Carbonate Play Models from Miocene Outcrops, Western Mediterranean: Part 2 – Stratigraphic and Diagenetic Plays*

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Search and Discovery Article #51631 (2019)**
Posted December 30, 2019

*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 #51630 (2019)
 DOI:10.1306/51631Goldstein2019

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Abstract

Miocene (Tortonian and Messinian) carbonate outcrops in SE Spain are reservoir analogs potentially useful for plays in the Eastern Mediterranean. The stratigraphic succession of heterozoan (lower), reefal platform (middle), and oolite-microbialite (upper) was affected by complex paleotopography. Thirteen distinct play analogs fall into 6 categories:

1) shallow-water heterozoans;
2) deep-water heterozoans;
3) coralgal reefal platforms;
4) deep water equivalents to coralgal platforms;
5) oolite-microbialite sequences; and
6) diagenetic plays.

(1) Three shallow water play analogs developed as heterozoan systems during times of cooler climate or nutrient excess. For one, a strait linking two basins concentrated current energy, depositing cross-bedded grainstone in the strait's paleotopography. An angular unconformity on top led to isolated paleohills, sealed after transgression. Another play analog consists of shallow-water grainy heterozoan carbonates deposited as a distal wedge during transgression. The third play analog consists of ramp deposits with seven draping and onlapping transgressive-regressive cyclothems; bryozoan, bivalve, and red algal facies dominate.

(2) In areas with steep substrate paleotopography, shallow-water heterozoan sediment was bypassed downslope as sediment gravity flows. The sediment accumulated in channels, minibasins, and straits. Internal stratigraphy is cyclic, and sediment gravity flows alternate with hemipelagic sediment deposited during high sea-level stands. Sediment gravity flow deposits onlap against paleotopography and are encased in deeper water hemipelagic sediment deposited as part of a long-term transgression.

(3) As conditions became favorable for photozoan carbonates, shallow-water coralgal reefal platforms dominated. One reefal play analog consists of isolated and fringing platforms. The reefal facies consists of corals, Halimeda, and associated components. Reefs are laterally discontinuous, with framework and moldic pores that may be variably connected. In comparison, a forereef slope play analog is volumetrically more important than the in-place reef. Forereef slope deposits are progradational and downlapping, consisting of breccias and grainy facies with better-connected porosity than the in-place reef.

(4) Three different types of deep-water play analogs developed at the same time as coralgal reefs. The most prospective play consists of focused flow deposits, where reefal debris was bypassed downslope by sediment gravity flows and focused into a deep-water channel. The paleotopographic focus led to a reservoir with high porosity and low heterogeneity. In areas lacking such a paleotopographic focus, grainy sediment gravity flows accumulated in isolated lobes, leading to high heterogeneity. In the most distal areas, hemipelagic chalks, diatomites, and low density turbidites led to deposition of high volumes of fine-grained deposits with petrophysical properties consistent with conventional chalk reservoirs, or with burial diagenesis, properties consistent with unconventional reservoirs or source rock.

(5) After initial deposition of Messinian evaporites, four sequences of oolite and microbialite draped basin margin paleotopographic highs. The oolite preserves abundant primary and moldic porosity, and the microbialite preserves variable porosity, depending on original fabrics and later cementation.

(6) Diagenetic processes contribute to three play analogs. The most important is dolomitization from ascending freshwater-mesohaline mixing, which is highly correlated with moldic porosity. The best reservoir porosity is created in distal settings close to the base of the carbonate platform. Other diagenetic plays are either not associated with, or are negatively associated with, subaerial exposure along seven subaerial unconformities. Most exposure events had little impact on reservoir porosity. Along one unconformity, however, significant amounts of calcite cement precipitated because of increased rainfall. This led to porosity preservation in areas away from water table cementation.

Finally, hypogene karstic porosity creates another play type, where sulfuric acid-rich chemically corrosive fluids were injected from below. The thirteen play analogs illustrate the complexity of predicting reservoir porosity in Eastern Mediterranean carbonate reservoirs. Despite such complexity, each play is either seismically or geologically predictable.

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Carbonate Play Models from Miocene outcrops, Western Mediterranean: Part 2 – Stratigraphic and diagenetic plays

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Notes by Presenter: Outcrops of Miocene Carbonates in the Western Mediterranean have excellent 3D exposures, have been intensively studied by the University of Kansas group for over 30 years, and preserve 11 pre-Messinian-evaporite play analogs that can inform explorers in the eastern Mediterranean and elsewhere.

11 Distinct Carbonate Play Analogs from Outcrop

(1) Shallow-Water Heterozoans

- High current energy strait linking two basins
- High current energy transgressive wedge
- Draping ramp with transgressive-regressive cyclothems

(2) Deepwater Heterozoans

- Onlapping downslope sediment gravity flows focused into deepwater channels and straits

(3) Coralgal Reefal Platforms

- In place fringing reefs
- Prograding forereef slopes

(4) Deepwater Equivalents to Coralgal Platforms

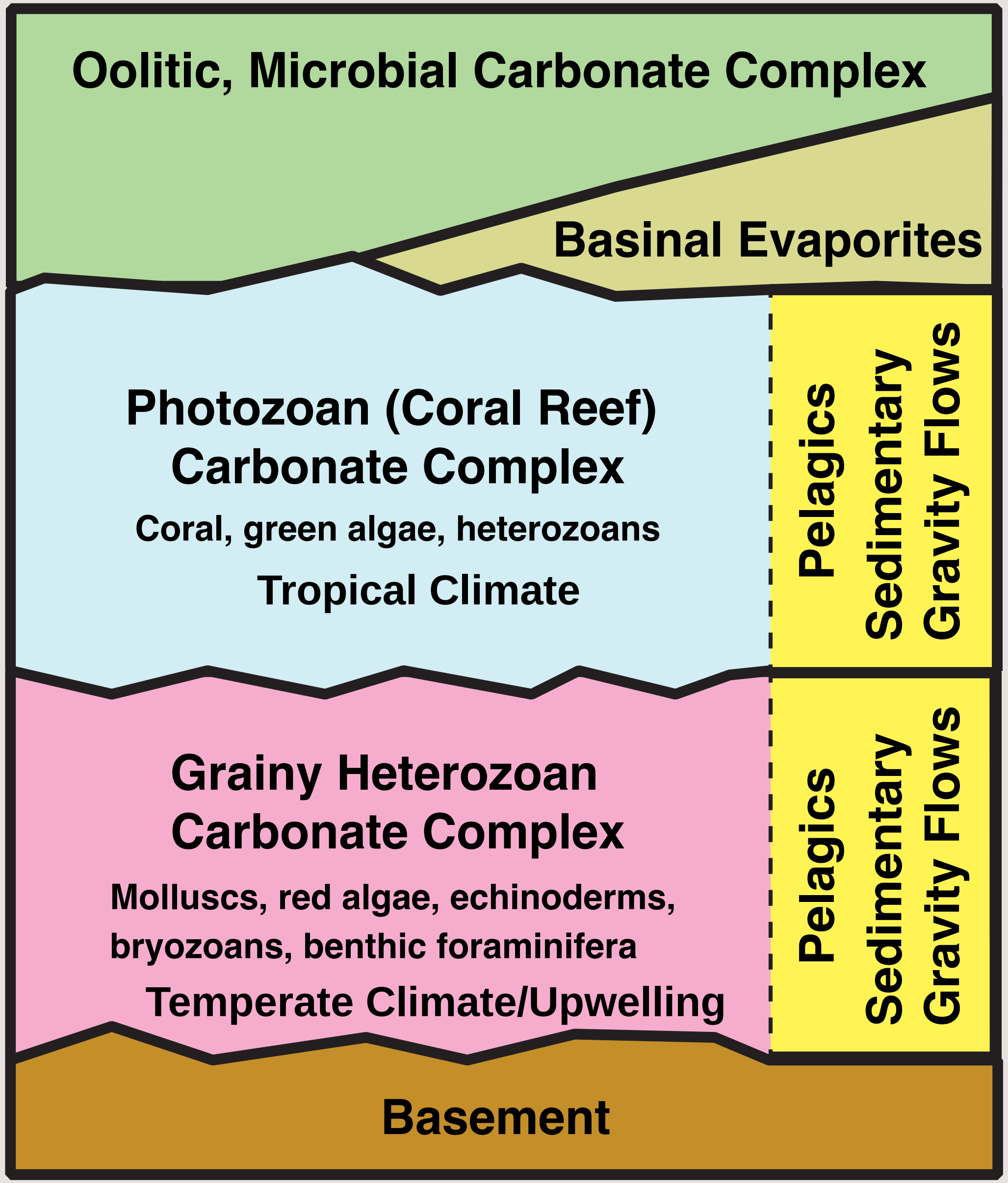
- Basin floor *focused flow* sediment gravity flows focused from channel or canyon morphology
- Basin floor *dispersed flow* sediment gravity flows without paleotopographic focus
- Hemipelagic *chalks and diatomites* on basin floor distant from sediment gravity flows

