin systems remain poorly understood when compared to their siliciclastic counterparts.

Re-appraisal of legacy published and unpublished work, combined with new work compiling a global database of surface and sub-surface examples of resedimented carbonates, has highlighted that downslope resedimentation of carbonate material is in large part controlled by the evolution of the parent platform margin, which in turn is best characterized in terms of various controlling processes such as carbonate factory type, tectonic setting, eustatic variations, and platform alignment relative to prevailing wind direction and ocean current patterns. Two generic play types are recognized: (i) attached carbonate slope play - developed immediately adjacent to the carbonate platform and dominated by rock fall and platform collapse deposits or in situ boundstone; and (ii) detached carbonate slope play - deposited further from the platform margin via channelized turbidity currents and other mass-flow processes.

High-rising, steep, bypass platform margins with scalloped reentrants and grain-dominated factories have the highest potential to generate channelized and detached deep-water reservoirs with high initial porosity and permeability. Best potential

reservoirs are aragonitic grainstones transported from the platform into the adjacent basin, and then subjected to submarine dissolution and early formation of secondary porosity to further enhance reservoir properties.

Any exploration model for identifying potential resedimented carbonate plays should be based on carbonate platform configurations and factory types favorable for re-sedimentation of large sedimentary bodies and preservation or enhancement of high original porosity. Using these proposed conceptual models in combination with global paleogeographic and paleotectonic maps, the explorer may be able to develop predictions for the likely age and location of resedimented carbonate plays with the greatest potential for further evaluation.

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Ted Playton (Chevron);

Xavier Janson, Charlie Kerans (BEG)

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Reserves: Our use of the term "reserves" in this presentation means SEC proved oil and gas reserves for all 2009 and 2010 data, and includes both SEC proved oil and gas reserves and SEC proven mining reserves for 2008 data.

Resources: Our use of the term "resources" in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves or SEC proven mining reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.

Organic: Our use of the term Organic includes SEC proved oil and gas reserves and SEC proven mining reserves (for 2008) excluding changes resulting from acquisitions, divestments and year-average pricing impact.

To facilitate a better understanding of underlying business performance, the financial results are also presented on an estimated current cost of supplies (CCS) basis as applied for the Oil Products and Chemicals segment earnings. Earnings on an estimated current cost of supplies basis provides useful information concerning the effect of changes in the cost of supplies on Royal Dutch Shell's results of operations and is a measure to manage the performance of the Oil Products and Chemicals segments but is not a measure of financial performance under IFRS.

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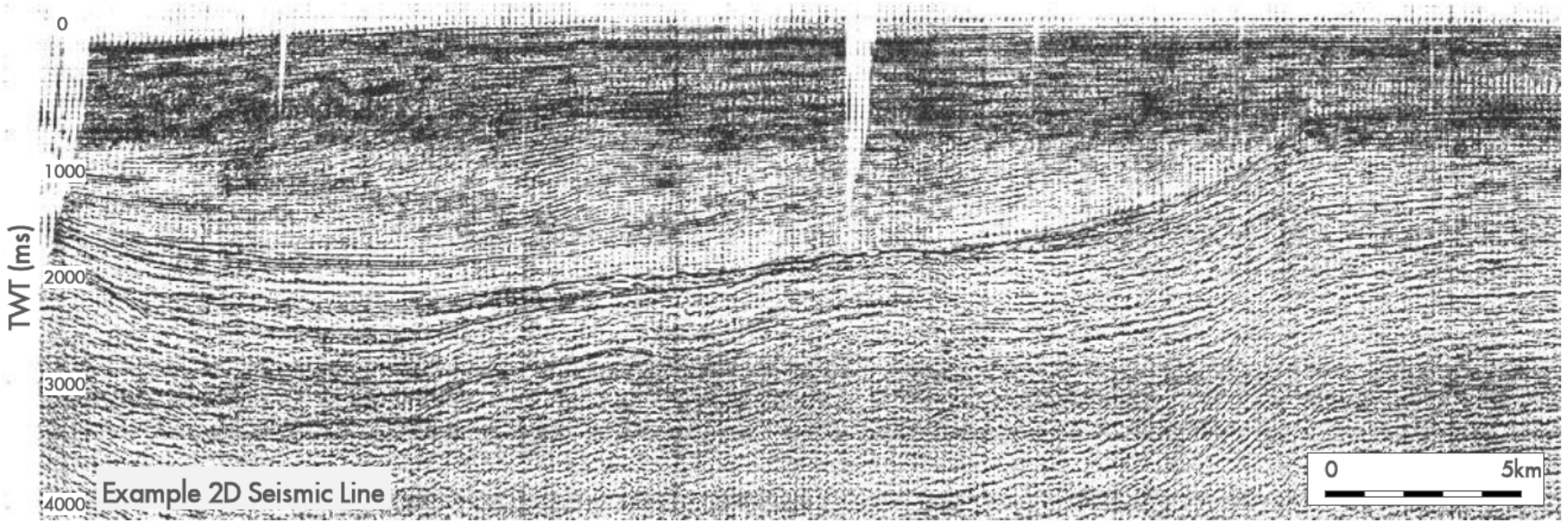
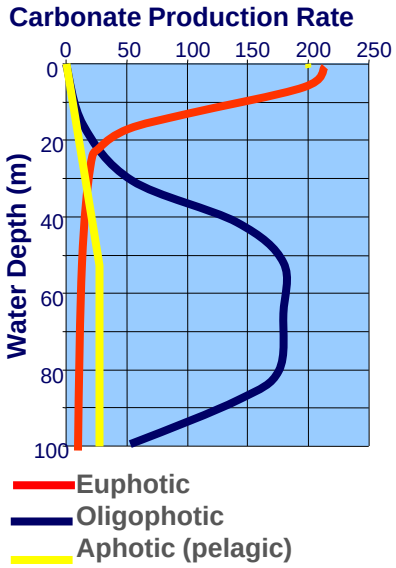
Introduction

- Frontier evaluation of carbonate plays commonly focused on platform top and margin
- Significant hc located in carbonate slope and adjacent basin (e.g. Mexico ~ 42 BBOE)
- Slope carbonate discoveries by accident or serendipity
- Significant legacy published & in-house research on carbonate slope potential

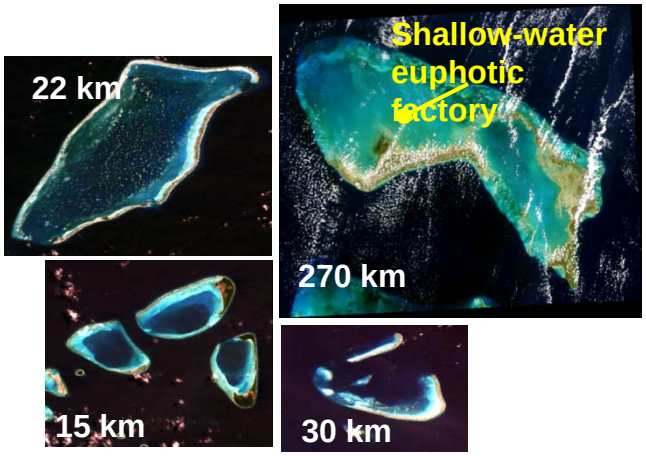


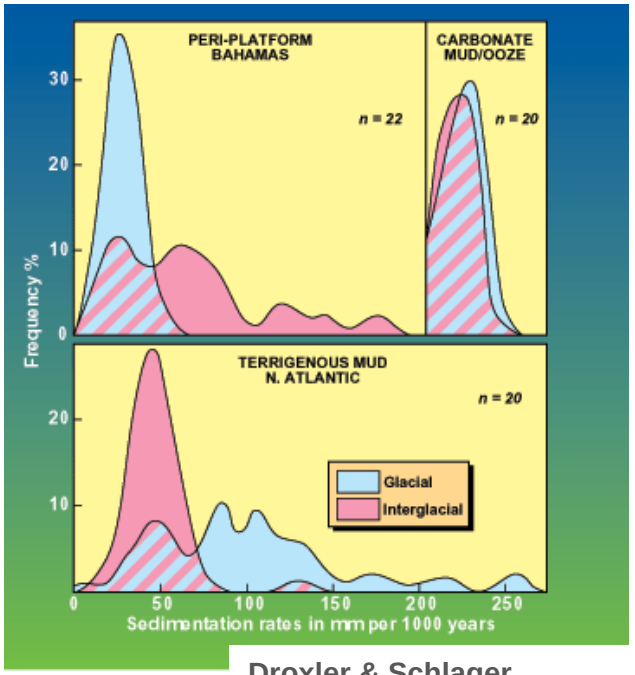
Process – Highstand shedding

1. Most carbonate grains are produced in shallow water



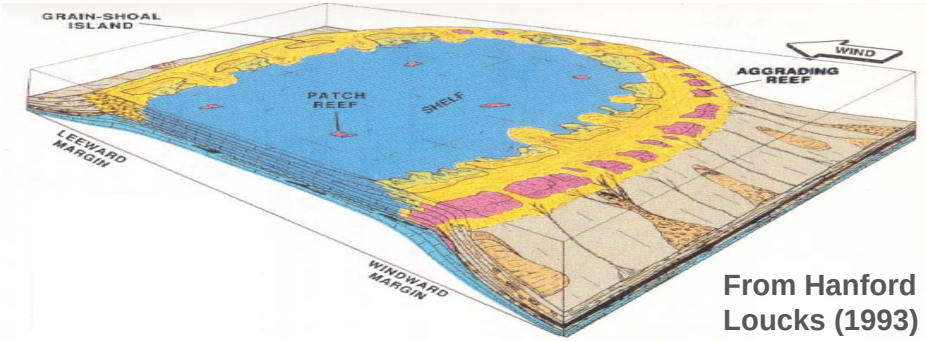
2. During highstands, flooded platform-tops are prolific "carbonate factories"





