Carbonate Play Models From Miocene Outcrops, Western Mediterranean: Part 1 - Setting and Stratigraphy*

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Search and Discovery Article #51630 (2019)**
Posted January 6, 2020

*Adapted from oral presentation given at 2019 AAPG Geoscience Technology Workshop, Exploration and Development of Siliciclastic and Carbonate Reservoirs in the Eastern Mediterranean, Tel Aviv, Israel, February 26-27, 2019. See related article Search and Discovery Article #51631 (2019)
 DOI:10.1306/51630Franseen2019

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Abstract

The Almeria region of southeastern Spain is known for exceptional exposures of Upper Miocene heterozoan, coral reef, and oolite-microbialite carbonate reservoir analog systems that developed regionally in the western Mediterranean. Miocene paleotopography is largely preserved and 3D exposures allow direct documentation of sequence architecture and facies distributions along proximal-to-distal transects in a variety of paleotopographic settings. Prior to carbonate deposition, Neogene volcanic and Paleozoic-Mesozoic metamorphic rocks were subaerially exposed and eroded, forming highly variable substrate paleotopography upon which the carbonates were deposited. The settings for carbonate deposition include archipelagos, with closely spaced steep-sided highs surrounded by straits and flooded paleovalleys, and marginal basins surrounded by carbonate platforms. Our studies for more than three decades have isolated and quantified the effects of sea level, paleotopography, oceanography, and climate on sequence architecture, facies distribution, and reservoir character.

Five major 3rd and 4th order sequences are identified in the study area. Marine inundation of the volcanic and metamorphic substrate resulted in deposition of two heterozoan carbonate sequences during temperate climate conditions. The heterozoans are mostly grainy deposits consisting of molluscs, red algae, foraminifera, bryozoans, and echinoderms (+/- siliciclastics). The loose grainy nature of these systems made them susceptible to reworking and transport, which depended on sea-level changes, water energy, and substrate slope angles. Where shallow water intersected gentle substrate slopes, shallow-water autochthonous sediments were preserved. Deposition and distribution was tied to sea-level fluctuations and where currents and nutrients were focused. Where shallow water intersected steep substrate slopes (> 15°), processes of downslope bypass dominated. Shallow water heterozoan sediments were not preserved in situ, and instead, they were transported as sediment gravity flows to areas of lower slope, where they are interbedded with hemipelagic deposits. Two overlying photozoan coralgal reef sequences indicate a transition to a tropical climate. Porites and Tarbellastrea corals are the major framebuilders.

When steep-sided volcanic slopes (> 15°) were in shallow water, processes of bypass dominated. Initially, fringing reefs developed on the steep slopes, but those steep slopes and relative sea-level falls promoted their transport as sediment gravity flows into deep water, without in place

preservation of reefs. Where shallow water intersected substrates with gentle slopes (< 15°) fringing and isolated reefal platforms developed, preserving reef to forereef slope to basin facies transitions over lateral distances of 0.5 to more than 2 km.

Aggradational, progradational, and downstepping geometries preserve much of the sea-level cycle. Downstepping in the latest stages of reef development indicate a major sea-level fall that culminated in subaerial exposure and erosion of the reefal platforms, forming an unconformity that is likely equivalent to the Messinian lower evaporite unit in the Mediterranean Basin. Sea-level rise after, or perhaps partially during, upper evaporite deposition resulted in deposition of an upper stratigraphic unit in margin areas composed of oolite, microbialite (thrombolite and stromatolite), and minor coralgal reefs. Within this unit, four sequences were deposited in association with high-amplitude glacioeustasy and evaporitic drawdown. At intermediate substrate positions (relative to sea-level history), each of the four sequences drape paleotopography and maintain relatively equal lateral thickness. Internally, the sequences have a build-and-fill architecture, characterized by a relief-building phase and a relief-filling phase. Microbialites dominate during the relative sea-level rises and build topographic relief. Oolites dominate during relative sea-level falls and fill topographic relief. The studied carbonate systems are excellent analogs for Miocene carbonate reservoirs, such as those in eastern and central Mediterranean areas, and the Indo-Pacific region. The results of our studies provide predictive capabilities for reservoir model development of thirteen play types.

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Carbonate Play Models from Miocene Outcrops, Western Mediterranean: Part 1 – Setting and Stratigraphy