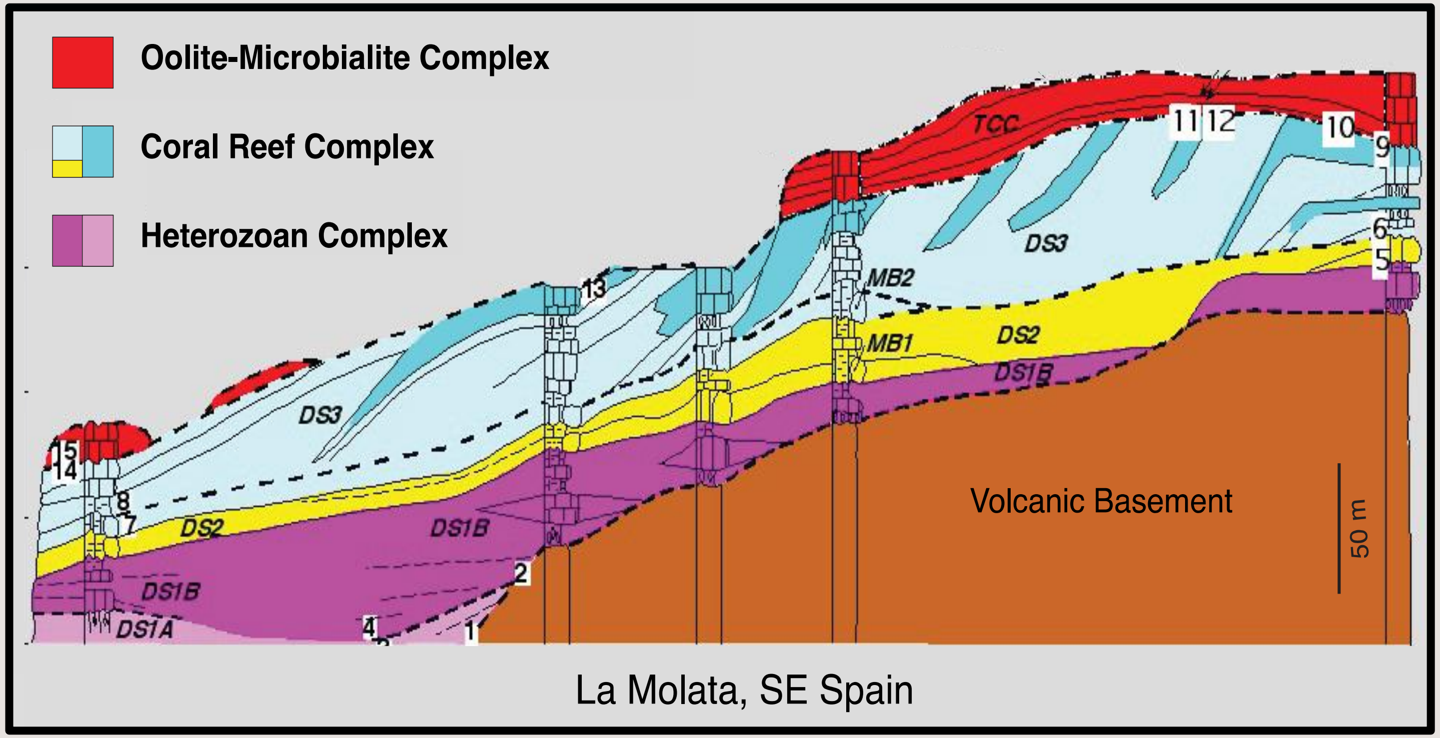
(5) Diagenetic Plays.

- Ascending freshwater-mesohaline mixing dolomitization
- Subaerial exposure and meteoric diagenesis

Notes by Presenter: For basic information on the setting and stratigraphy, please refer to Search and Discovery paper: *Carbonate Play Models from Miocene Outcrops, Western Mediterranean: Part 1* – Setting and Stratigraphy, by Evan K. Franseen & Robert H. Goldstein.

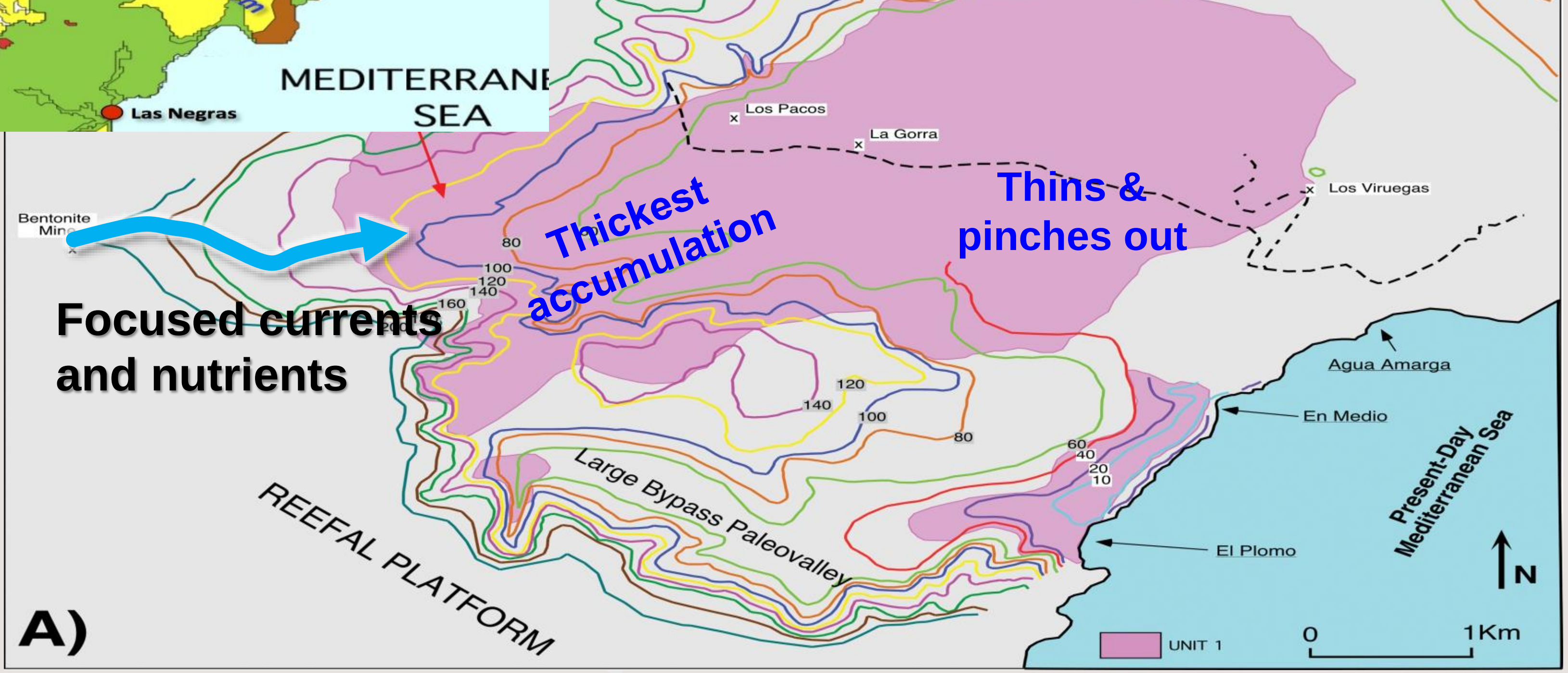
Western Mediterranean Upper Miocene General Stratigraphy





Franseen, Goldstein and Whitesell (1993)
Goldstein and Franseen (1995)