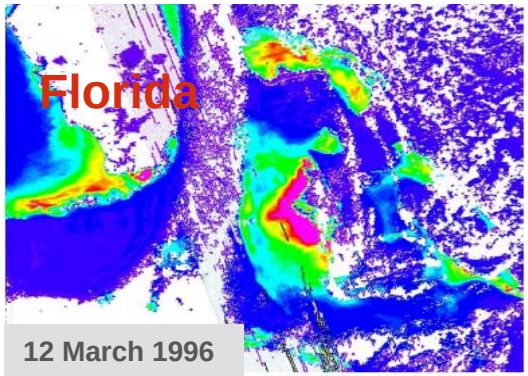
Droxler & Schlager (1994)

3. Carbonate grains produced on the flooded platform top can be transported across the platform, and down the slope into adjacent deep-water

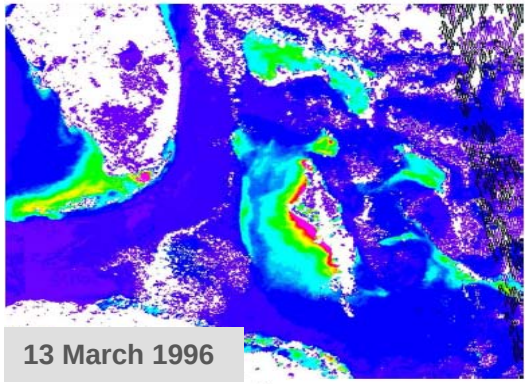


From Hanford & Loucks (1993)