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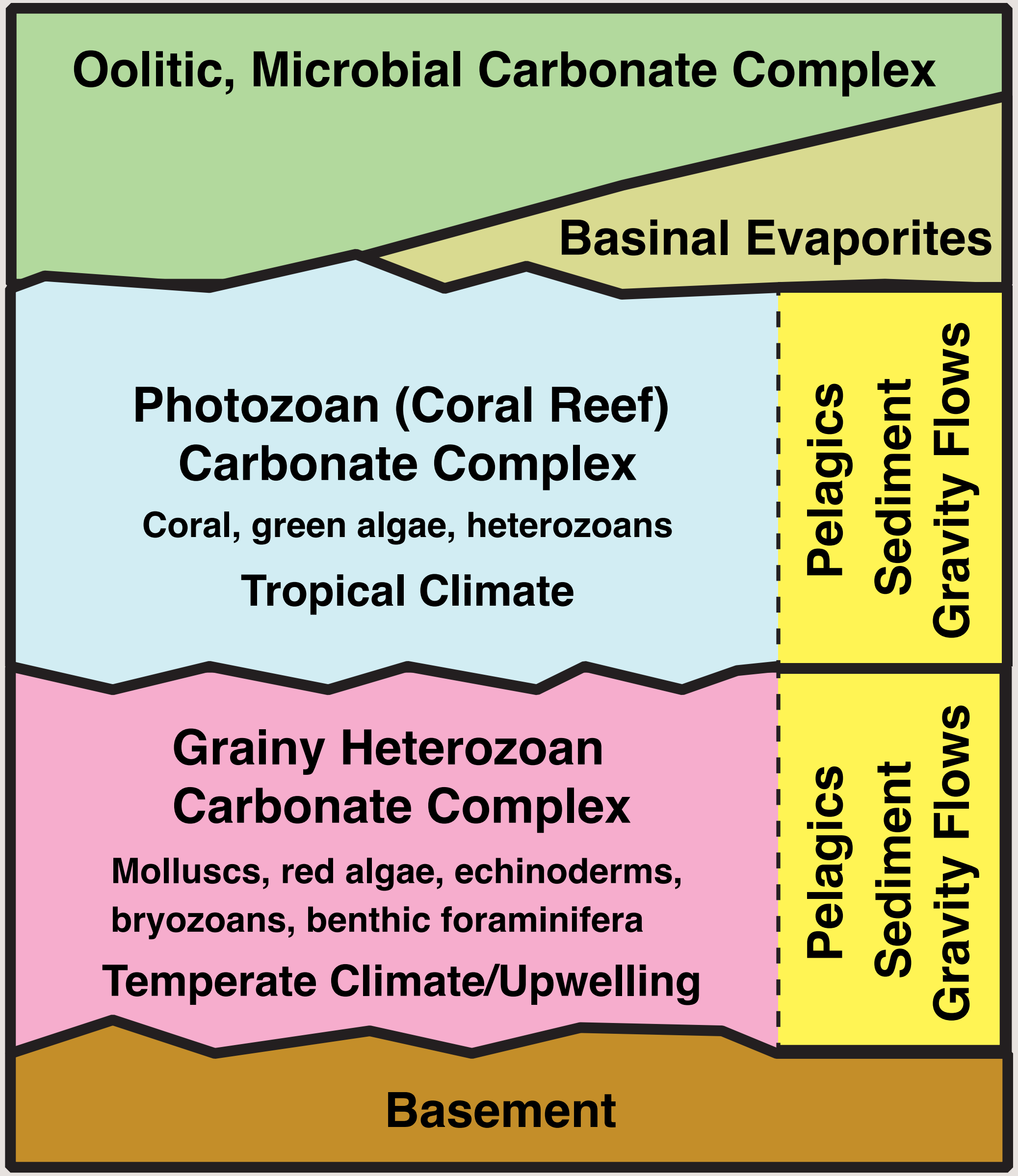
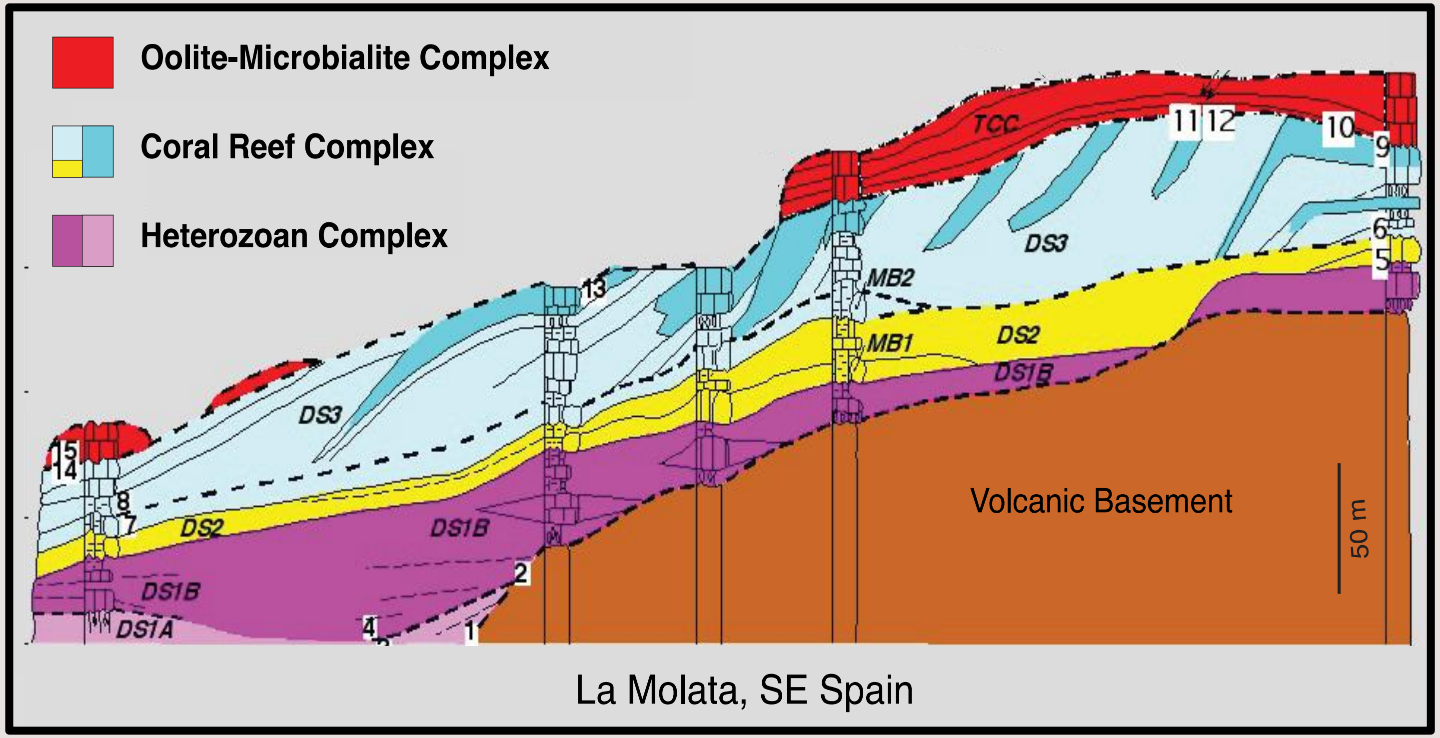
Introduction

* The Almeria region of southeastern Spain is known for exceptional exposures of Upper Miocene heterozoan, coral reef, and oolite-microbialite carbonate reservoir analog systems that developed regionally in the western Mediterranean.
* Settings for carbonate deposition include archipelagos, with closely spaced steep-sided highs surrounded by straits and flooded paleovalleys, and marginal basins surrounded by carbonate platforms.
* Our studies have isolated and quantified the effects of sea level, paleotopography, oceanography and climate on sequence architecture, facies distribution, and reservoir character.