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

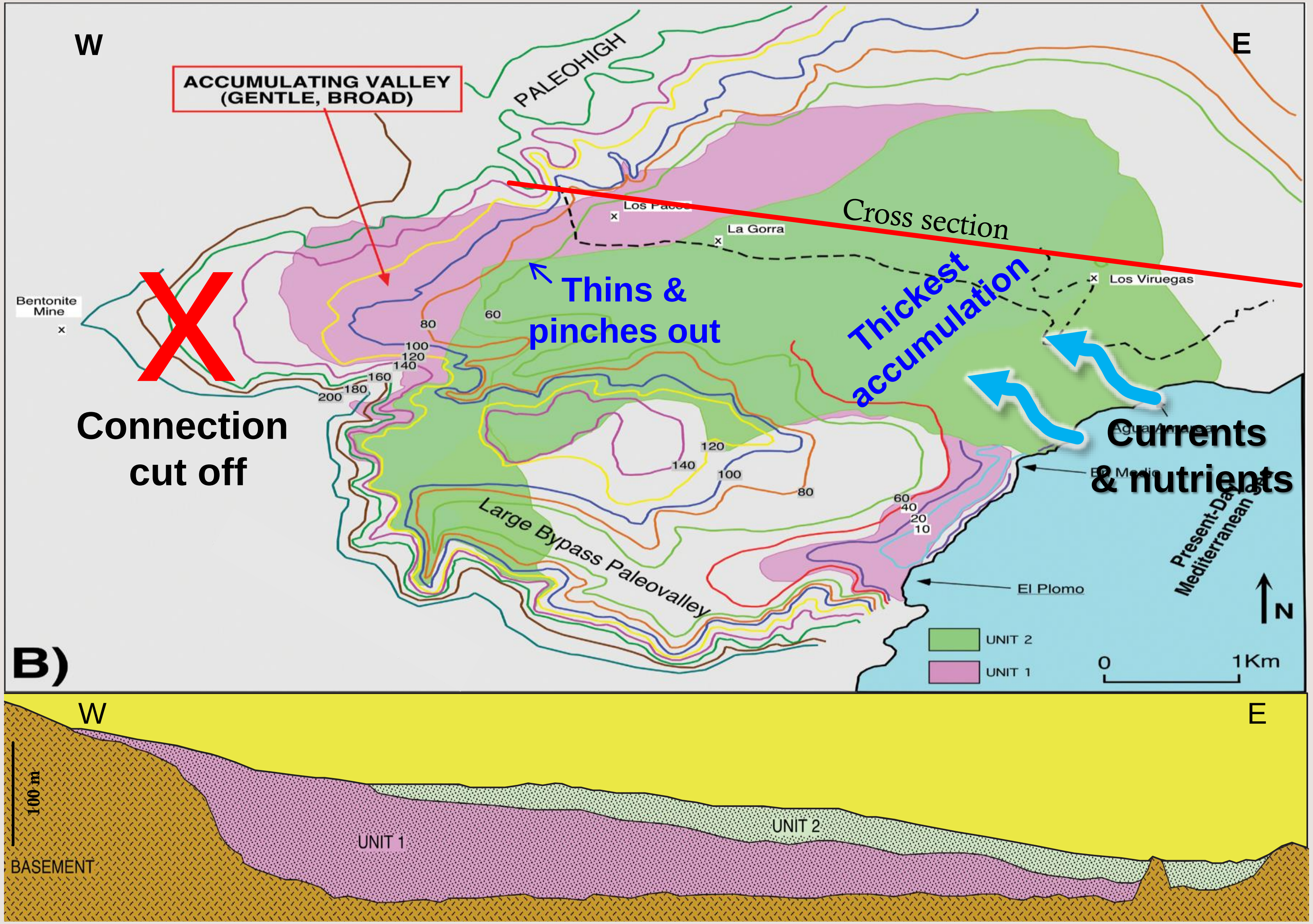


* Gently dipping substrate promotes preservation of shallow-water heterozoans.
* Most abundant and thickest accumulations where currents and nutrients focused.
* Updip onlap and erosion towards strait

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.

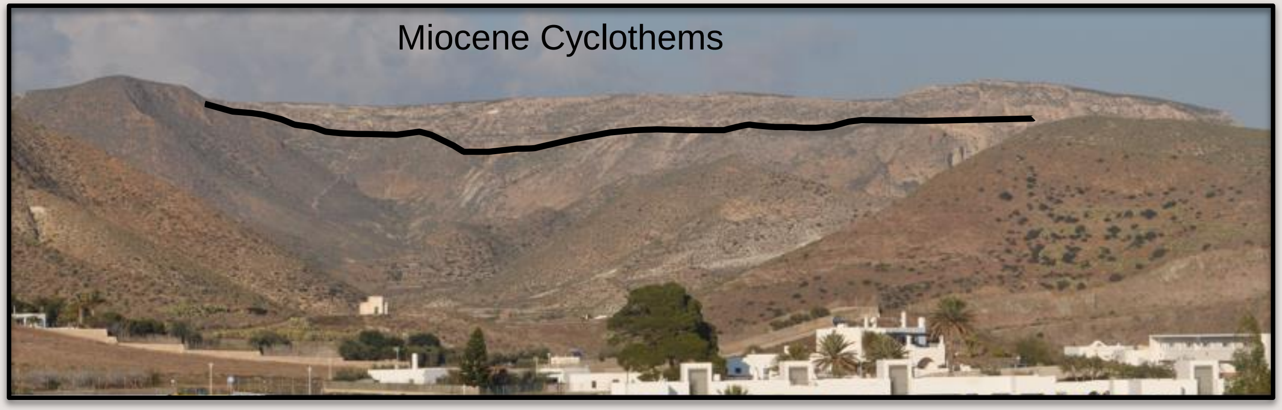
* Thickest towards currents and nutrient source (opposite first unit).

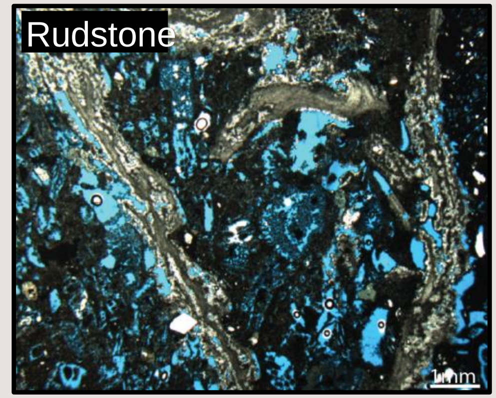
* Continued transgression - deep water hemipelagics covering grainy facies (potential seal).

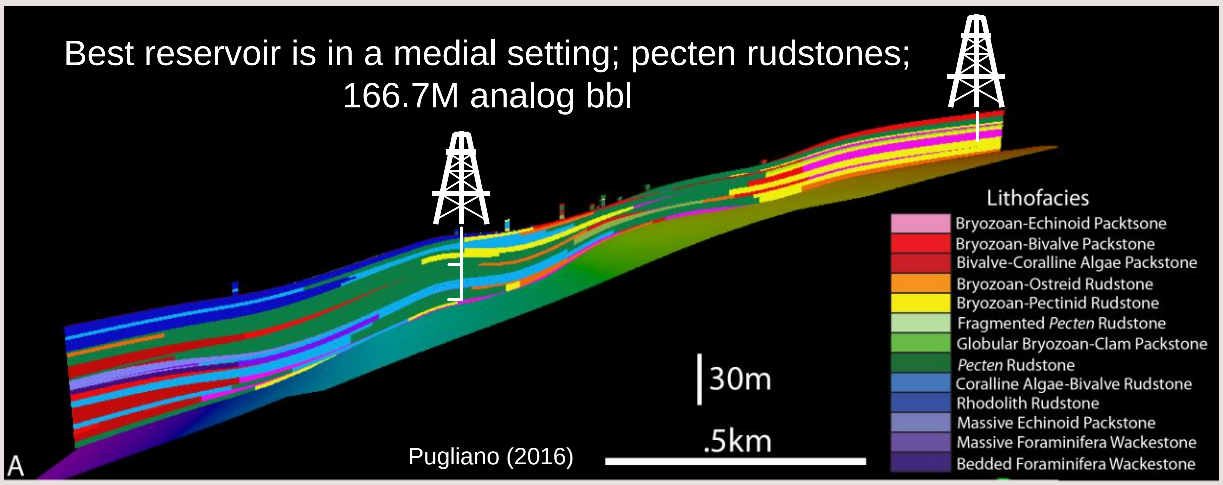
* Gentle substrate slopes promote preservation of shallow-water grainy heterozoan facies with favorable reservoir character.

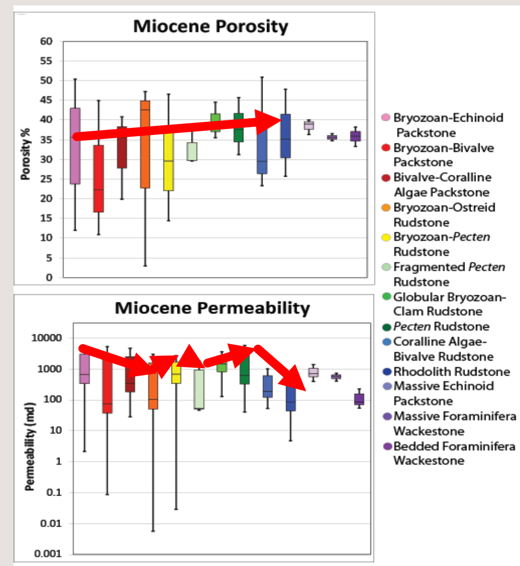
* Thickness and updip onlap related to substrate paleotopography and location(s) of currents/nutrients.