Modern settings

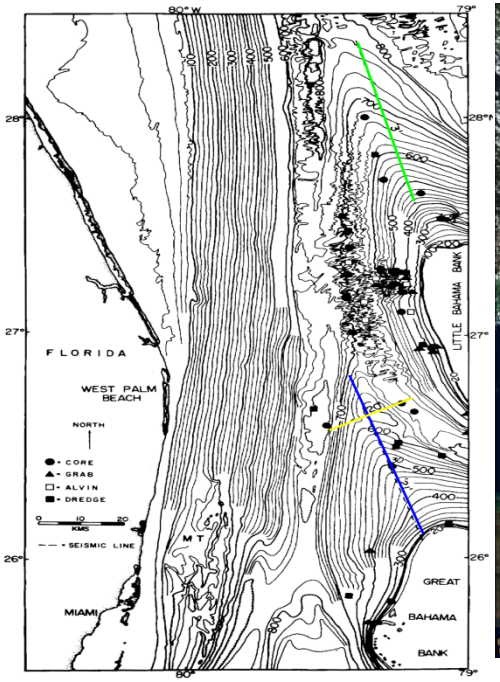


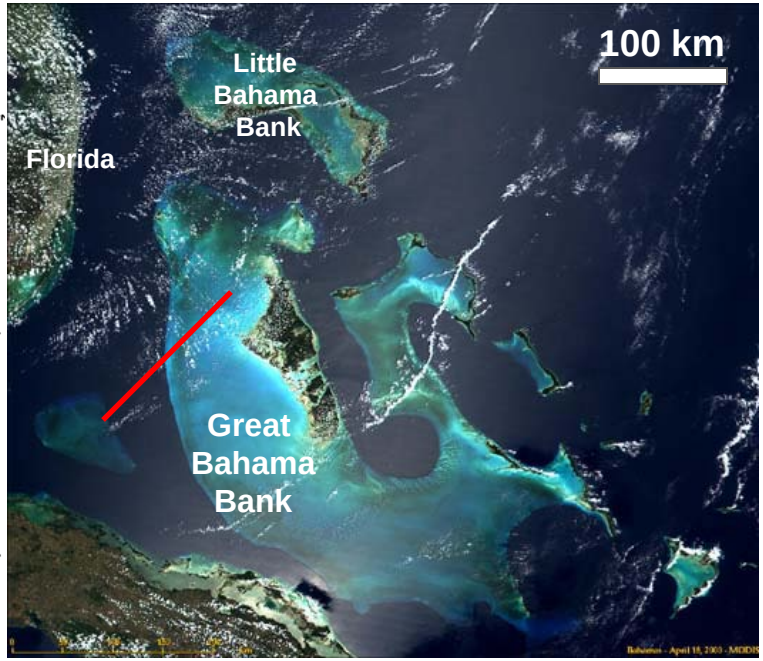
12 March 1996

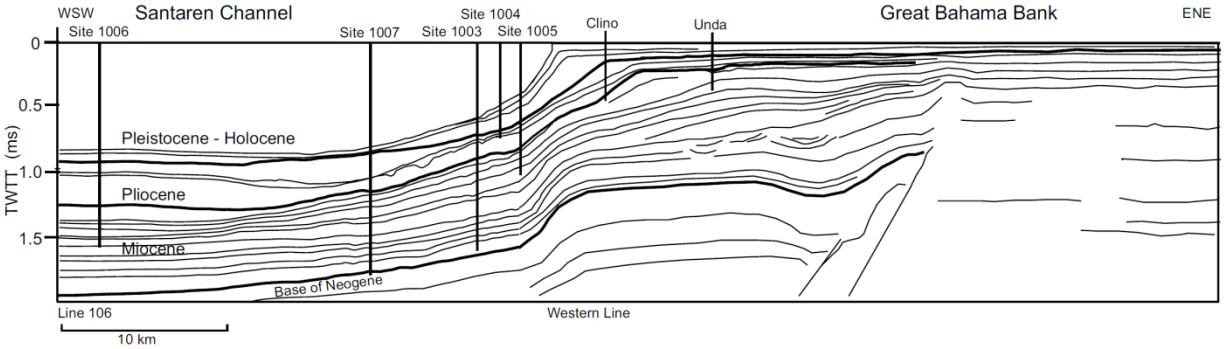


13 March 1996

From Acker et al. (2002) – reflectance image

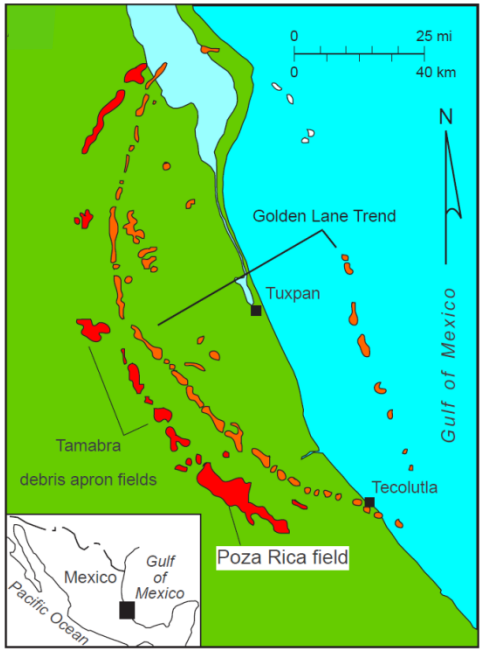


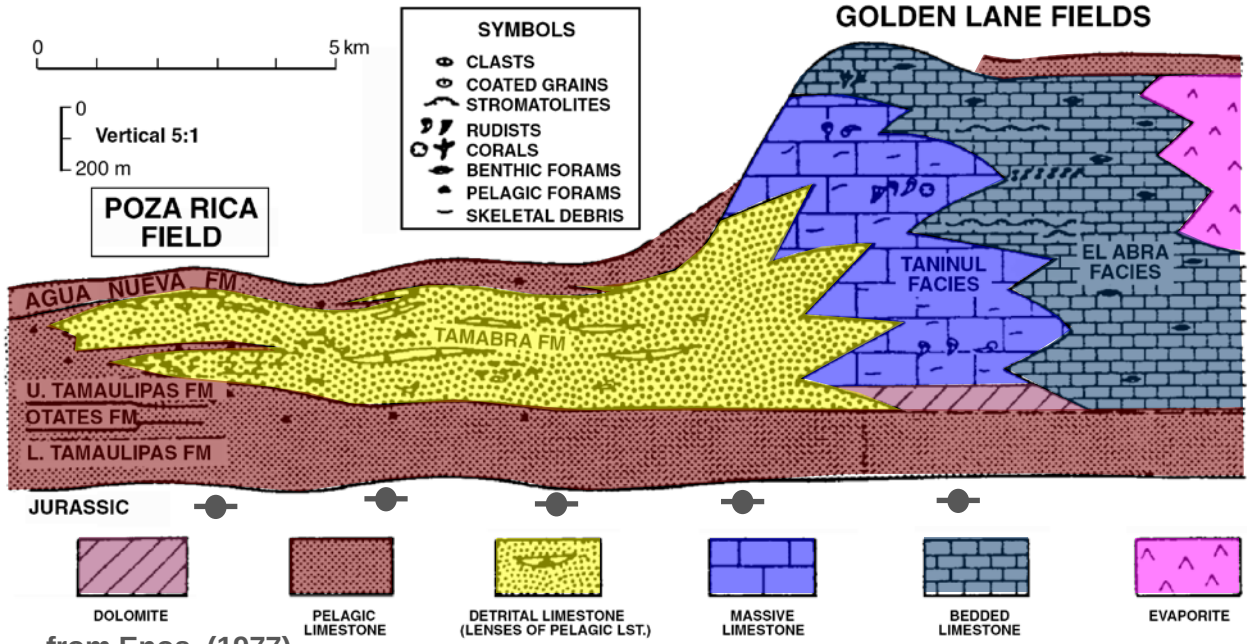




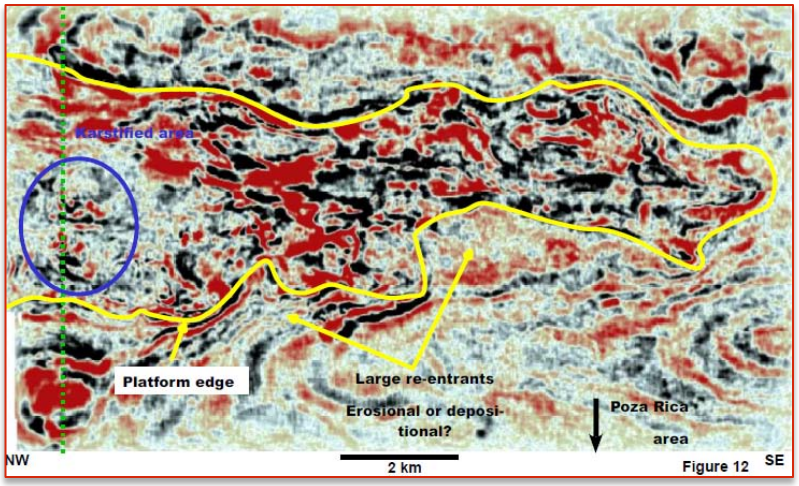
After Eberli et al. (2002)

Working example: Poza Rica





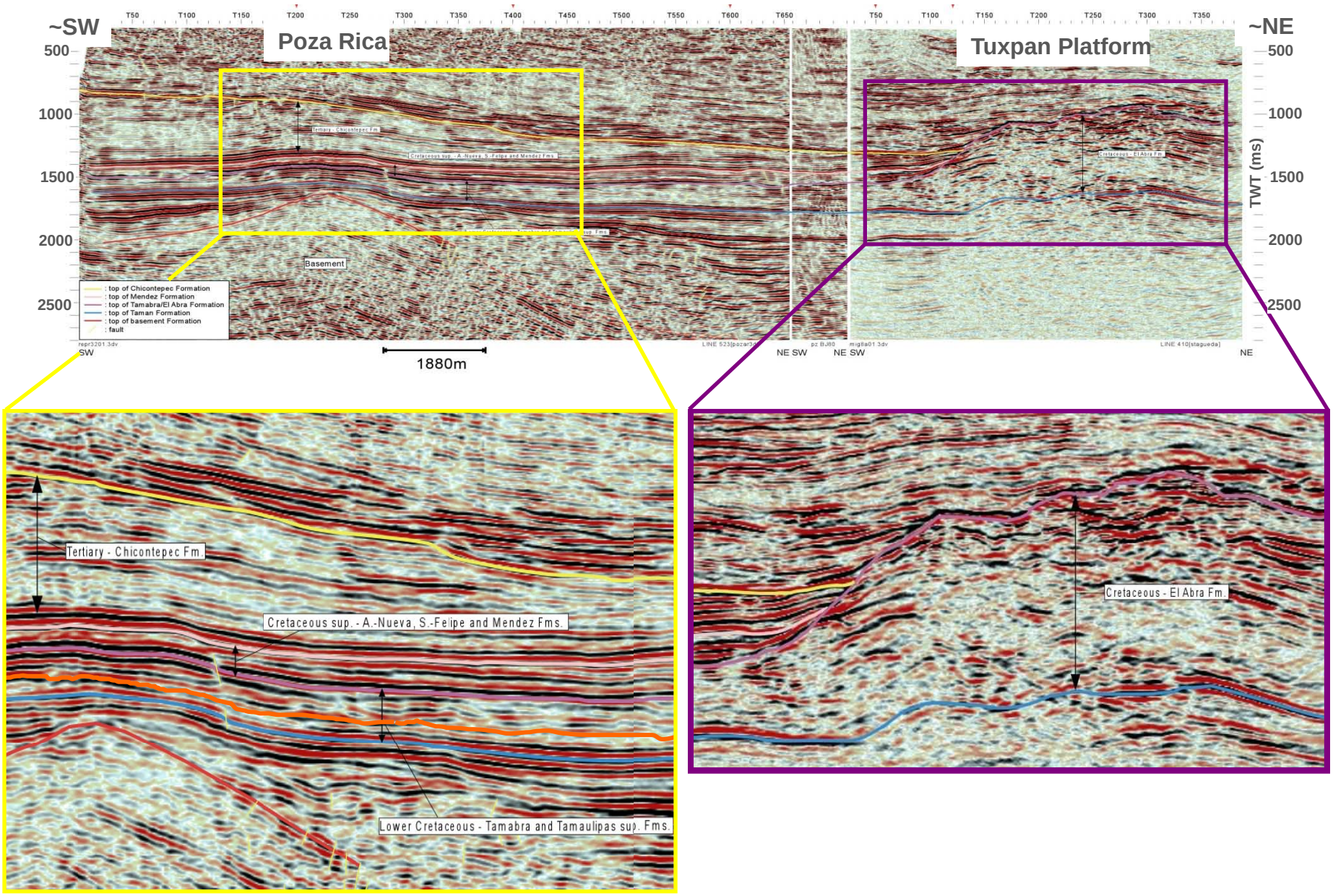
from Enos (1977)



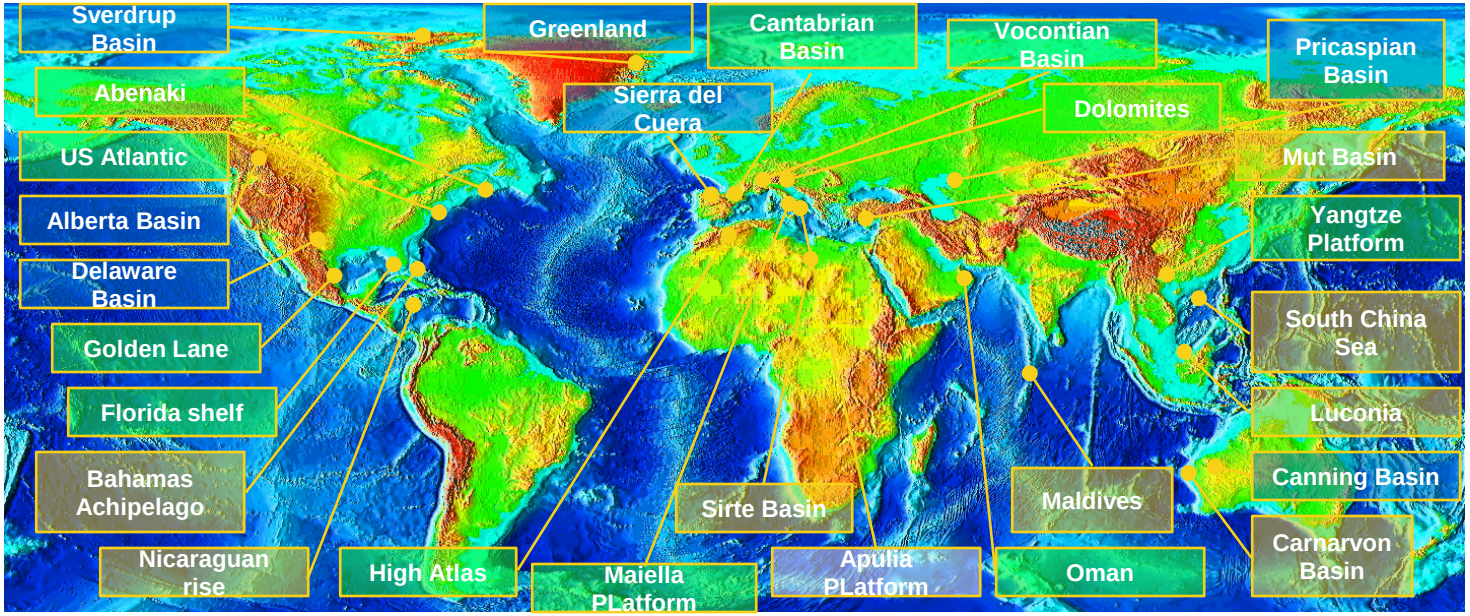
from Janson et al. (2011)