Western Mediterranean Upper Miocene General Stratigraphy

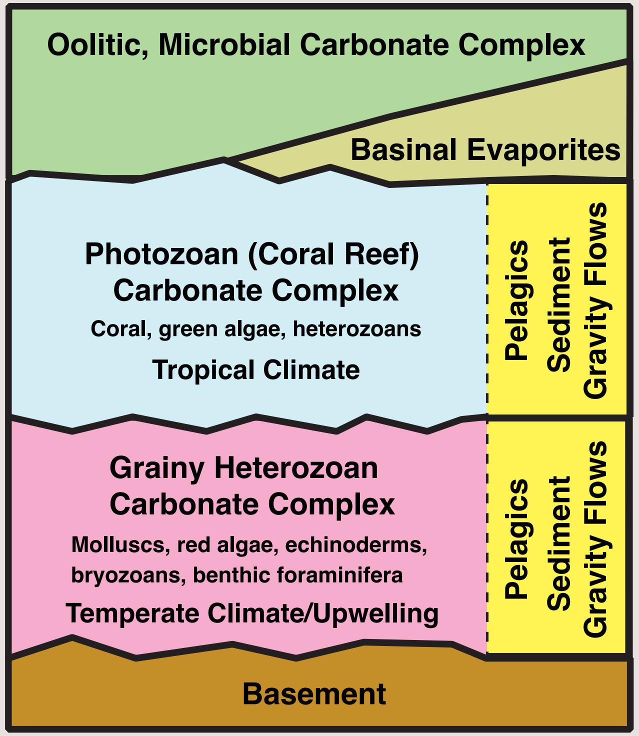


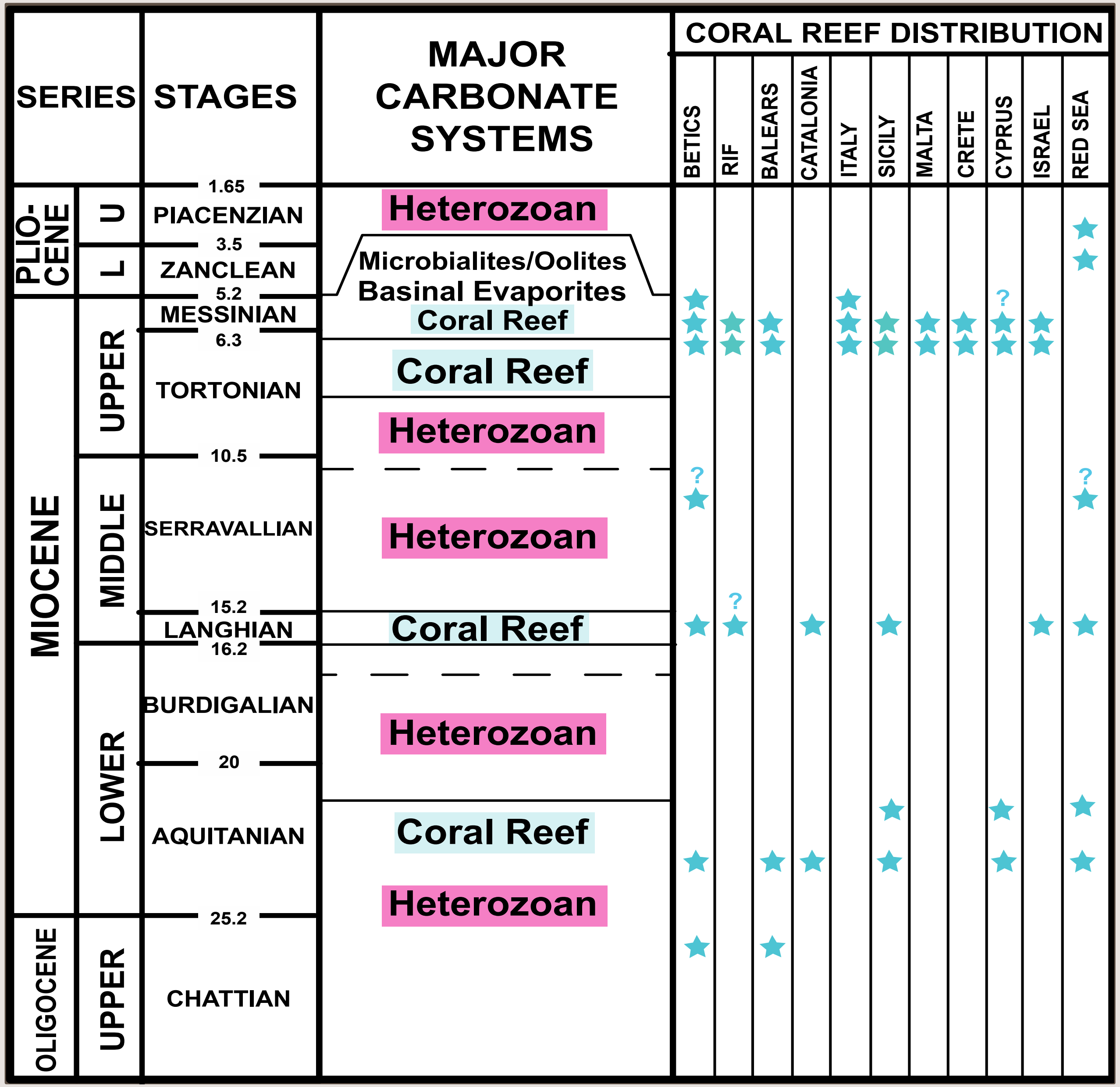


Miocene Carbonate Complexes Developed in the Mediterranean

Upper Miocene outcrops in W. Mediterranean are representative of Miocene systems developed throughout Mediterranean.

