

# Diagenetic Controls on Porosity and Permeability in Upper Miocene Carbonates, La Molata, SE Spain\*

Zhaoqi Li<sup>1</sup>, Robert H. Goldstein<sup>2</sup>, and Evan K. Franseen<sup>2</sup>

Search and Discovery Article #50709 (2012)\*\*

Posted August 31, 2012

\*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012

\*\*AAPG©2012 Serial rights given by author. For all other rights contact author directly.

<sup>1</sup>Department of Geology, The University of Kansas, Lawrence, KS ([lizhaoqiku@ku.edu](mailto:lizhaoqiku@ku.edu))

<sup>2</sup>Department of Geology, The University of Kansas, Lawrence, KS

## Abstract

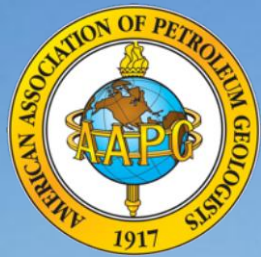
Relating diagenetic processes to porosity and permeability is essential for carbonate reservoir quality prediction. We utilize Miocene heterozoan, photozoan, and oolitic - microbial sequences in SE Spain where paleotopography is preserved to evaluate the effect of a mesohaline mixing-zone and multiple events of meteoric diagenesis on porosity within a well-constrained stratigraphic framework and known sea-level history. Seven subaerial exposure surfaces allow evaluation of exposure duration, and climate on meteoric diagenesis. Only minor diagenesis occurred during early arid and short-lived subaerial exposure events. Later end-Miocene dolomitization and dissolution had the most profound effect on porosity. Dolomite  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  range from +0.9 to +6.0‰ PDB, -4.5 to +3.0‰ PDB, respectively. Covariation suggests fluid mixing. Downdip areas have more enriched  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$ . Isotopic evaporation modeling of the most positive  $\delta^{18}\text{O}$  suggests a salinity of 42 ppt. Fluid inclusion measurements of freezing point depression yield Tm-ice ranging from -0.2 to -2.3 °C, indicating salinities ranging from 4 ppt to 43 ppt, with highest values in downdip areas. These data confirm fluid mixing and rule out physical mixing or recrystallization of multiple dolomite phases. Dolomitization was from a mixture between meteoric water and slightly evaporated seawater, here termed mesohaline mixing, a possible predictable type of dolomitization given specific climate and hydrogeologic conditions. Petrographic relationships indicate mesohaline mixing created major moldic and vuggy dissolution. Dolomitization was followed by 5 million years of subaerial exposure, during which times of more humid climates and erosion during uplift resulted in two zones of significant calcite cementation, separated by a zone with little calcite cementation. Calcites have negative  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ , and fluid inclusion Tm-ice of 0.0 °C, indicating precipitation from meteoric water. The two cemented zones likely represent two different paleo-water tables formed during uplift and erosional downcutting. The results of mesohaline mixing enhancing porosity and permeability in relation to paleotopography, and later stages of meteoric calcite cementation decreasing porosity and permeability are predictable and can be incorporated into geomodels for better prediction of porosity and permeability distribution in carbonate reservoirs.

## **References**

Johnson, C.L., Franseen, E.K., and Goldstein, R.H., 2005, The Effects of Relative Sea Level and Paleotopography on Lithofacies Distribution and Geometries in Heterozoan Carbonates, Southeastern Spain: *Sedimentology*, v. 52, p. 513-536.

Franseen, E.K., R.H. Goldstein, M.R. Farr, 1998, Quantitative controls on location and architecture of carbonate depositional sequences; upper Miocene, Cabo de Gata region, SE Spain: *JSR*, v. 68/2, p. 283-298.

Lipinski, C.J., 2009, Stratigraphy of Upper Miocene oolite-microbialite-coralgal reef sequences of the Terminal Carbonate Complex: Southeast Spain: Unpublished MS Thesis, University of Kansas Department of Geology, 116 p.