Draping Heterozoan Ramp with Cyclothems

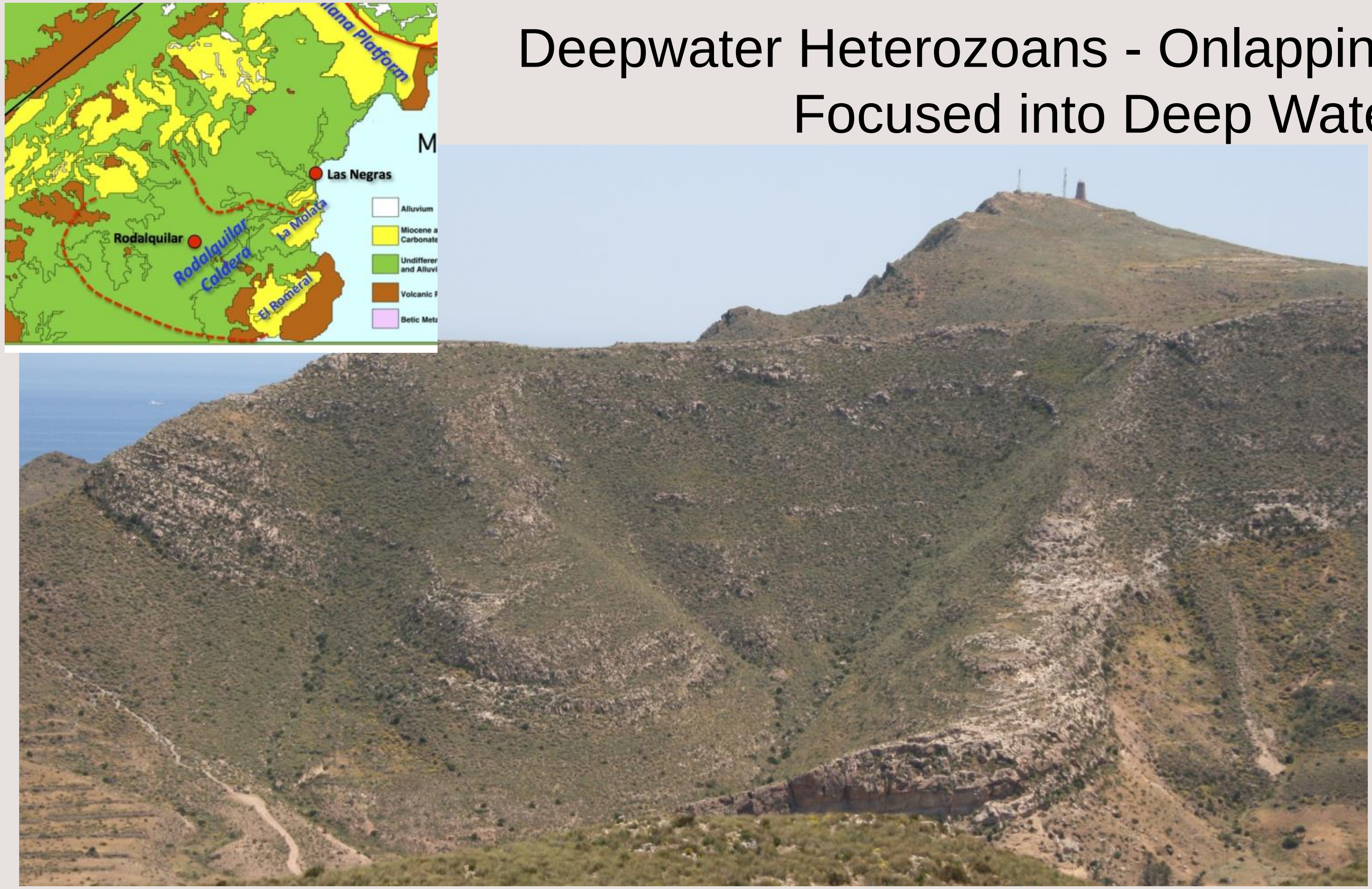




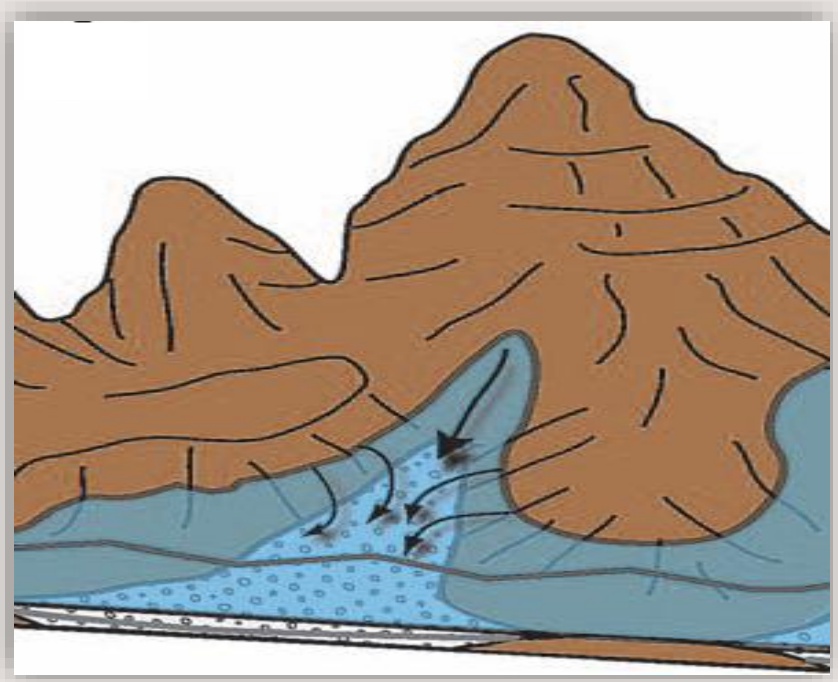




Notes by Presenter: This play analog consists of 7 transgressive-regressive sequences that drape a 6 degree sloping surface. The units lap out updip. Porosity and permeability of various facies can be traced from proximal to distal position. The sweet spot is a facies belt that is rich in pecten rudstones. The tendency for most explorers would be to drill the more proximal settings, however, the medial setting would likely be more predictable in terms of high volumes of the best reservoir facies.



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



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

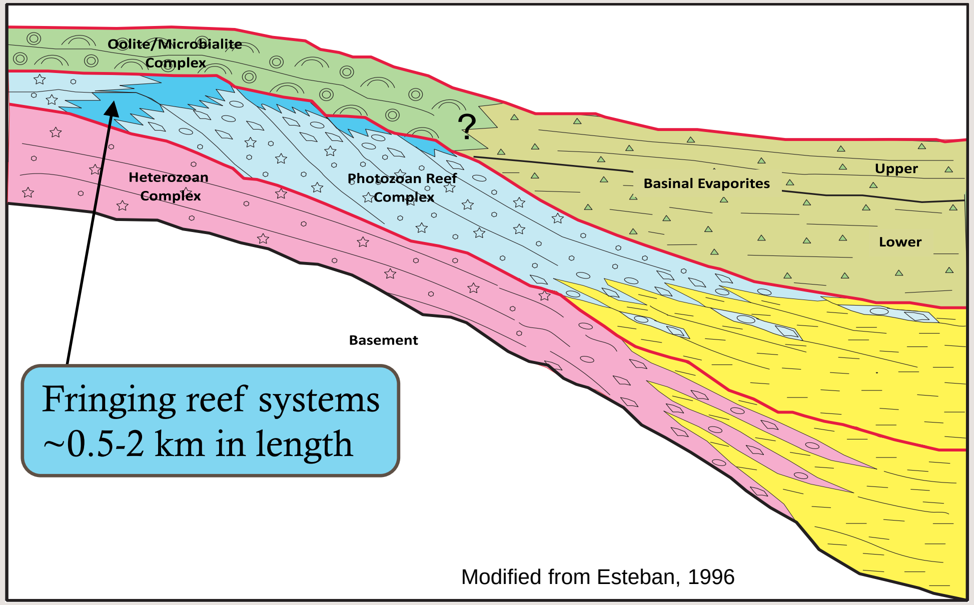
Johnson et al. 2005

Inherited steep substrate slopes result in bypass of shallow-water heterozoans to deep water as sediment gravity flows.

Topographic funneling mechanism forms point-sourced deep water deposits that onlap at toes-of-slopes.

Transported carbonate facies have favorable reservoir character and are interbedded with hemipelagics (potential baffles/seals/source rock/reservoir).

Coralgal Reefal Platforms - In Place Fringing Reefs



* Substrate slope angles important for development and size.