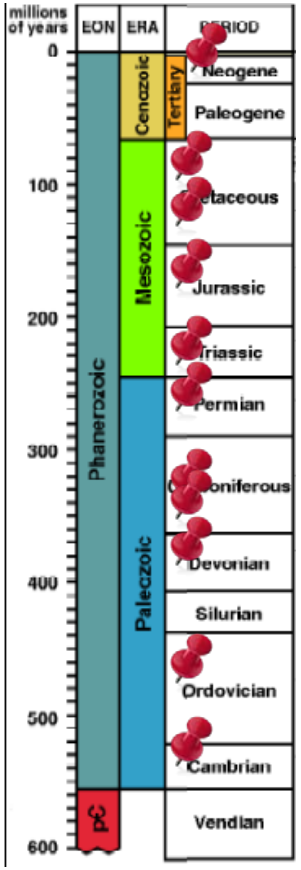
- World-class field discovered in 1930 (~2.7 BBOE recoverable
- Cretaceous Tamabra carbonate debris flows and calciturbidites
- Sourced from scalloped margin?
- Combined stratigraphic structural trap

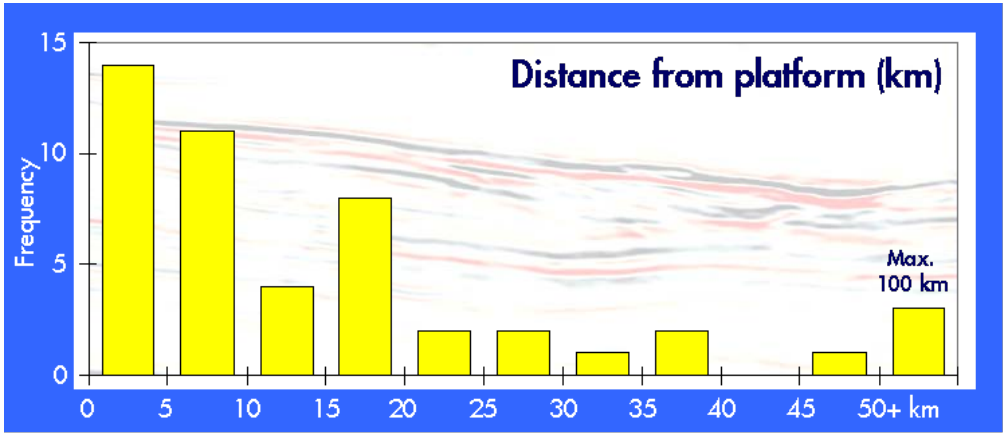
Working example: Poza Rica

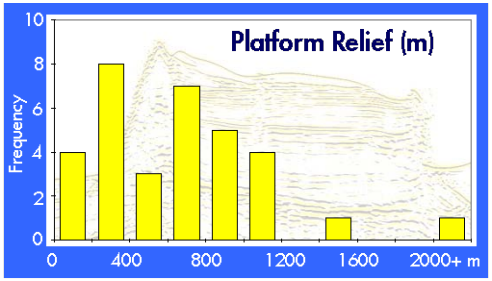


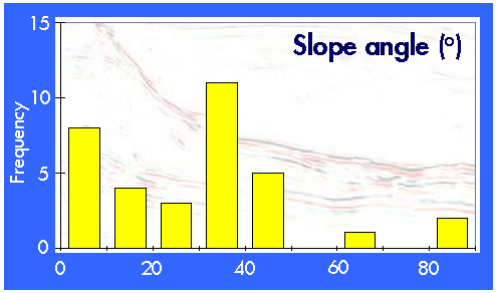
Carbonate Slope Database



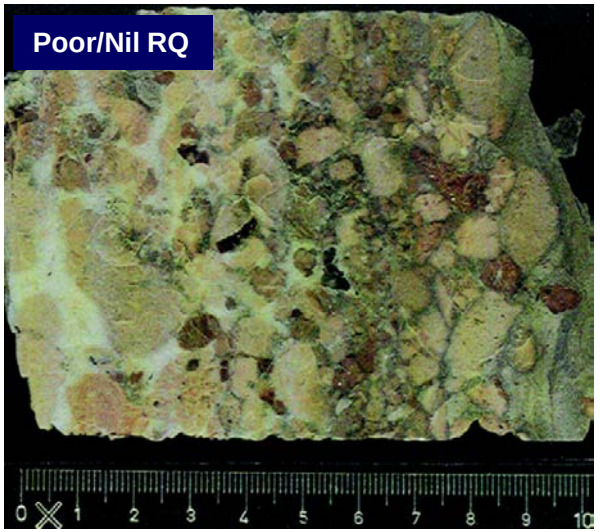


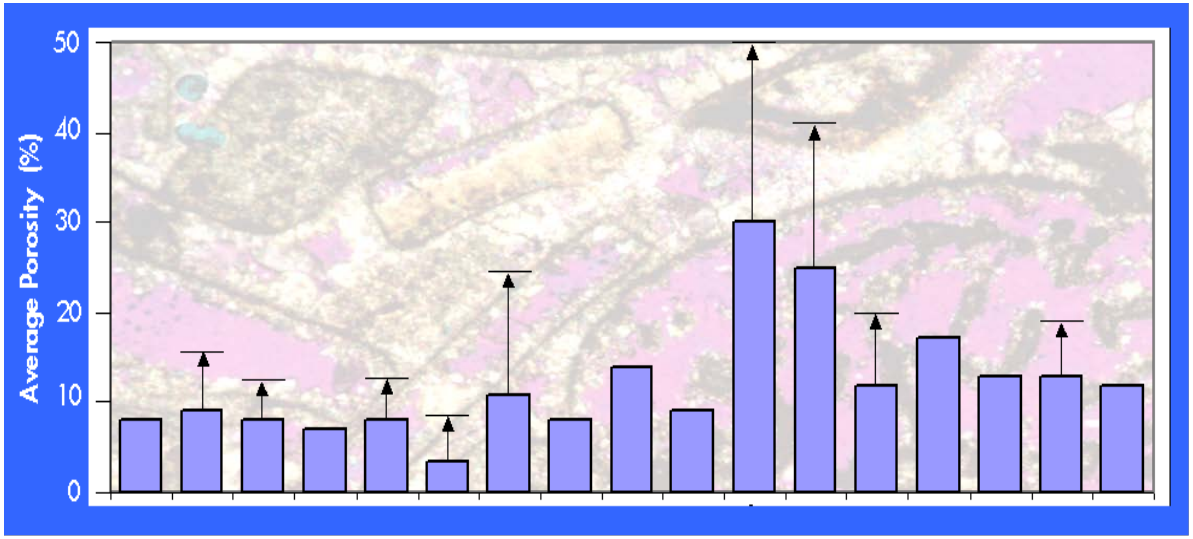


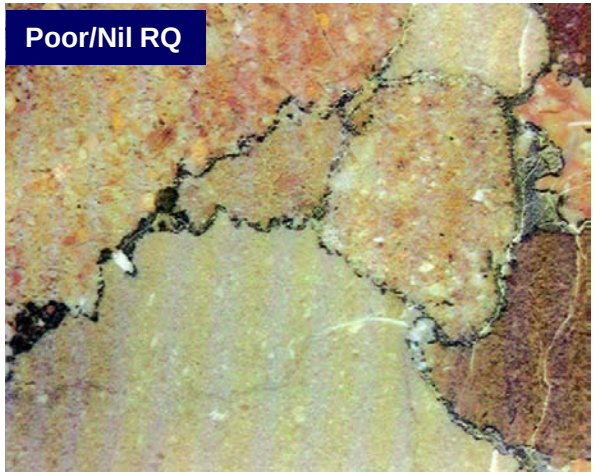


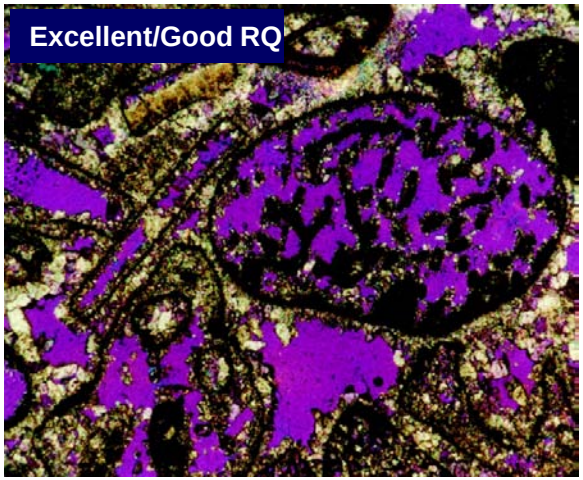


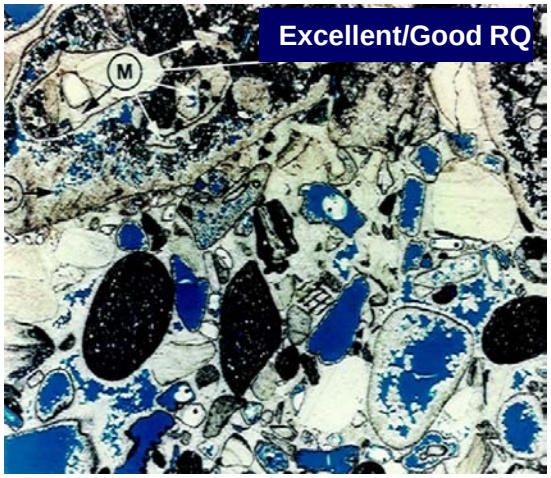
Carbonate Slope Database





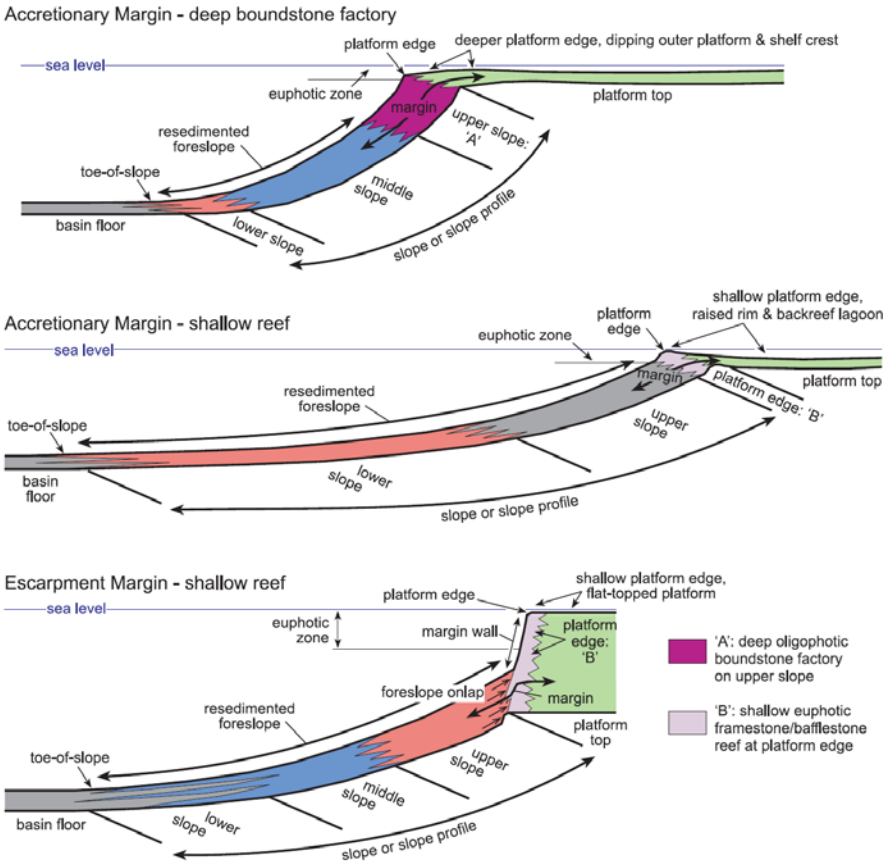






Characteristics of end-member margin types

Lithified Margin Sediment Type	Shallow Euphotic Framestn/Bafflestn Reef	Deep Oligophotic Boundstone Factory
Dominant Faunal Assemblage	**skeletal** (i.e. coralgal, rudistid, stromatoporoid)	**microbial** & ahermatypic fauna
Depth Range	centered at platform edge; generally **0-50 m (euphotic)**; within influence of wave base and relative sea level changes	centered on upper slope; generally **30-300 m (oligo-photic)**; large portions of factory are often below the influence of wave base and relative sea level changes