# Diagenetic Controls on Porosity and Permeability in Upper Miocene Carbonates, La Molata, SE Spain

*Zhaoqi Li*

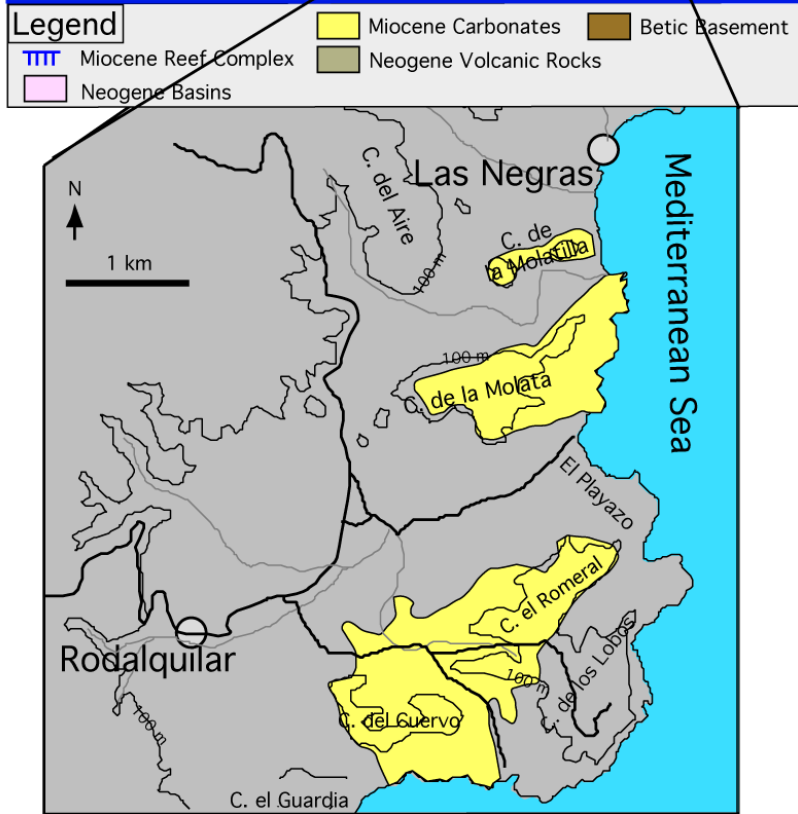
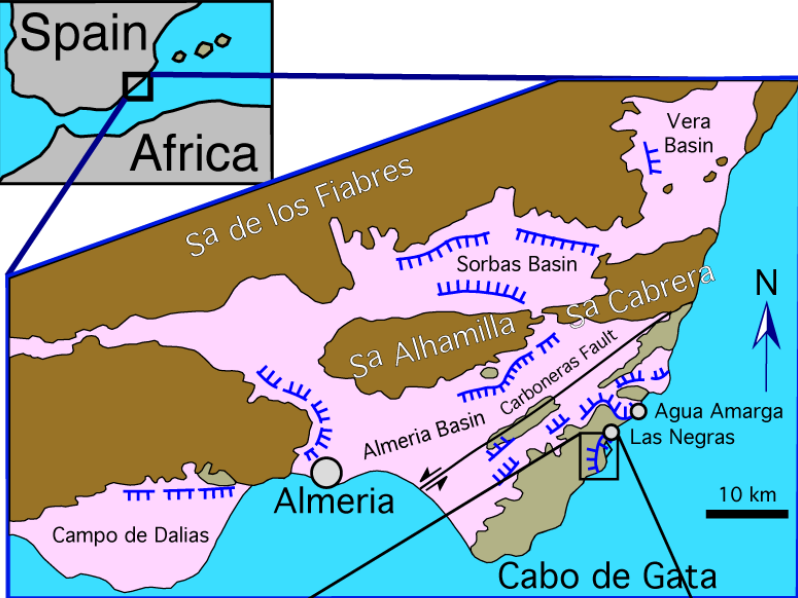
*Robert H. Goldstein*

*Evan K. Franseen*

*Dept. of Geology, The Univ. of Kansas, Lawrence, KS*

# Key Findings

1. Documents pervasive dolomitization in upper Miocene carbonates from mixing of freshwater and evaporated seawater. Mixing-zone dolomitization remains alive.
2. Short-lived subaerial exposure during arid climate seems to have had only a minor diagenetic effect on porosity and permeability. In contrast, long-lived surfaces of subaerial exposure and a wetter climate led to more of an impact.
3. Aspects of setting, such as climate, duration of exposure, paleotopography and hydrogeology are significant controls on diagenesis.