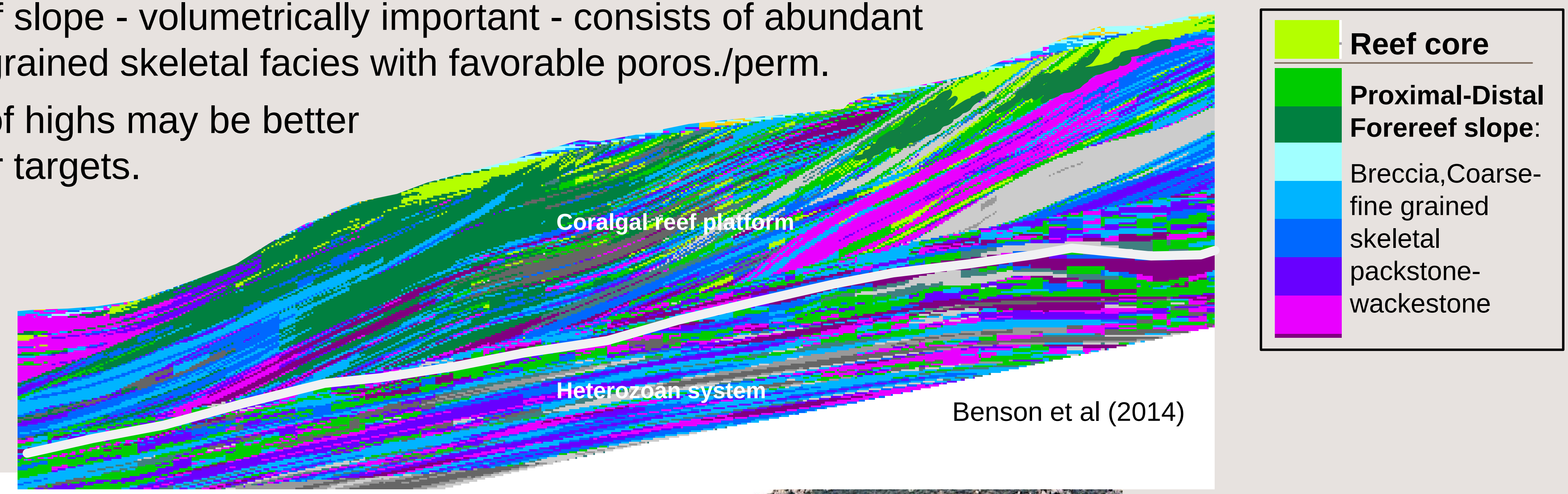
* Aggradational and progradational geometries related to sea level.

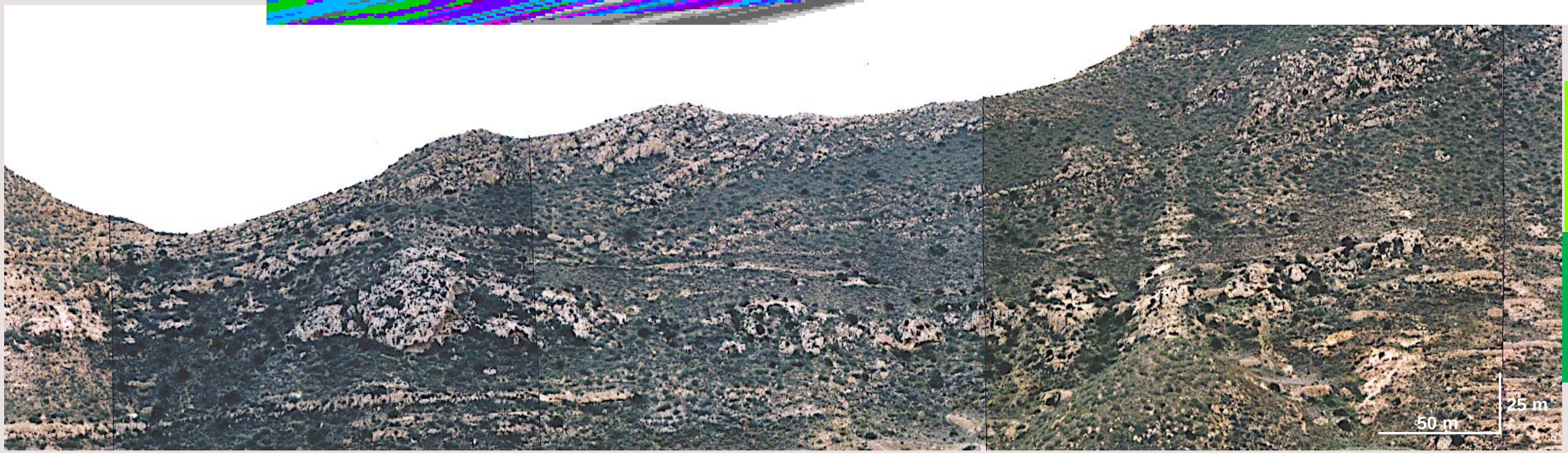
* Downstepping progradation during sea-level fall just prior to basinal evaporite deposition.

* Aragonitic components (corals, green algae) - moldic porosity.

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.

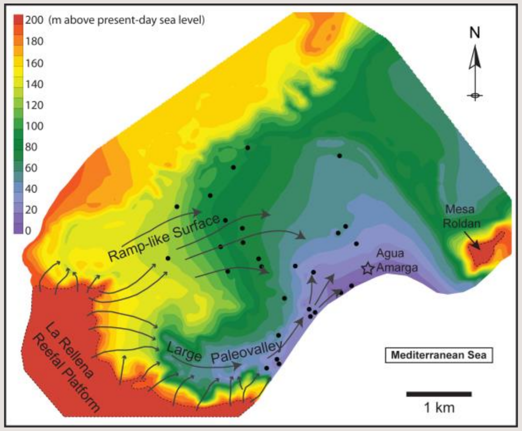


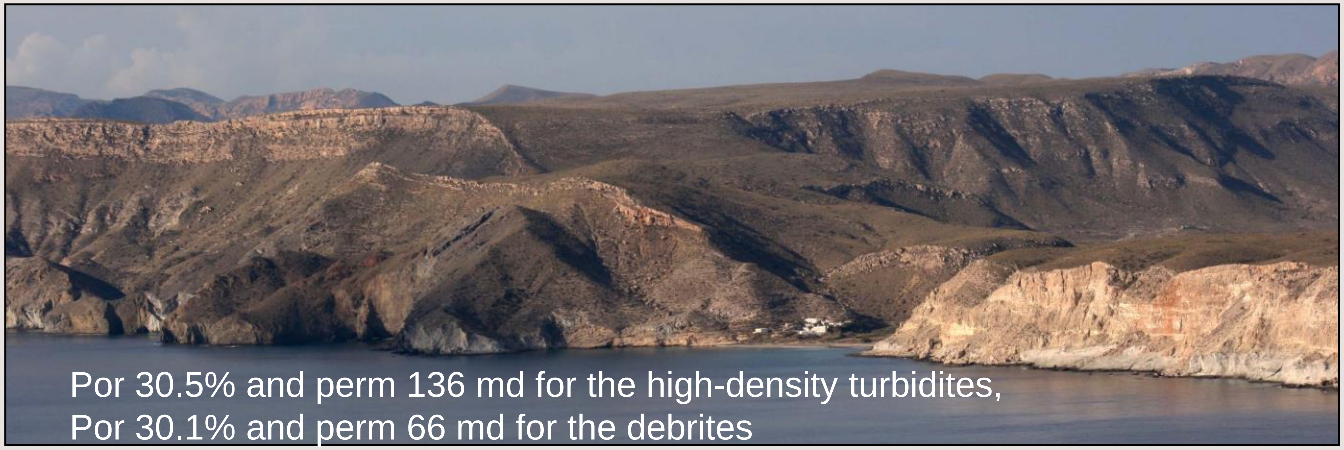


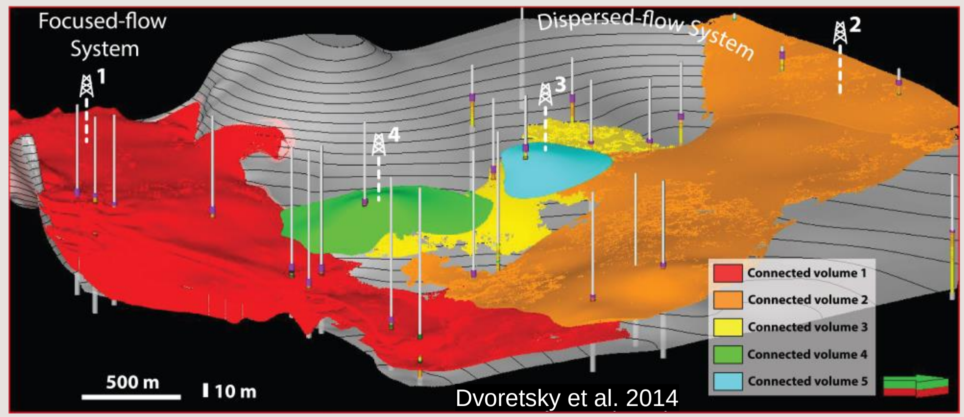
Reef: phi = 20%±; K = 184md (0-1689md)