UPPER MIOCENE BASIC STRATIGRAPHY





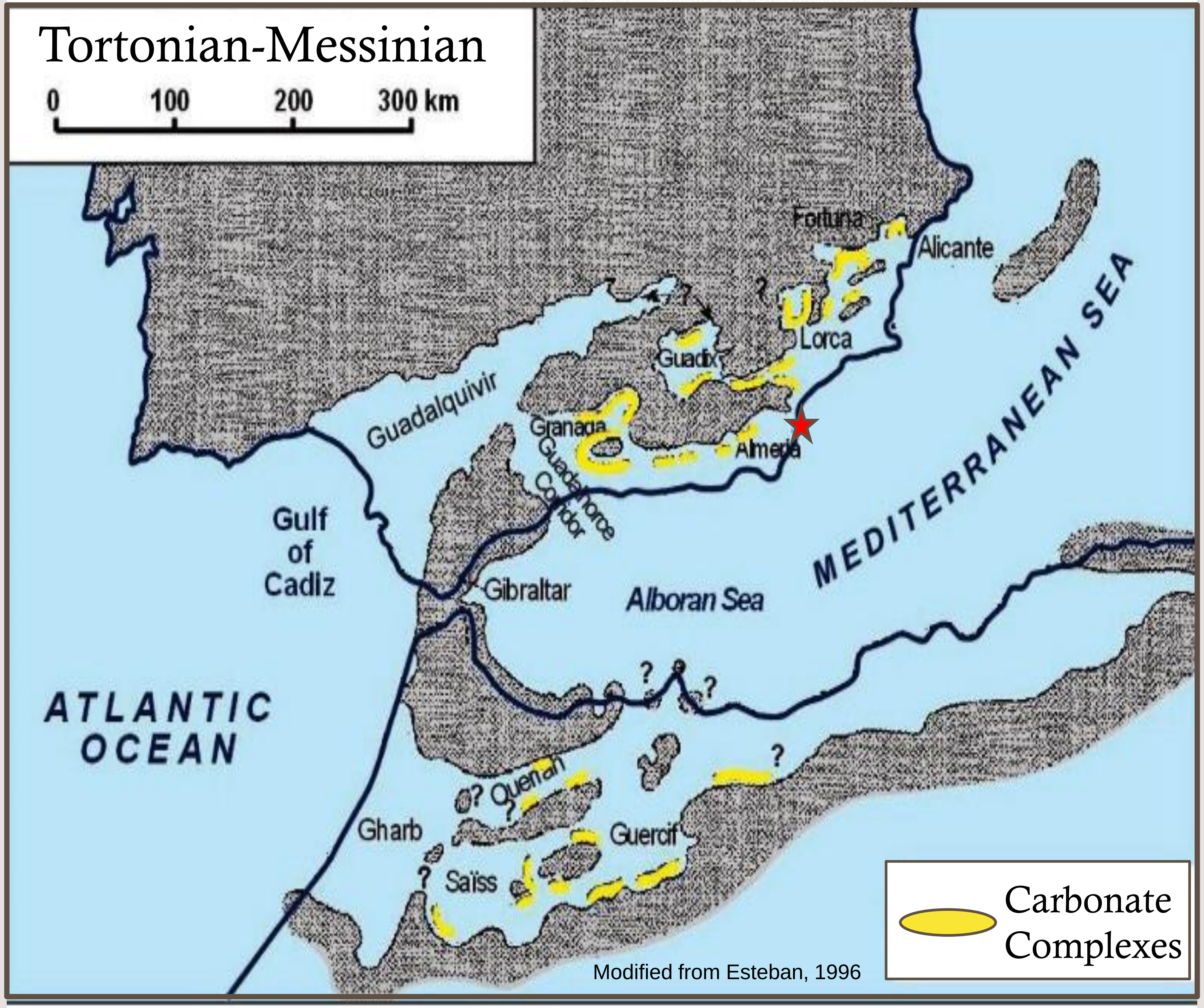
Modified from Esteban, 1996

* Alternations of Heterozoan and Photozoan systems throughout the Miocene.

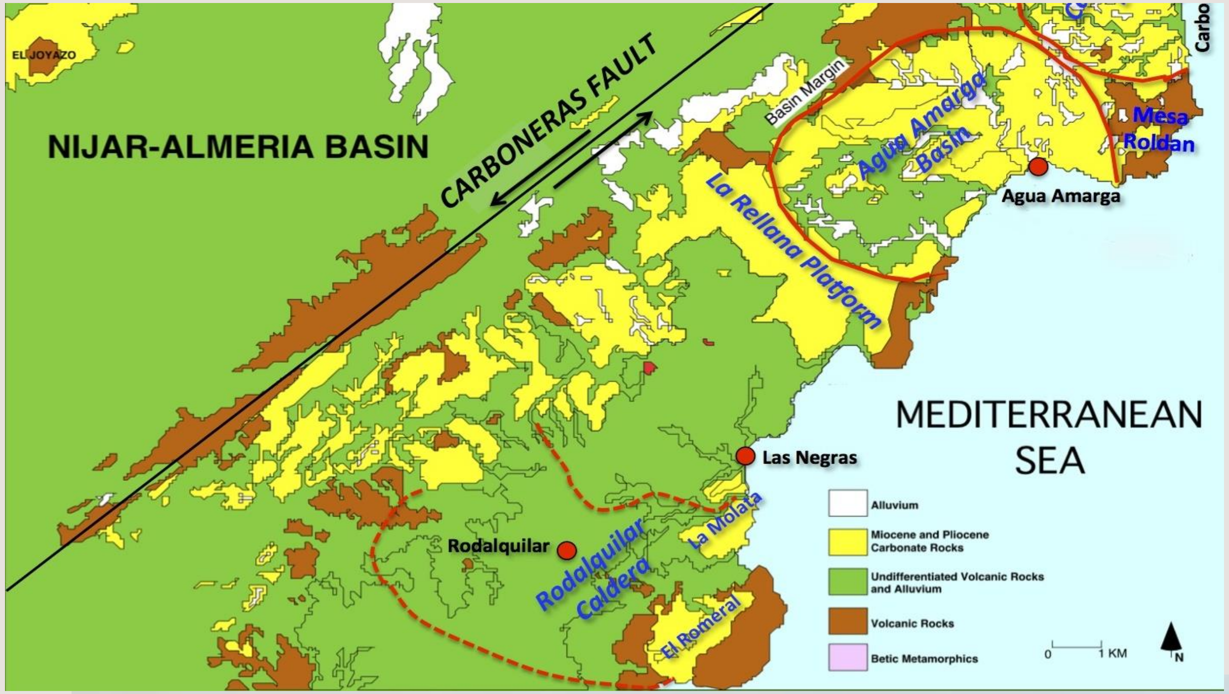
* Pattern seen throughout the Mediterranean.

* Facies and geometries of the systems are similar.

Western Mediterranean Upper Miocene Paleogeography & Locations of Carbonate Complex Outcrops



* SE Spain – Almeria region
  - 35 years of research.
* Exceptional 3D exposures of the various carbonate systems.
* Paleotopography preserved.
* Different basement configurations
  - Marginal basins, archipelagos, straits, flooded paleovalleys.
* Analogs for Eastern Mediterranean, Indo-Pacific, Middle East, Caribbean, South & Central America reservoir systems.



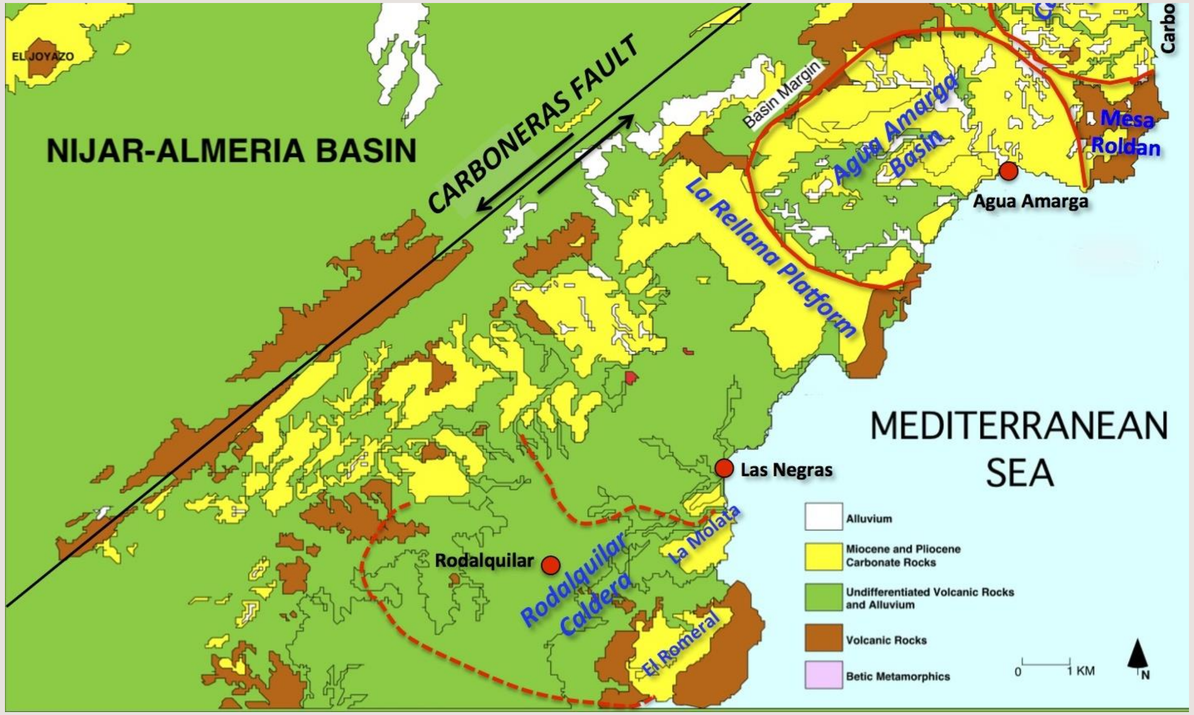
Paleotopographic Settings

* Archipelago characterized by steep volcanic hills, flooded paleovalleys and straits.