Surface Area of Sediment Factory	**10,000s m^2** per km along strike; comprises < 20% of slope surface area	**100,000s m^2** per km along strike; comprises up to 30-40% of slope surface area
Dominant Sediment Production	**grain-dominated and debris deposit production**; skeletal sand, pebbly bioclasts, & cobbles/boulders	**debris deposit production**; minimal sand production; pebbles, cobbles, and boulders from cms to 10s m
Collapse Controls	**interlinked with relative sea level**; sensitive to exposure/ submergence & degree of current energy; episodic collapse	**autogenic basinward accretion**, local instability & collapse; tied to nutrient levels, much less so relative sea level changes; +/- continual collapse
Morphological Features	associated with **raised rims and flat-topped platforms** built to sea level; backreef aprons and lagoons	associated with **dipping outer platforms**, deeper platform edges (20-50 m), and shelf crests
Accessory Skeletal Organisms	**abundant**; significant fractions both bound within reef framework & not bound	**moderate to rare**; most skeletal material bound within factory and/or volumetrically minor



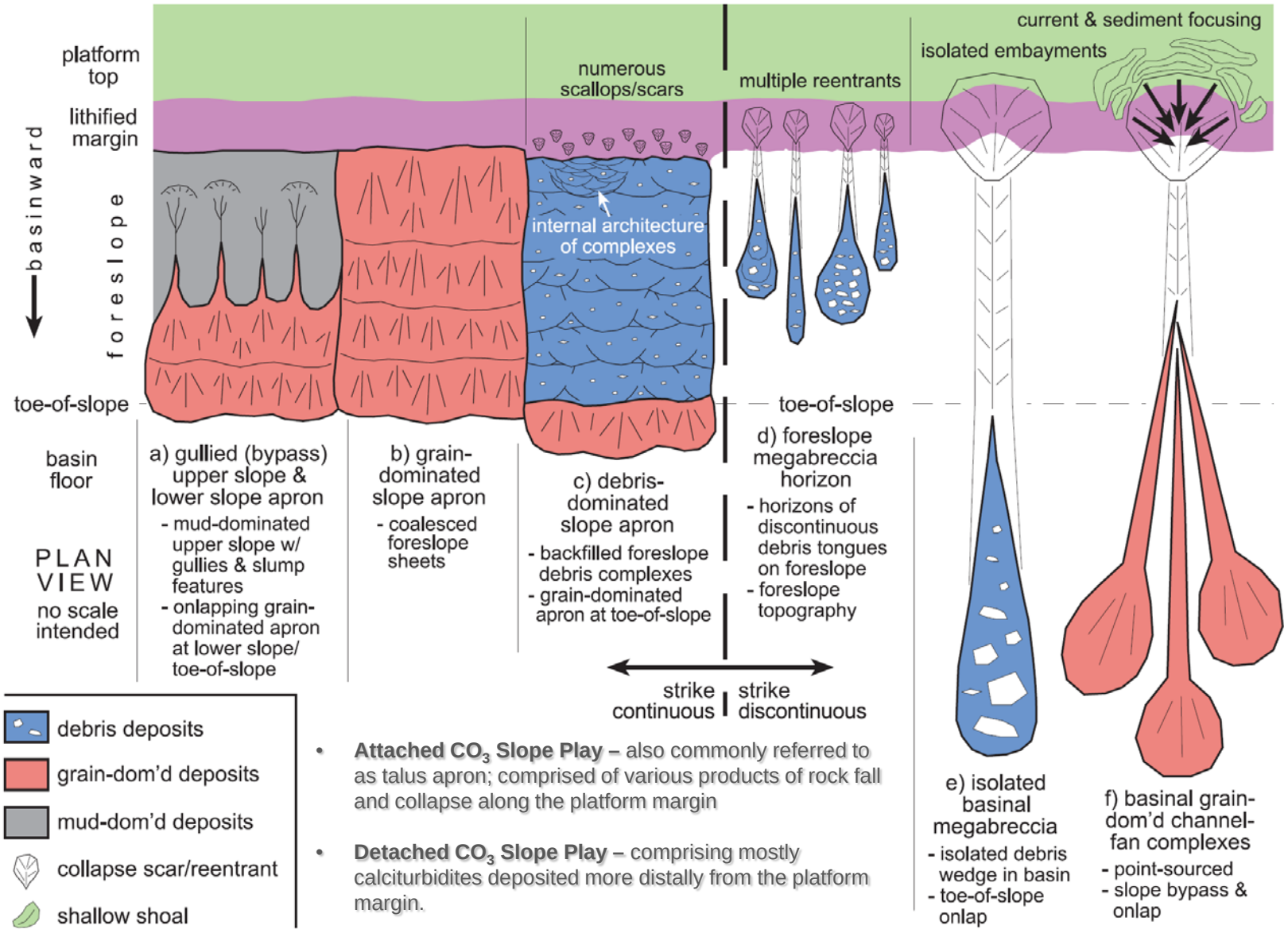
debris deposits

grain-dom'd deposits

mud-dom'd deposits

From Playton, Janson and Kerans (2010)