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

Deepwater Equivalents to Coralgal Reefs – *Focused Flow*

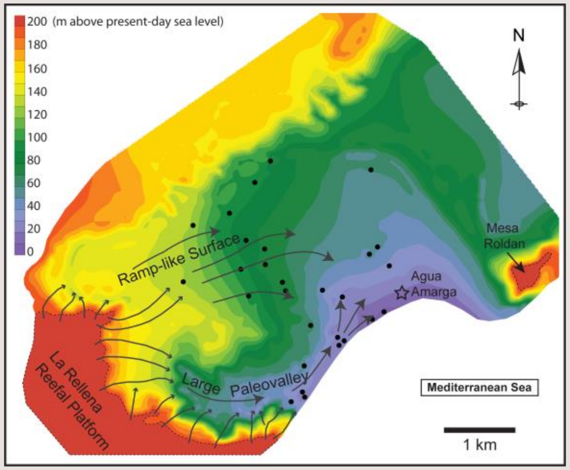


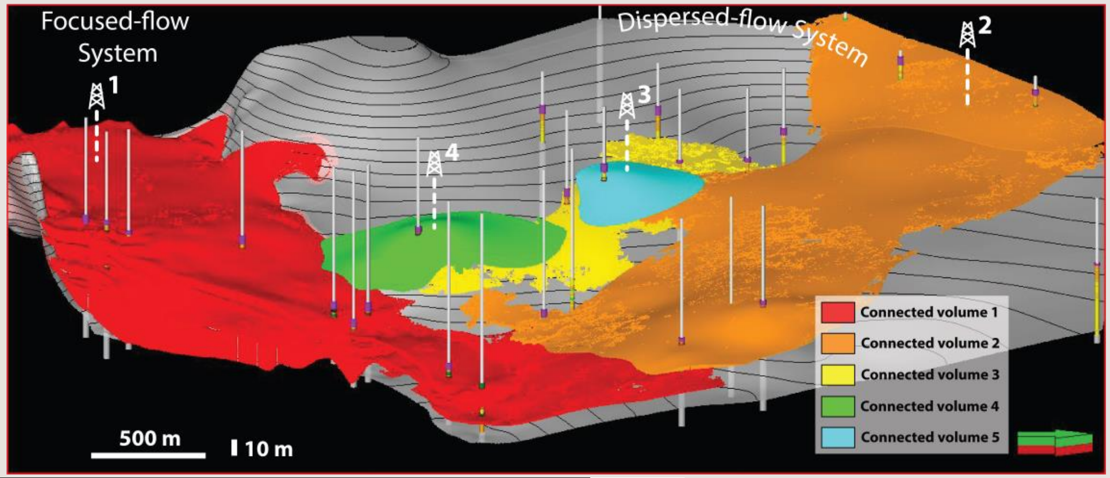


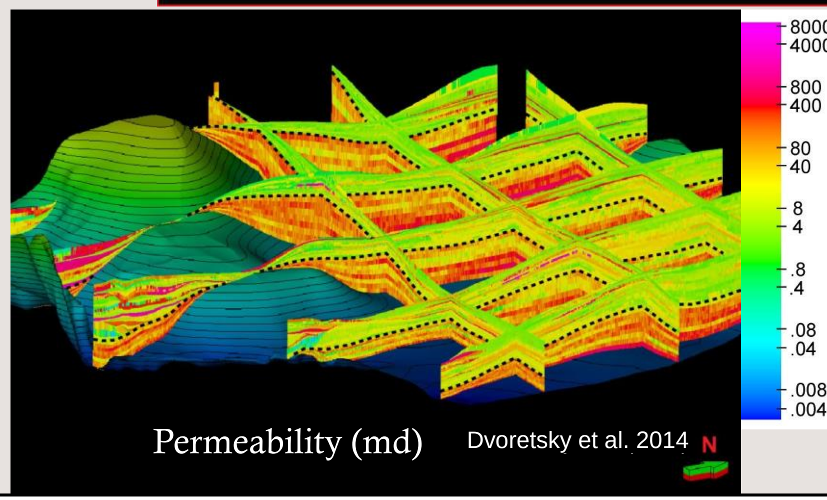


Notes by Presenter: Downslope of reefal platforms, there are areas where sediment gravity flows deposit reservoir rock on the basin floor. In one setting, a paleotopographic focus leads to concentration of sediment gravity flows in one channel-shaped area. A paleotopographic map is shown here that illustrates 5 km of reefal platform margin with all flows focused into a single topographic feature. The entire system is exposed in outcrop. One photo exposes a cross section across the reefal platform and exposing the basin floor. Another photo is taken from the location of the reefal platform looking in to the deepwater channel-like feature. The petrophysical properties of rocks in this feature are typically good and every bed is connected. In the model shown of the basin, the area in red is the largest connected volume. It is located in the area of paleotopographic focus.

Deepwater Equivalents to Coralgal Reefs – *Dispersed Flow*



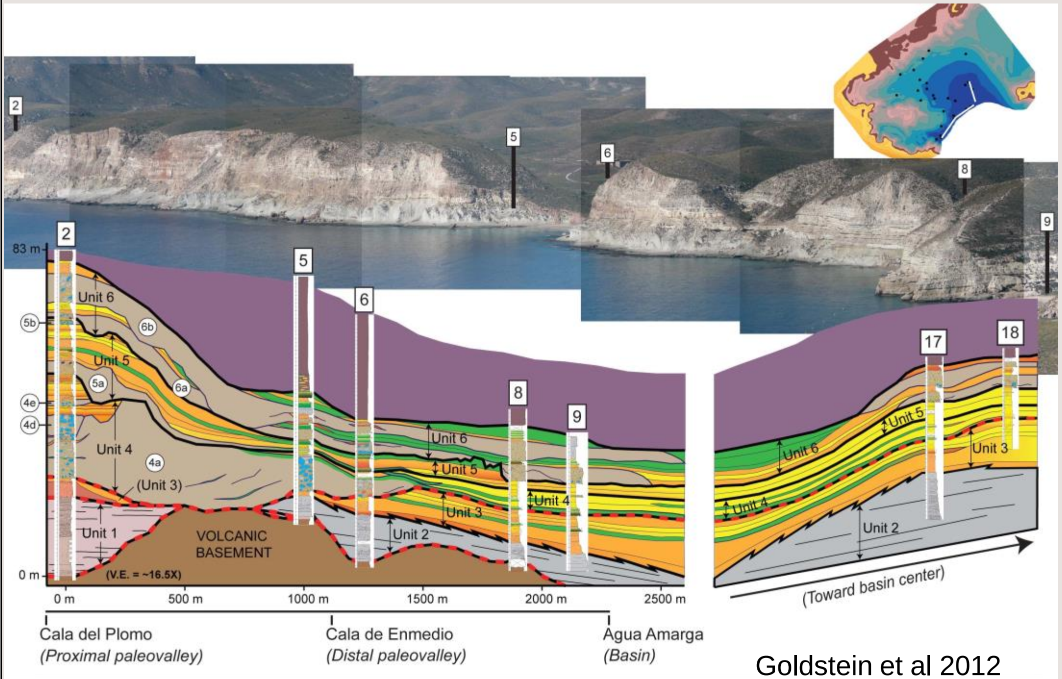




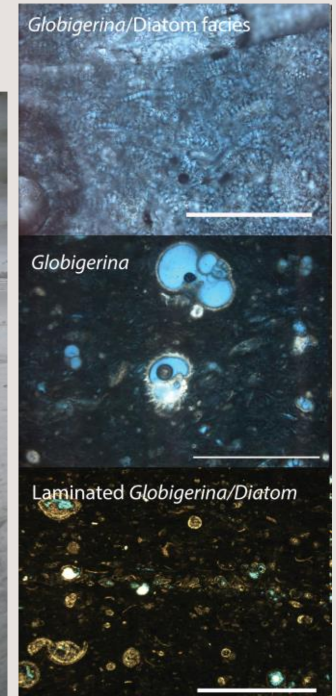
- Dispersed flow system has isolated lobes of grainy sediment gravity flows
- Much more heterogeneous than focused flow

Notes by Presenter: In contrast to the focused flow deposits, other areas of the basin lack a paleotopographic focusing mechanism, and sediment gravity flows are more dispersed as isolated lobe-shaped bodies. The paleotopographic map shows an area of reefal platform margin, where the area downslope forms a ramp-like surface. This results in deposition of isolated lobes of grainy sediment gravity flows. The 3D model shows the five largest connected volumes. The largest is in the focused flow area and all others are in the dispersed flow area. In this area where flows were dispersed, there are small isolated lobes that do not connect with one another. In the permeability model, there are thin high permeability streaks isolated by lower permeability sediment in that area. Overall, this leads to much more heterogeneity in the dispersed flow area than in the focused flow area.