* Sea level intersecting steep substrate slopes (>15^{o}), processes of bypass dominate.

* Sea level intersecting gentle substrate slopes (< 15^{o}) in-place shallow-water facies preserved.

Paleotopographic Settings



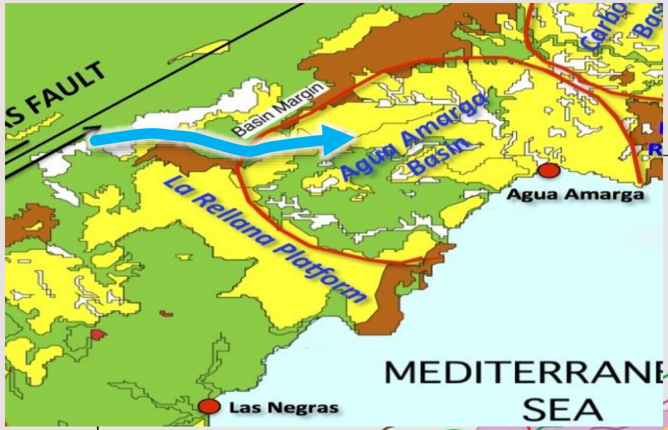
* Horse-shoe shaped flat-floored marginal basin with steep basin margin and extensive carbonate platform rimming the margin.

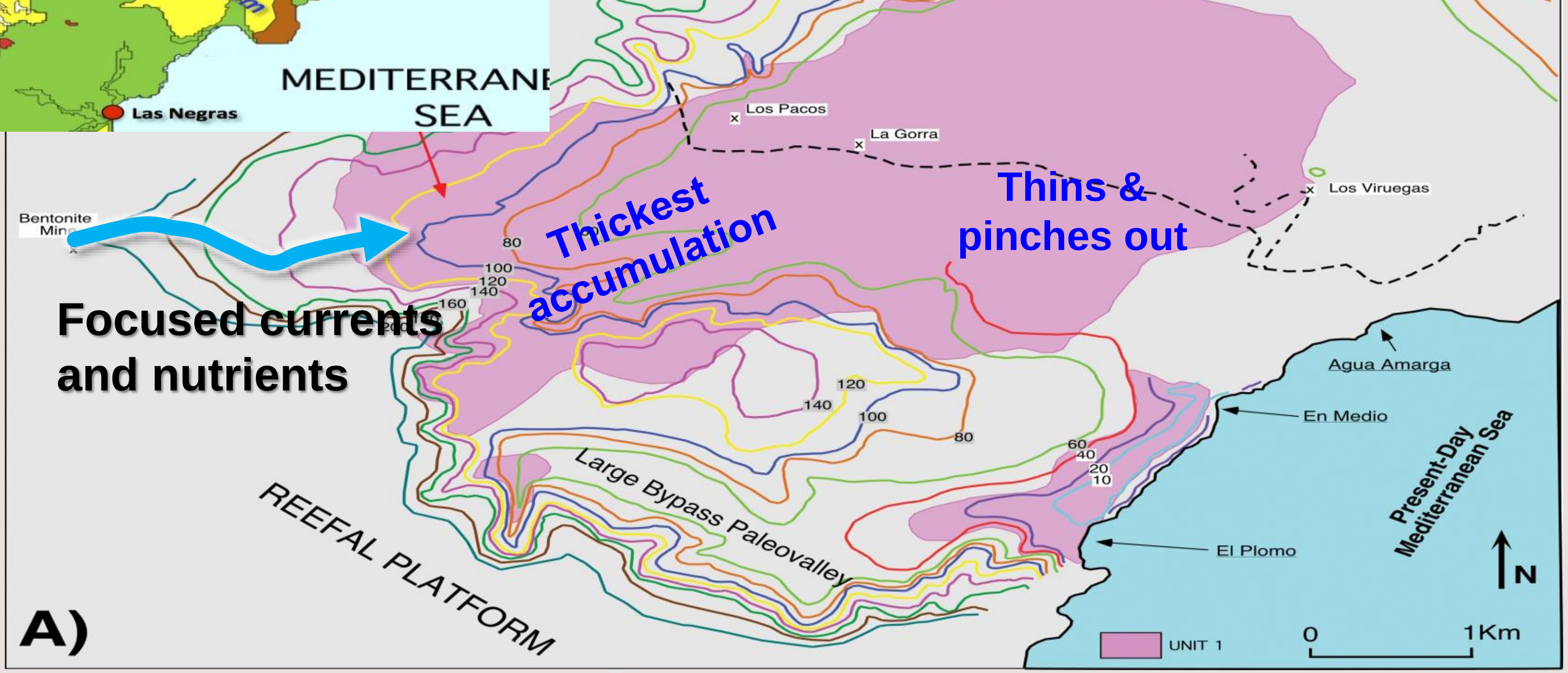
* Extensive platform development and 1.3 km of progradation related to gentle substrate slope north of a drainage divide.

* Substrate slope steepens on south side of drainage divide and carbonates are less extensively developed.

* Platform-sourced material abundant in the basin.

Shallow-Water Heterozoans – Gentle Substrate Slope
High Current Energy Strait Linking Two Basins