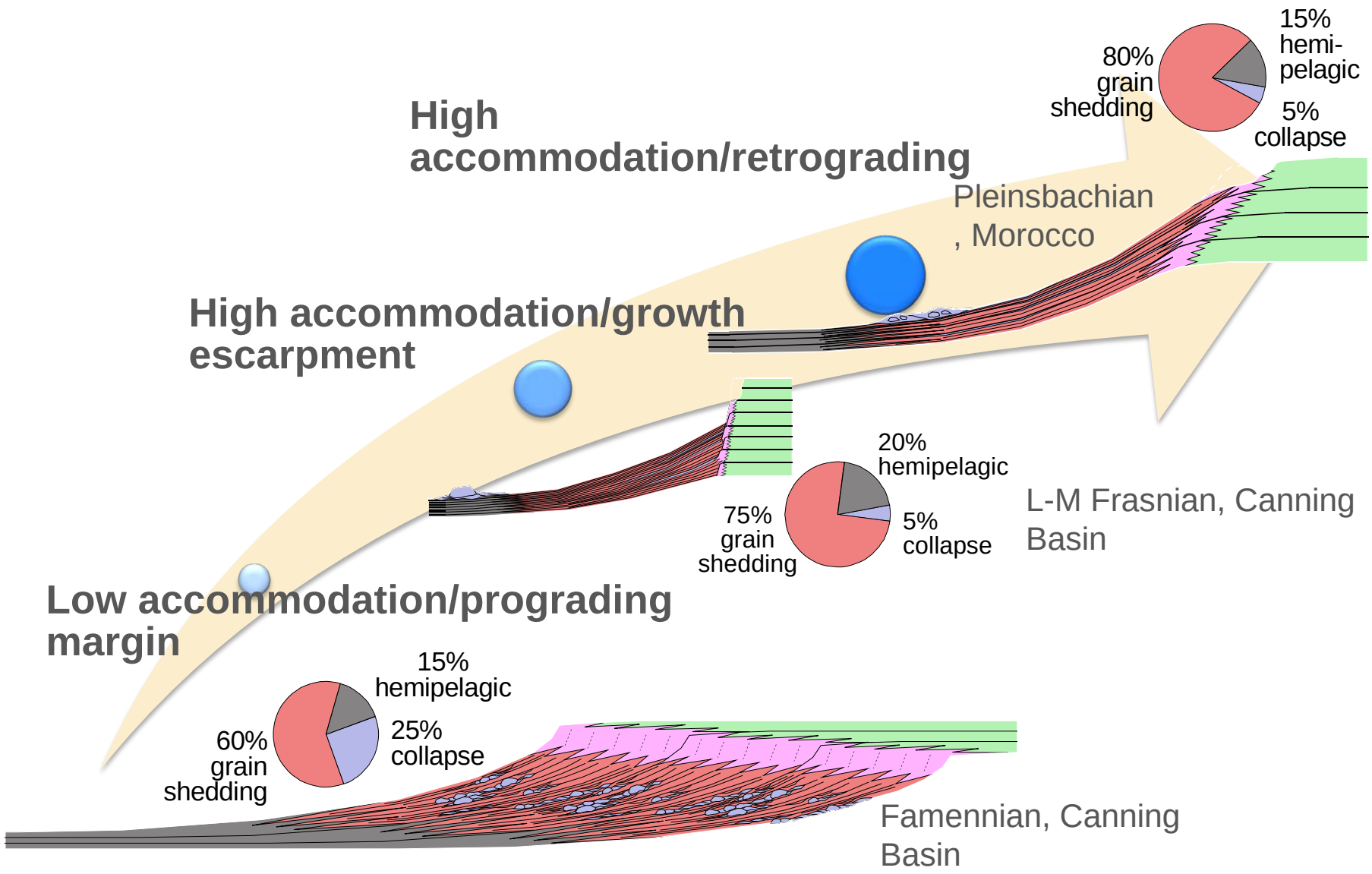
Carbonate slope and basin spatial architecture



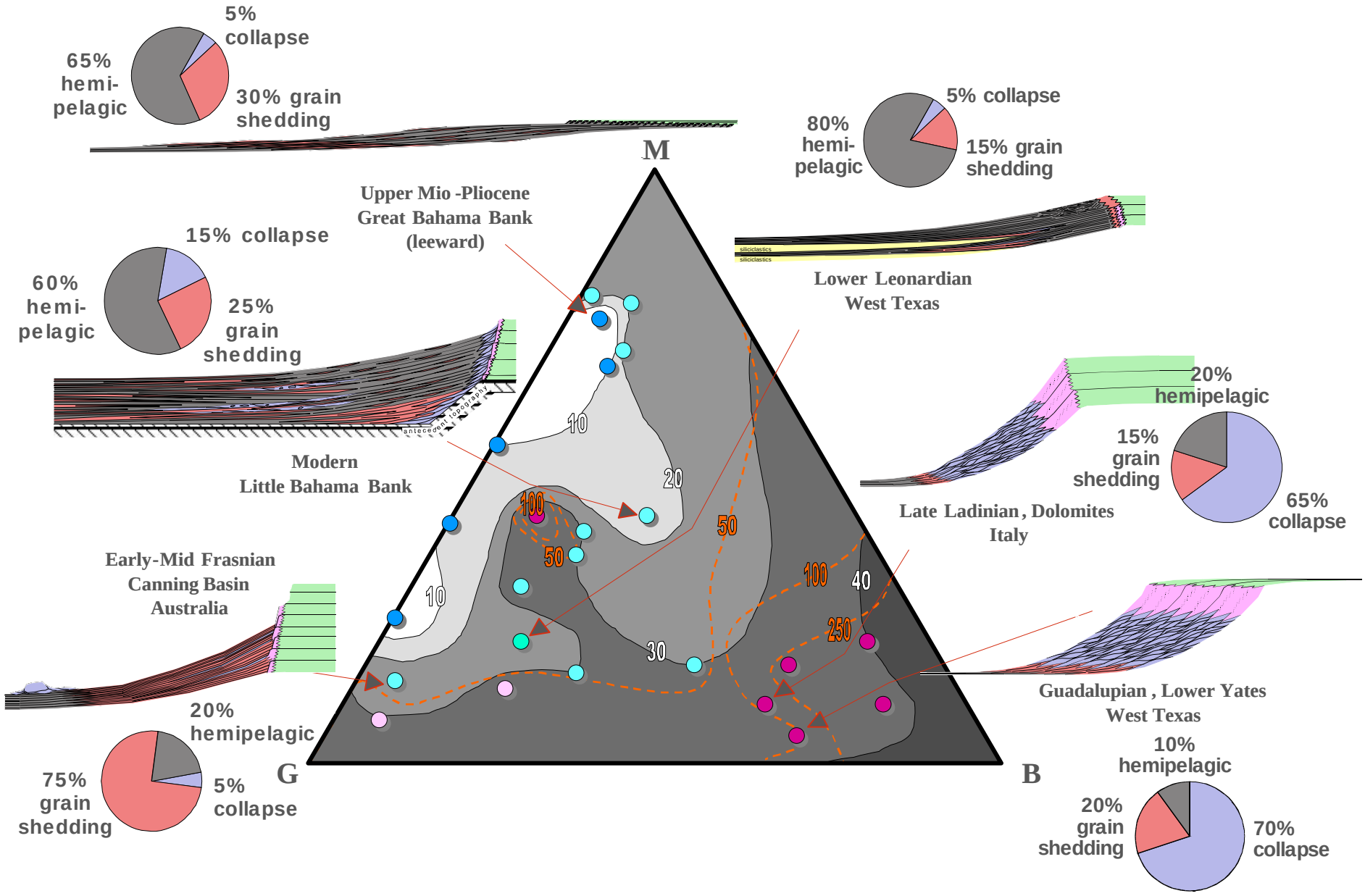
- **Attached CO_3 Slope Play** – also commonly referred to as talus apron; comprised of various products of rock fall and collapse along the platform margin
- **Detached CO_3 Slope Play** – comprising mostly calciturbidites deposited more distally from the platform margin.