Deepwater Equivalents to Coralgal Reefs – *Chalks and Diatomites*



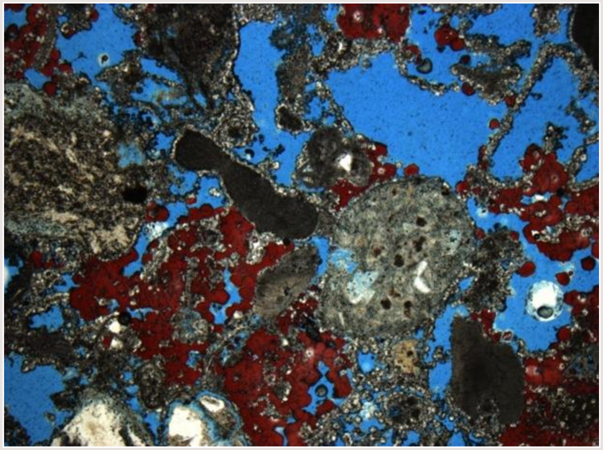
Goldstein et al 2012

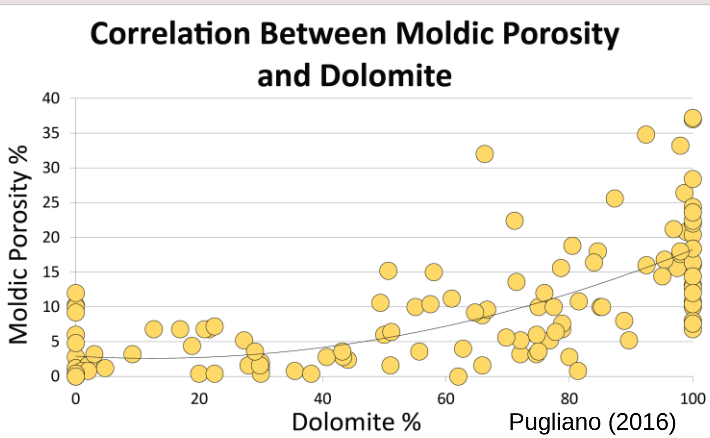


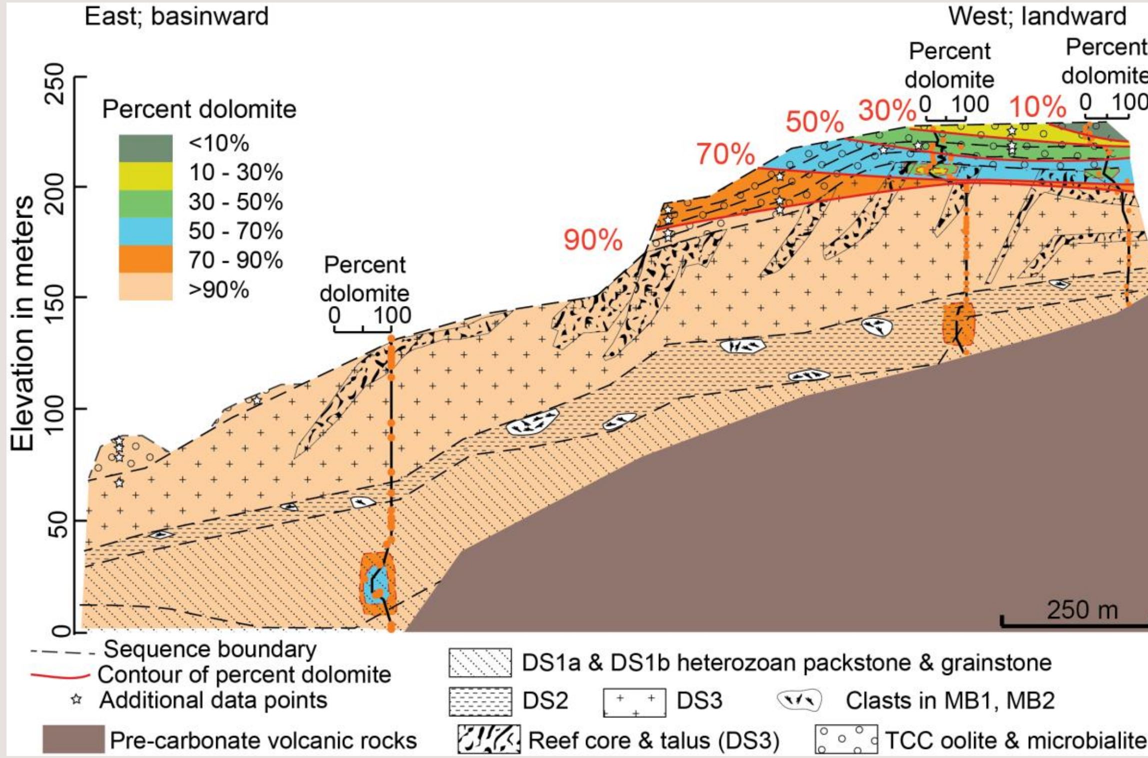
- Chalk and diatomite por. 35.9% and perm. 12.3md
- Mostly greater than 3 km from basin margin – distant from sources of coarse sediment gravity flows
- Potential for self sourcing with TOCs ranging from 0.2 to 23% (Lorca Basin; Rouchy et al. 1998)

Notes by Presenter: Chalks and diatomites are in more distal settings, farther from the source of sediment gravity flows. In the proximal-to-distal cross section shown, the yellow colors are chalks and diatomites and the other colors are mostly sediment gravity flows. About 3 km away from the toe of slope, facies are dominated by chalks and diatomites. These fine-grained facies preserve reasonably high porosity and can be regarded either as conventional or unconventional reservoir analogs. They preserve the highest TOC of the succession.

Diagenetic Plays – *Dolomitization from Ascending Freshwater-Mesohaline Mixing*





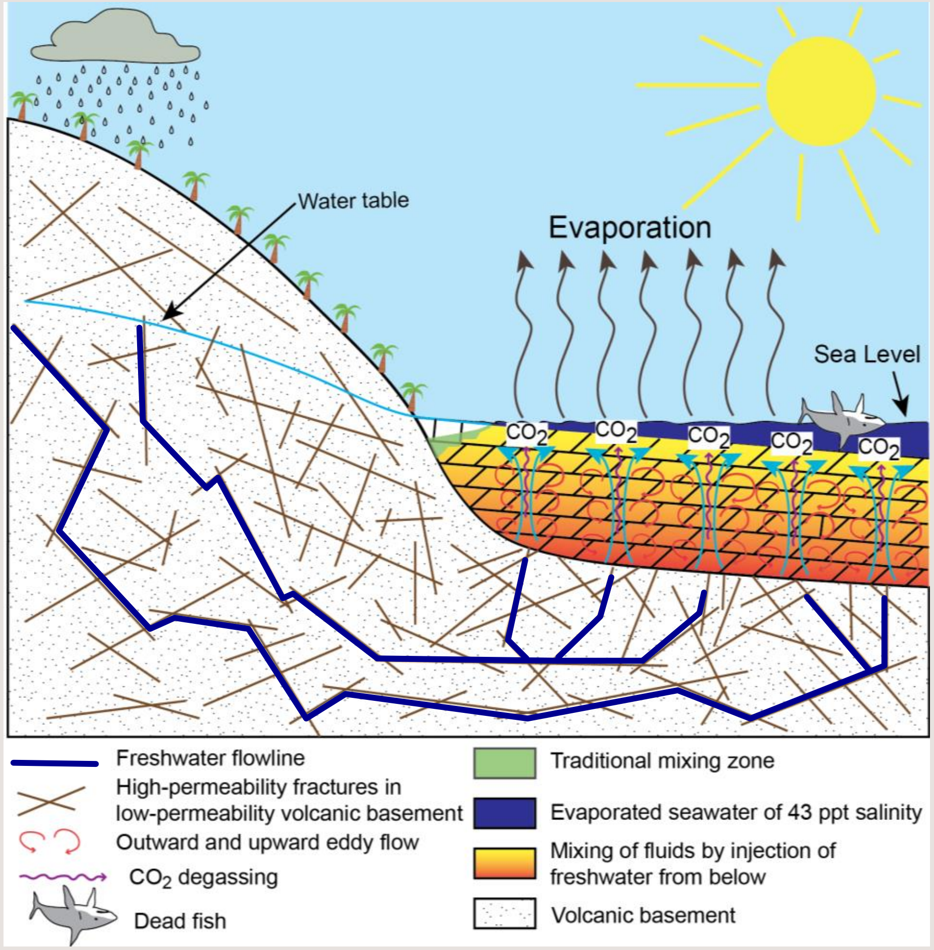


After Li et al (2013)

- Improved petrophysical values in distal areas, close to basement
- Not as good in proximal areas because of less dolomitization

Notes by Presenter: One diagenetic play is related to dolomitization of the carbonates. The dolomitized rock commonly preserves abundant moldic porosity. There is a correlation between quantity of dolomite and moldic porosity. Petrography supports that dolomitization was coincident with formation of moldic pores. Distribution of dolomite can be mapped out in cross section. Updip in the most proximal areas, dolomite percentage becomes very low. It increases in more distal areas and areas close to the volcanic basement.