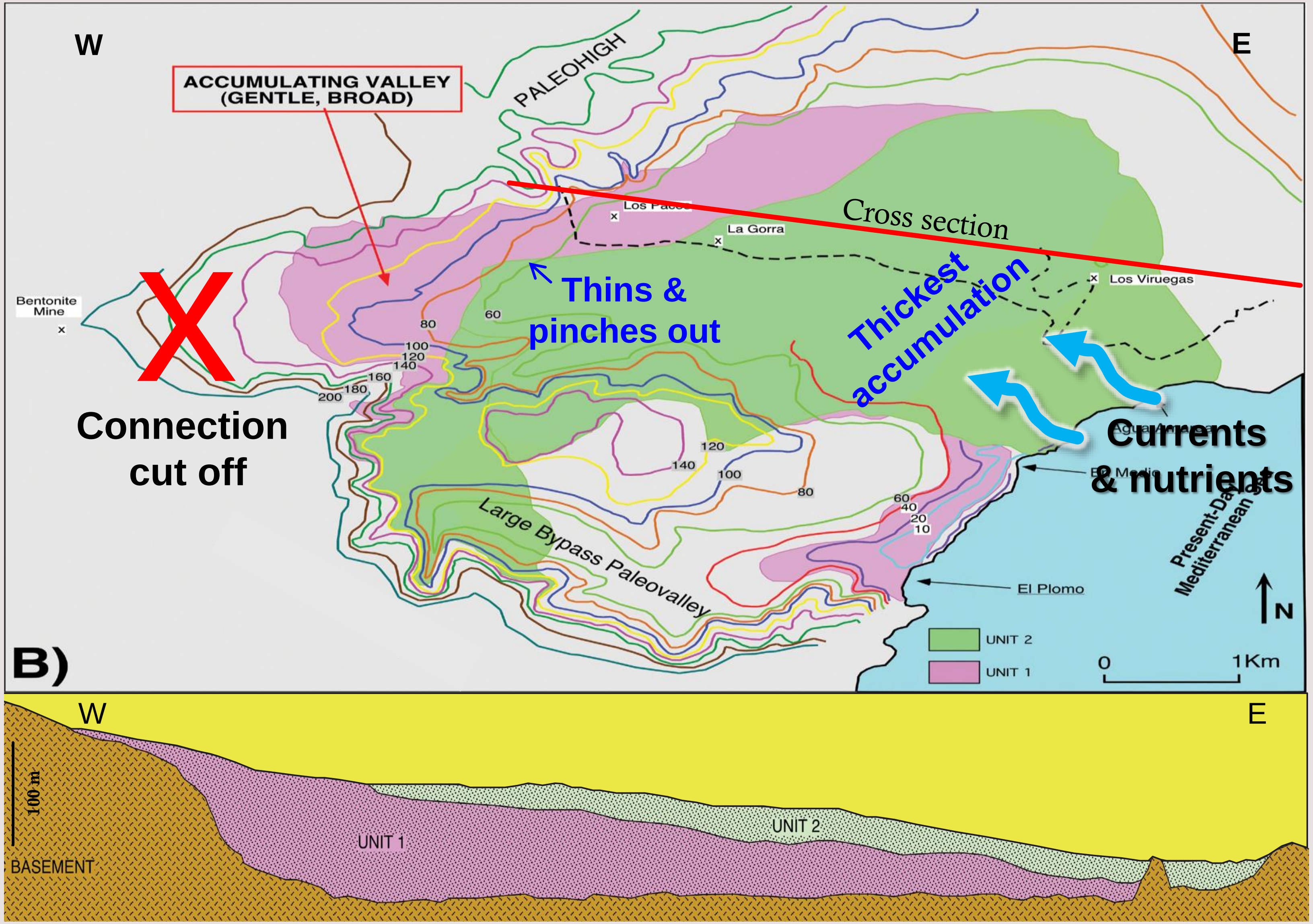


* Gently dipping substrate promotes preservation of shallow-water heterozoans.
* Most abundant and thickest accumulations where currents and nutrients focused.
* Updip onlap and erosion towards strait

Skeletal grainstone: phi-29%, k-815 md

Volcanic skeletal packstone: phi-36%, k-1439 md

Shallow-Water Heterozoans – Gentle Substrate Slope
High Current Energy Transgressive Wedge



* 2nd grainy heterozoan unit deposited during transgression.

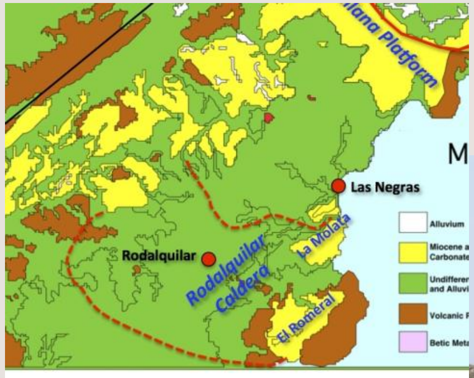
* Thickest towards currents and nutrient source (opposite first unit).

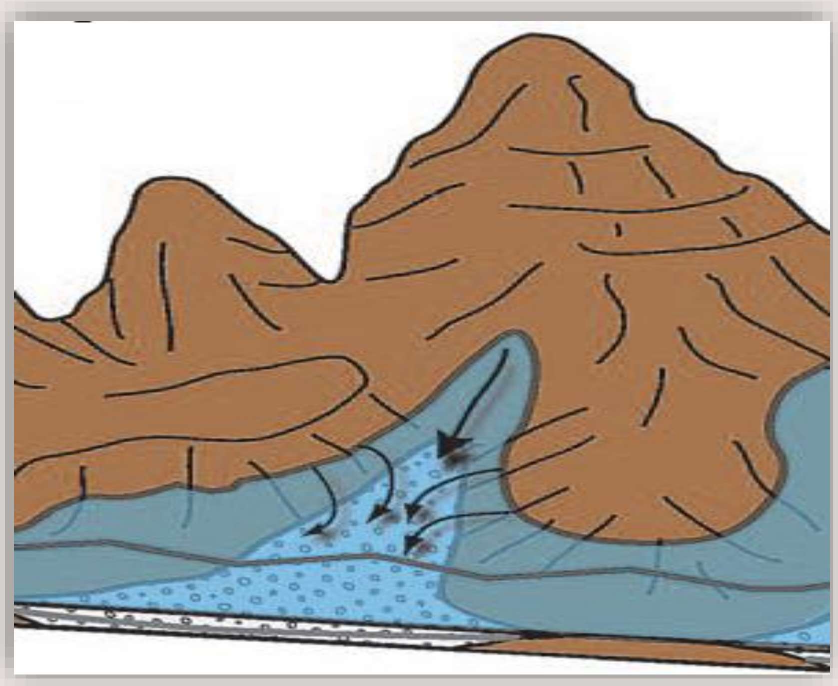
* Continued transgression - deep water hemipelagics covering grainy facies (potential seal).

* Gentle substrate slopes promote preservation of shallow-water grainy heterozoan facies with favorable reservoir character.

* Thickness and updip onlap related to substrate paleotopography and location(s) of currents/nutrients.

Deepwater Heterozoans - Onlapping Downslope Sediment Gravity Flows Focused into Deep Water Paleovalleys and Straits





* Inherited steep substrate slopes result in bypass of heterozoans to deep water as sediment gravity flows that onlap at toes-of-slopes.