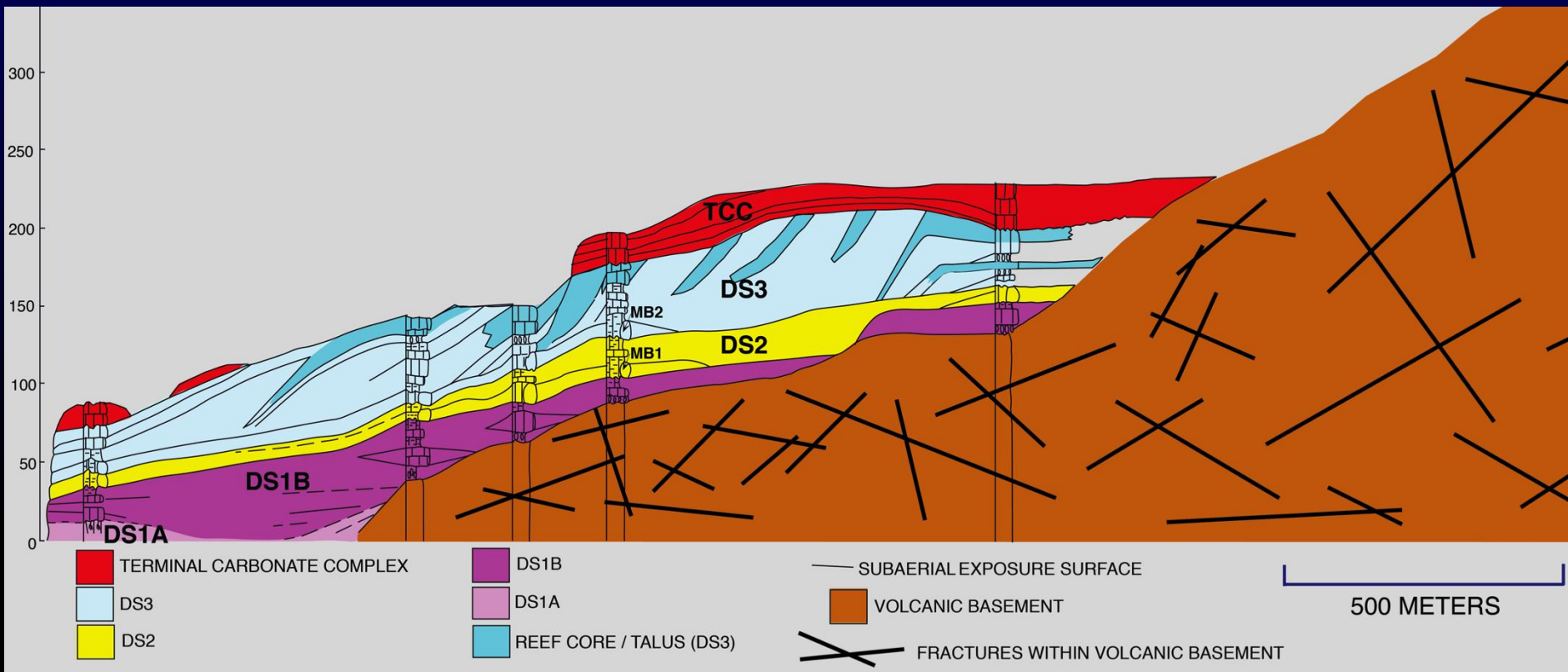
# Location

- Volcanic archipelago with adjacent interconnected Neogene basins.
- Upper Miocene carbonates were deposited on the flanks of Neogene volcanic highs.