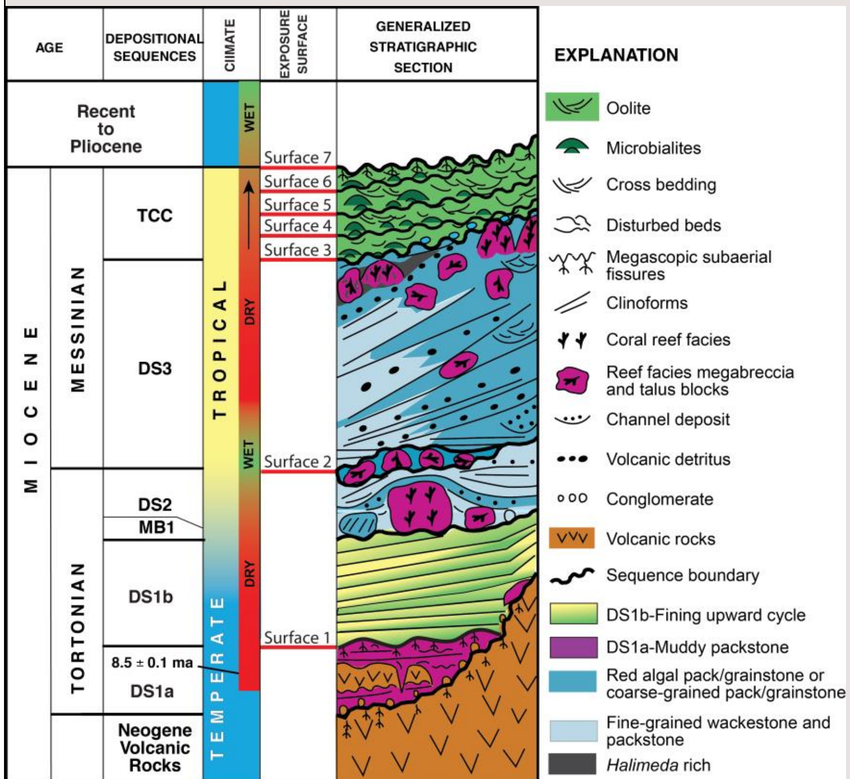
Diagenetic Plays – *Dolomitization from Ascending Freshwater-Mesohaline Mixing*



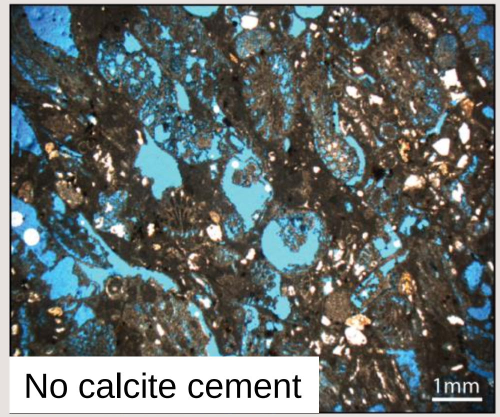
After Li et al (2013)

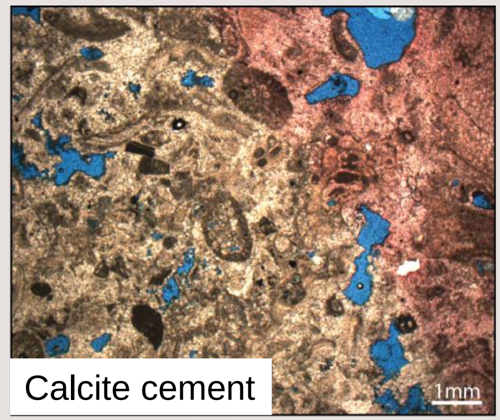
Notes by Presenter: The mechanism of dolomitization is by ascending freshwater mixing with marine or evaporated marine water. It requires an aquifer providing freshwater to the underside of the carbonate platform, which allows the freshwater and seawater to mix. This produced dolomite and porosity in more distal areas and areas above the basement, but no dolomite updip in proximal areas.

Diagenetic Plays – *Subaerial Exposure*

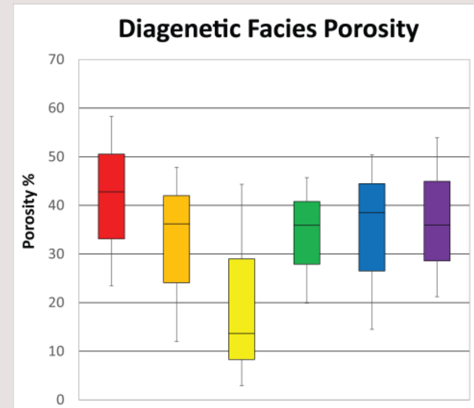


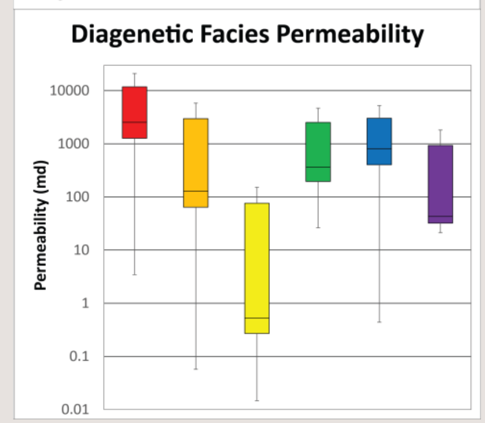
- Seven unconformities – **no major karst**
- The first six each only affected the uppermost 0.5-2 m
- Surface 7 - 53% of platform, molds increase by 8%, *but* **intense calcite cementation at two paleo-water tables**





Li et al (2014)





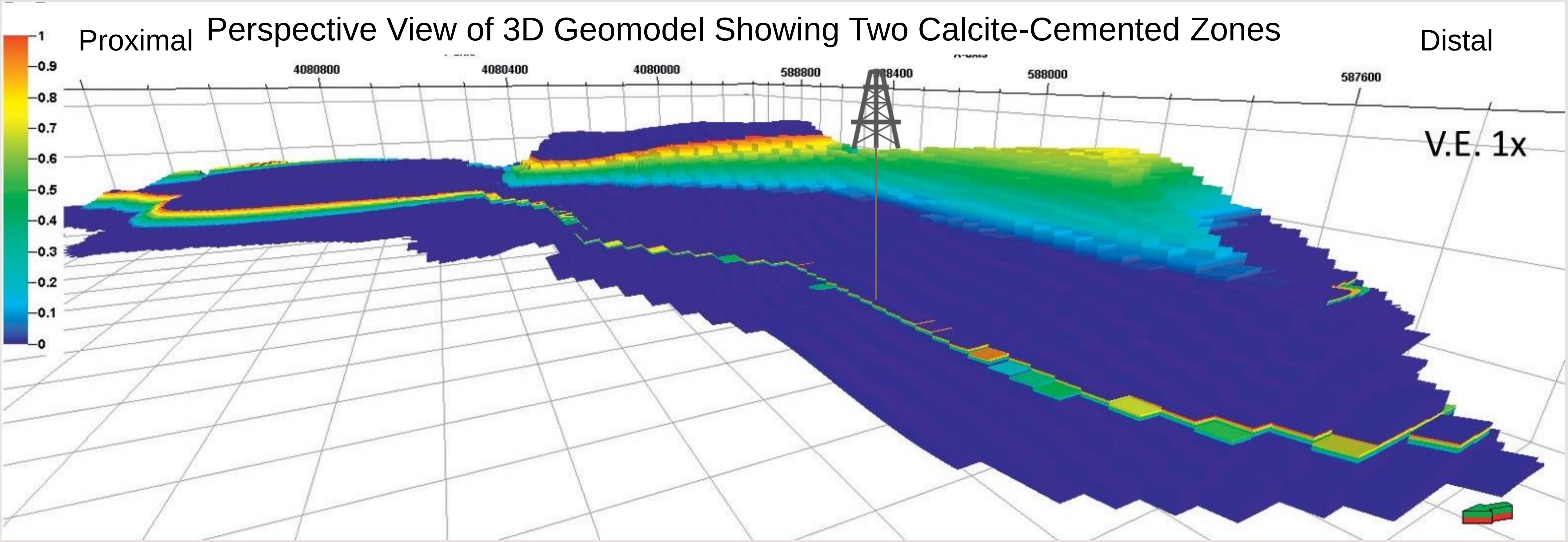
- Primary pores, calcite, low cement (Pliocene)
- Primary pores, calcite, low cement (Miocene)
- Moldic pores, calcite, high cement

Notes by Presenter: Another diagenetic play is related to subaerial exposure and meteoric diagenesis. There are seven unconformities.

Diagenetic Plays – *Subaerial Exposure*

- Calcite cementation converges updip and yields a high percentage of tight carbonate
- Porosity and thick reservoir facies is best preserved in medial settings
- The play is medial reservoir with updip convergence of cemented zones

Perspective View of 3D Geomodel Showing Two Calcite-Cemented Zones



Benson et al (2014)

Conclusions

(1) 11 carbonate play analog models that work in the Miocene of the Mediterranean

(2) Include:

- Shallow-Water Heterozoans
- Deepwater Heterozoans
- Coralgal Reefal Platforms
- Deepwater Equivalents to Coralgal Platforms
- Diagenetic Plays

(3) May be predicted from seismic topography and stratigraphy

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To learn more:
- join our consortium (KICC) or
- attend our field seminar in Spain

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