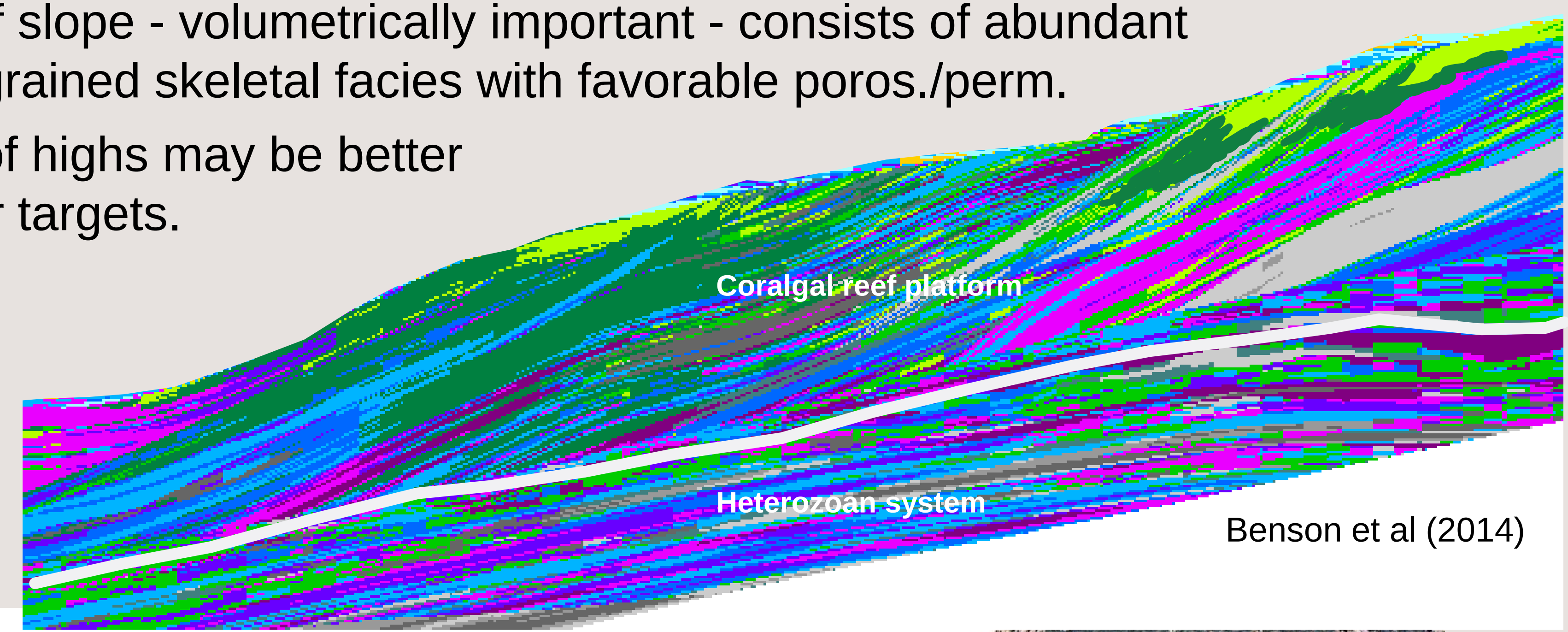
* Upslope funneling mechanism forms point-sourced deep water deposits similar to siliciclastic reservoirs.

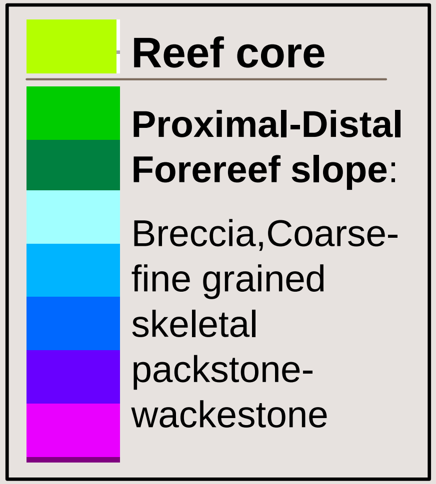
* Transported shallow-water carbonate facies with favorable reservoir character interbedded with hemipelagics (potential baffles/seals/source rock/reservoir).

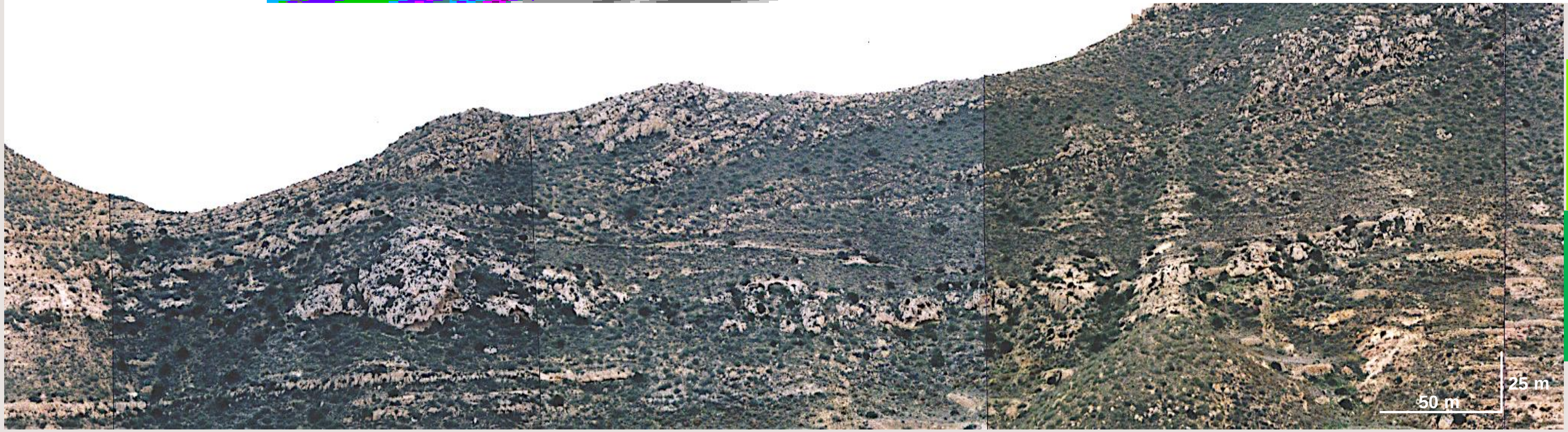
Facies	Porosity avg (%)	Permeability avg (mD)
Coarse - medium-grained intraclastic ps	38	375
Coarse - medium-grained graded ps/gs	37	550
Trough cross-bedded ps/gs	35	340
Fine-grained facies	40	175

Coralgal Reefal Platforms - Prograding Forereef Slopes

* Reef core is minor volumetrically - porosity/permeability can be highly variable.
* Forereef slope - volumetrically important - consists of abundant coarse-grained skeletal facies with favorable poros./perm.
* Flanks of highs may be better reservoir targets.