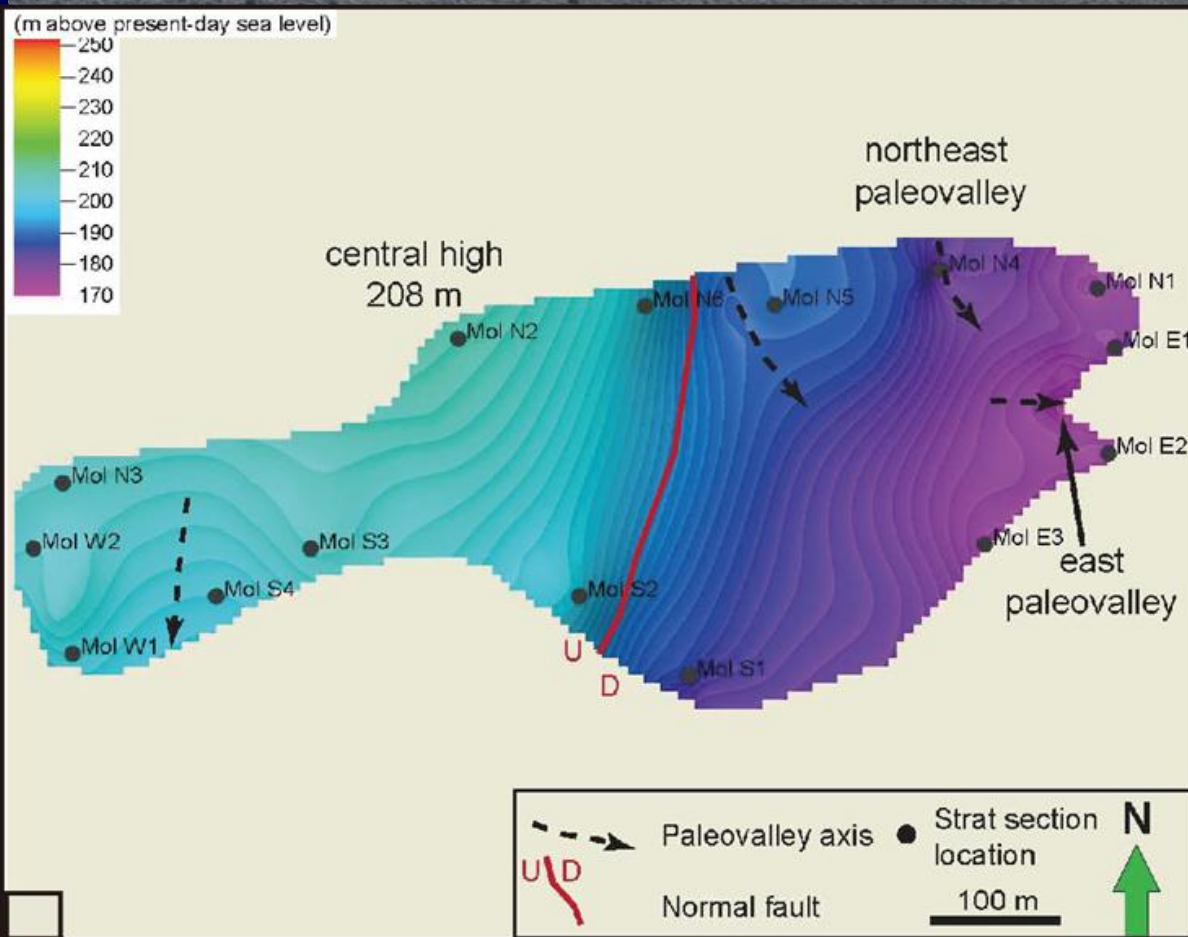
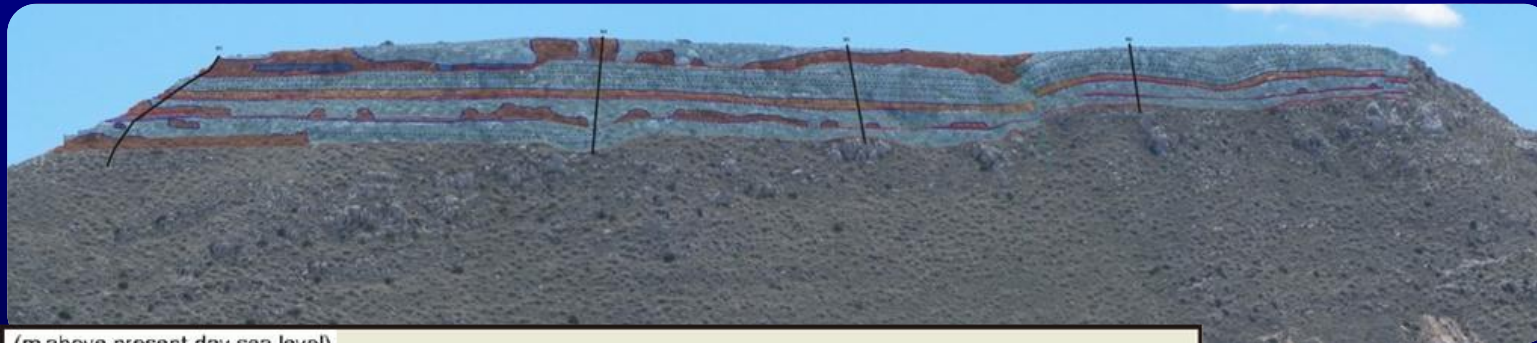


# Stratigraphy



Modified from Franseen et al., (2005).