From Playton, Janson and Kerans (2010)

Controls: accommodation and tectonic setting

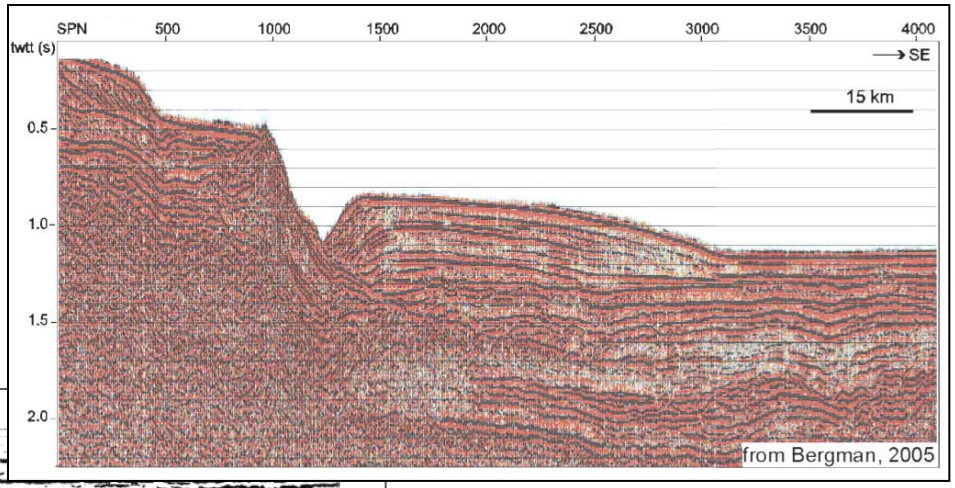


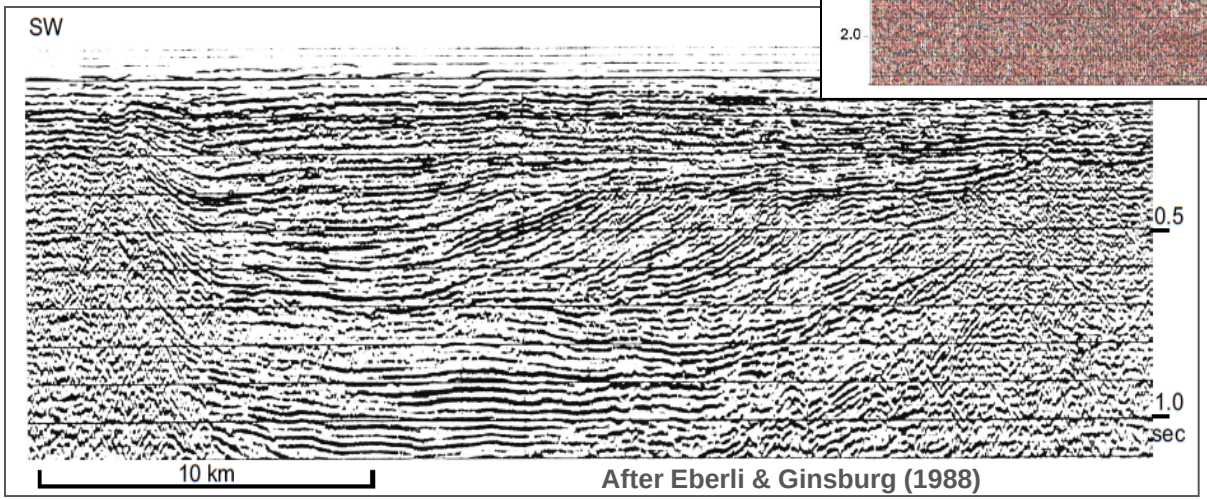
Controls: carbonate factory type



Other controls

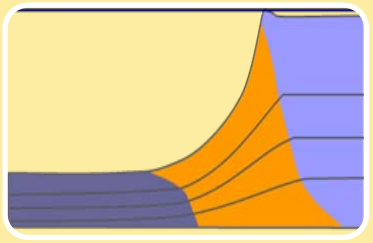
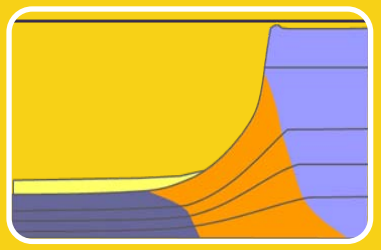
- Eustatic variations in sea level
- Platform alignment relative to prevailing wind direction and ocean current patterns
- Bottom currents (reworking)
- Pre-existing topography
- Basin fill patterns



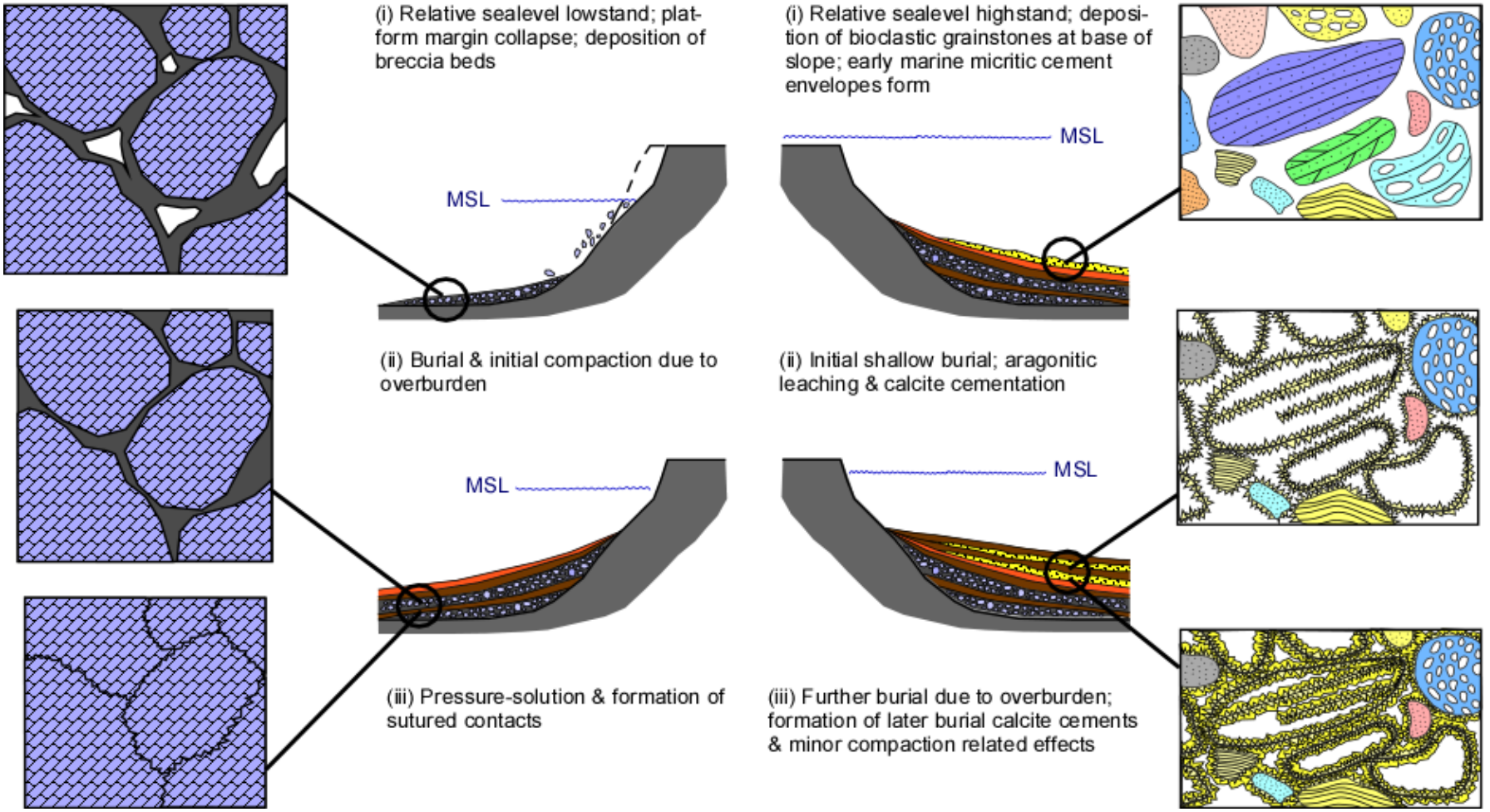


After Eberli & Ginsburg (1988)