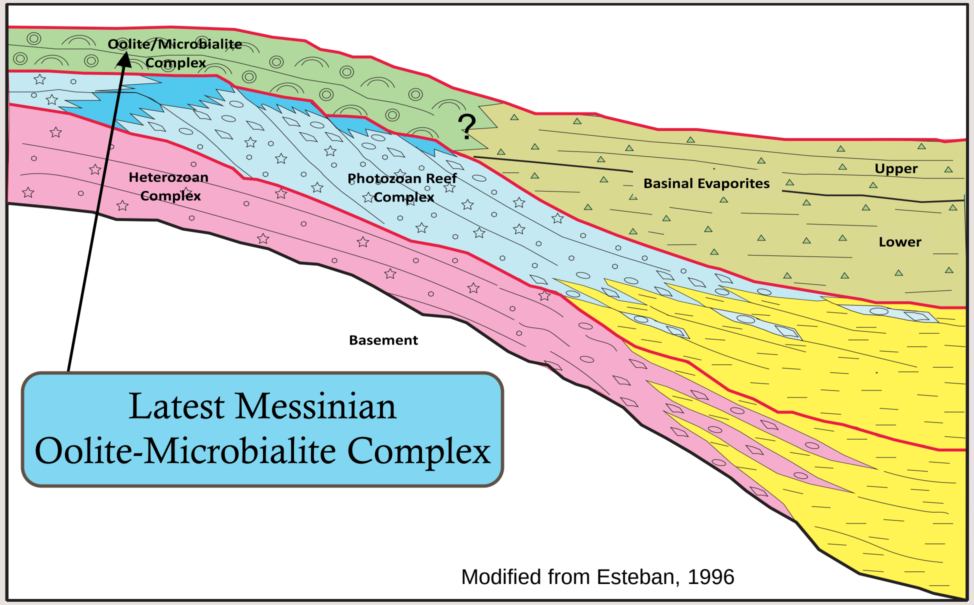


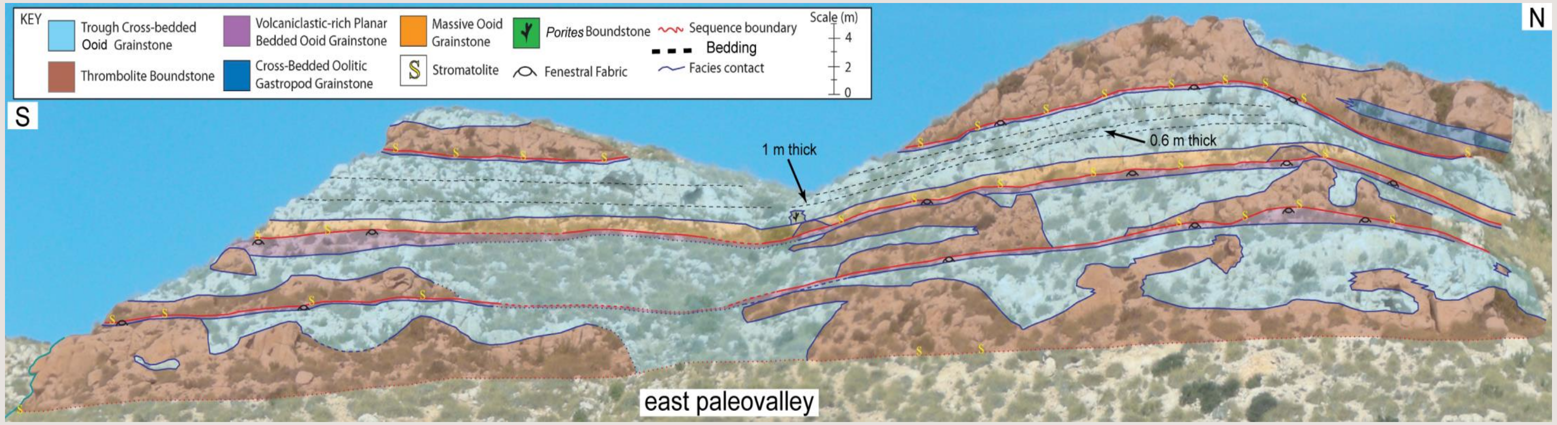
Reef: phi = 20%±; K = 184md (0-1689md)

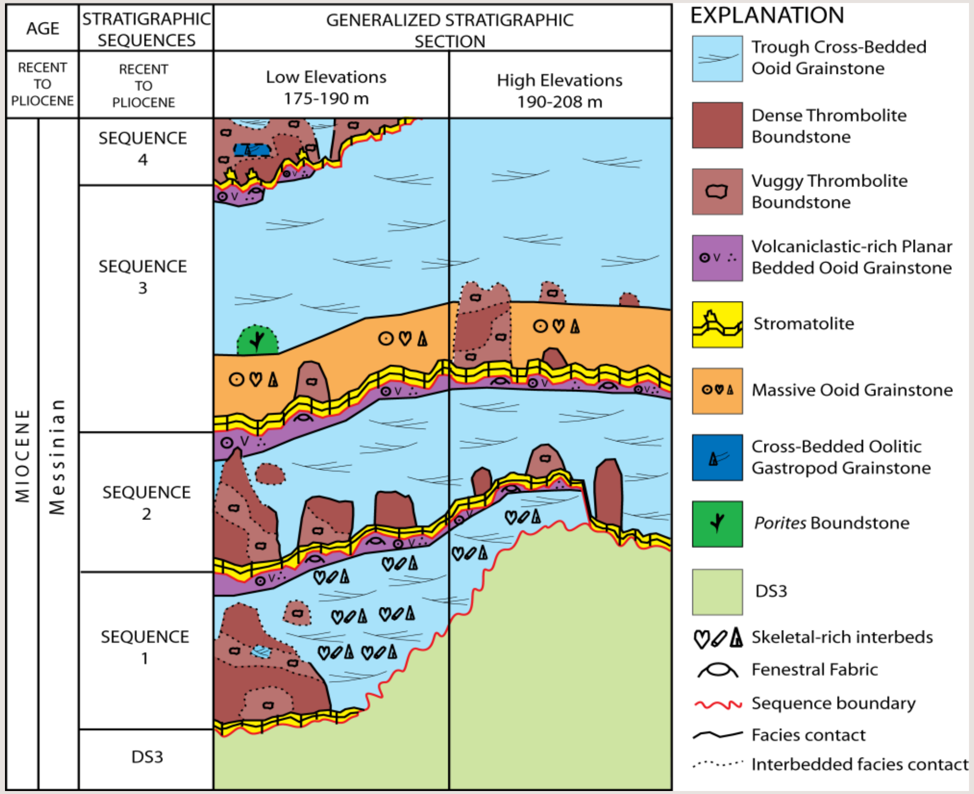
Forereef slope: phi = 30%; K = 65md

Oolite-Microbialite Build-and-Fill Sequences

* 4 sequences deposited in association with glacioeustacy and evaporitic drawdown.
* Each sequence drapes paleotopography and maintains relatively equal lateral thickness.
* Internally sequences have complex build-and-fill architecture.
* Microbialites dominate during relative sea-level rises and build topographic relief.
* Oolites dominate during relative sea-level falls and fill topographic relief.







Concluding Remarks

* The studied carbonate systems are excellent analogs for Miocene carbonate reservoirs, such as those in eastern and central Mediterranean areas and the Indo-Pacific region.

* The results of our studies provide predictive capabilities for reservoir model development of thirteen play types, which include:
  - Shallow Water Heterozoans
  - Deep Water Heterozoans
  - Coralgal Reefal Platforms
  - Deep Water Equivalents to Coralgal Platforms
  - Diagenetic Plays

* See Part 2 abstract & presentation for details of play types - Carbonate Play Models from Miocene outcrops, Western Mediterranean: Part 2 – Stratigraphic and Diagenetic Plays: R.H. Goldstein and E.K. Franseen.

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