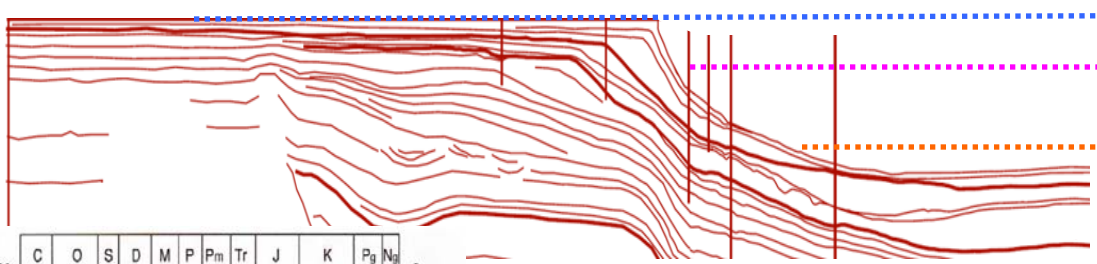
Slope types and play characteristics

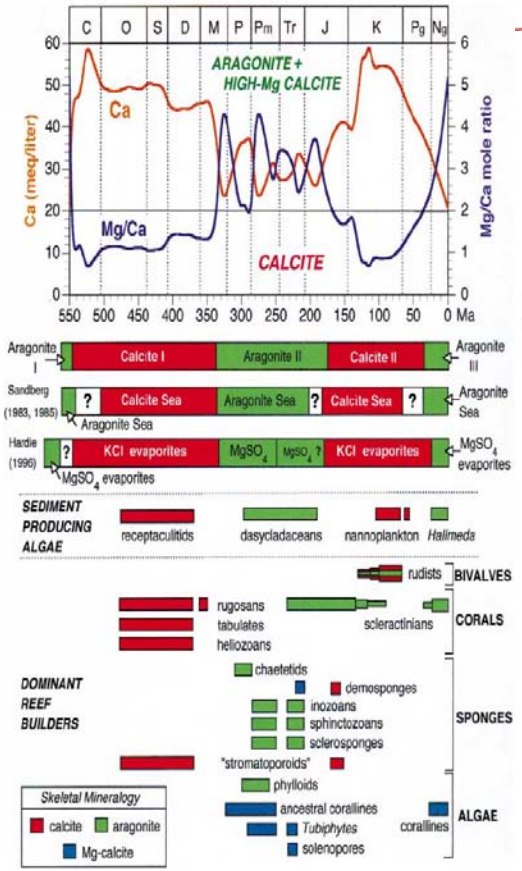
Margin Type	Focus of deposition	Dominant processes	Architectural elements	Reservoir, seal & trap predictions
Accretionary 	Slope	In-situ depositional, gravity flows, pelagic deposition	• In-situ slope deposition • Slope gravity flow channels & lobes • Minor basin-floor fan systems	• In-situ slope reservoirs?? • Slope channel & lobe grainstone reservoirs • Updip pinchout stratigraphic traps with pelagic top seals?
Bypass 	Toe of slope Basin floor	Gravity flows & pelagic deposition	• Slope channel systems • Basin-floor fan systems • Pelagic deposition	• Basin-floor fan grainstone reservoirs • Toe-of-slope pinchouts and pelagic topseal or detached 4-way dip closures
Erosional 	Toe of slope Basin floor	Margin collapse & gravity flows	• Toe-of-slope debris aprons • Basin-floor fan systems • Pelagic deposition	• Toe-of-slope debris apron reservoirs • Toe-of-slope pinchout strat traps • Basin-floor fan grainstone reservoirs • Channel strat traps and/or 4-way dip closures

Reservoir Quality

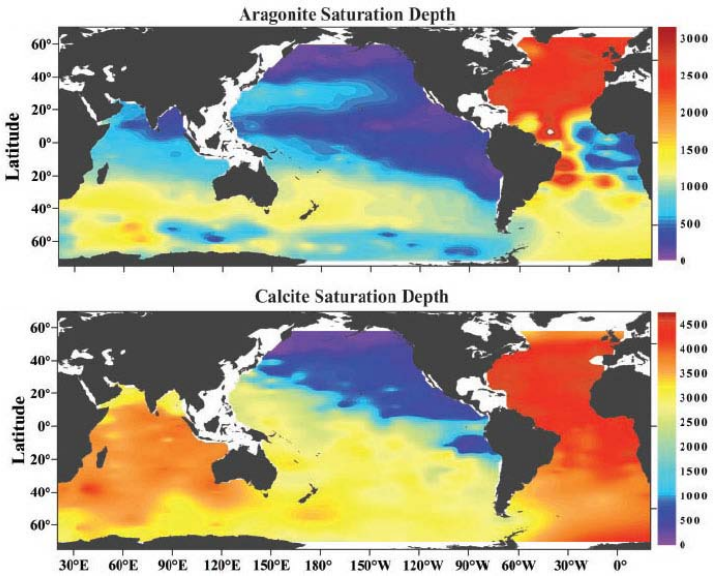


Reservoir Quality

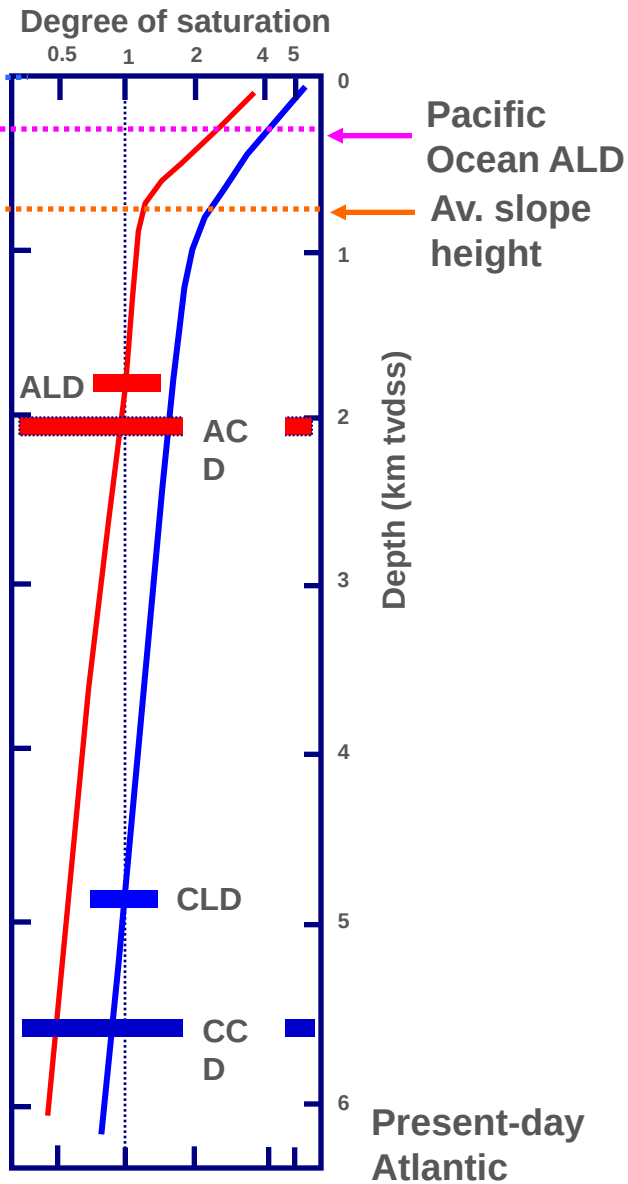




After Stanley & Hardie (1999)



After Feeley et al. (2009)



After Scholle et al. (1983)

White-space Selection Criteria

Depositional & Stratigraphic Setting

- Reservoir Presence/absence criteria and gross volume
- Large-scale reservoir architecture

Age & Type of Carbonate Factory

- Total carbonate production
- Type and mineralogy of carbonate constituents
- Depth of carbonate and aragonite saturation

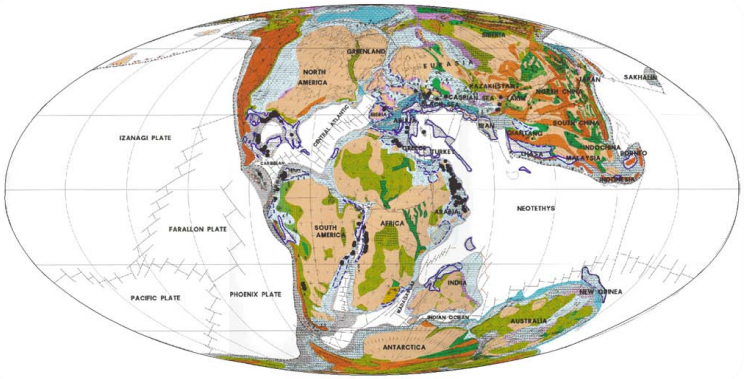
Syn-depositional Tectonic Setting

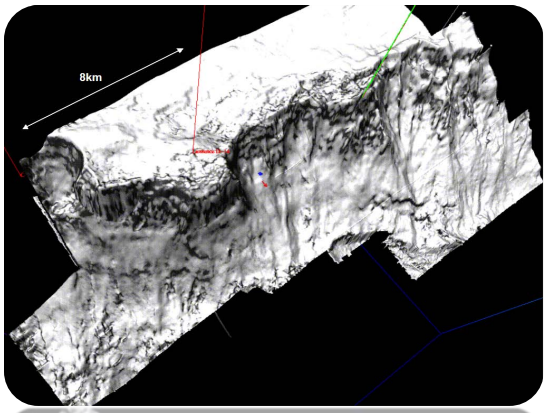
- Margin type/accommodation
- Platform relief

Post-depositional deformation

- Likelihood of 4-way closure
- fracturation

Presence of Petroleum System





Summary: key play elements (what to look for)

- Large carbonate platforms shedding abundant (preferably aragonitic?) grains
- Steep platform margins with adjacent water depths in excess of 500 m
- Starved basins and fault-controlled escarpments
- Be aware of the factory type and paleo-oceanographic regime
- Detached systems may be better sorted and provide better reservoir and trapping potential