# Paleotopographic Setting

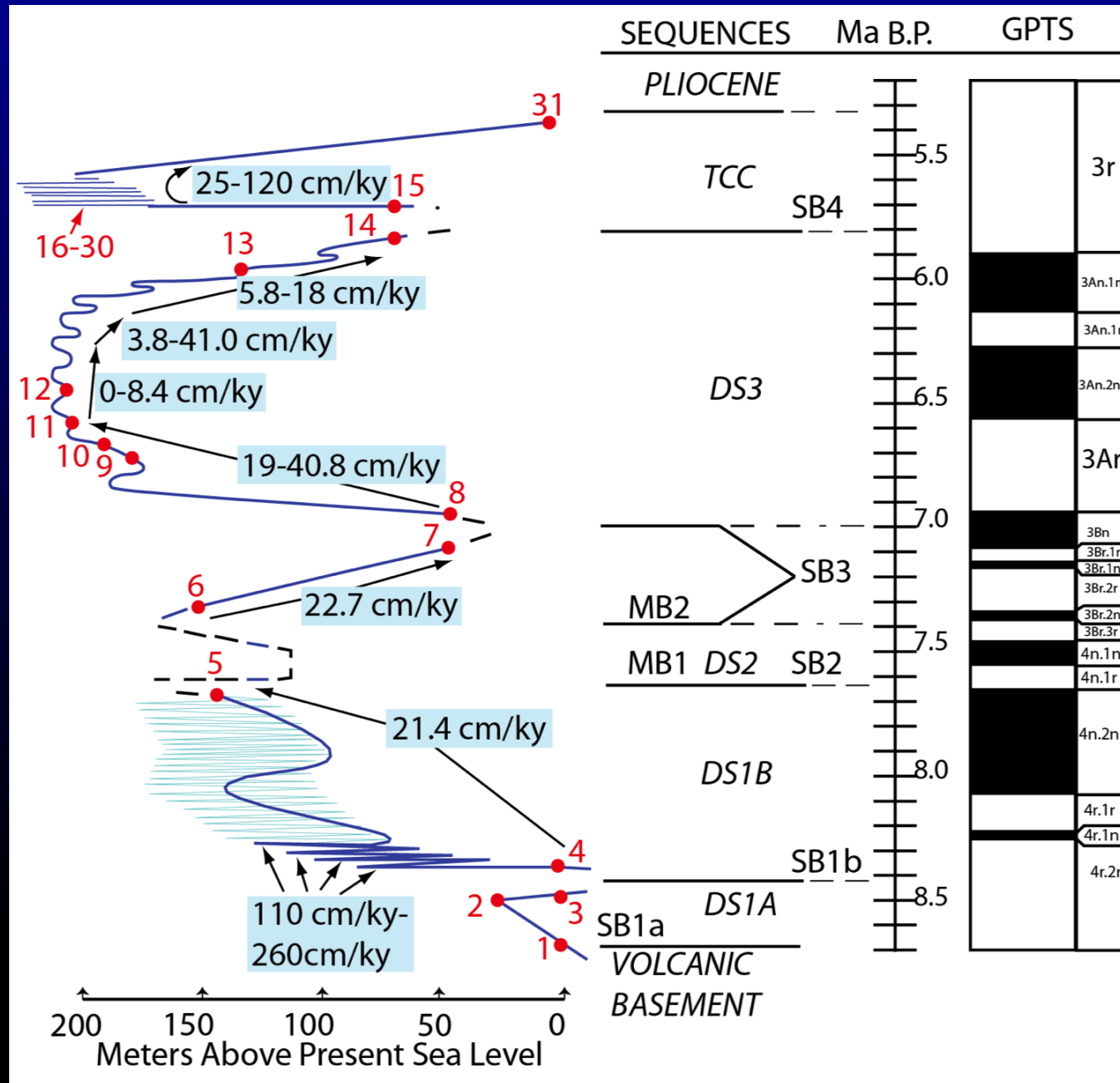


The TCC drapes 33 meters of paleotopographic relief.

Lipinski, 2009

# Duration of Subaerial Exposure

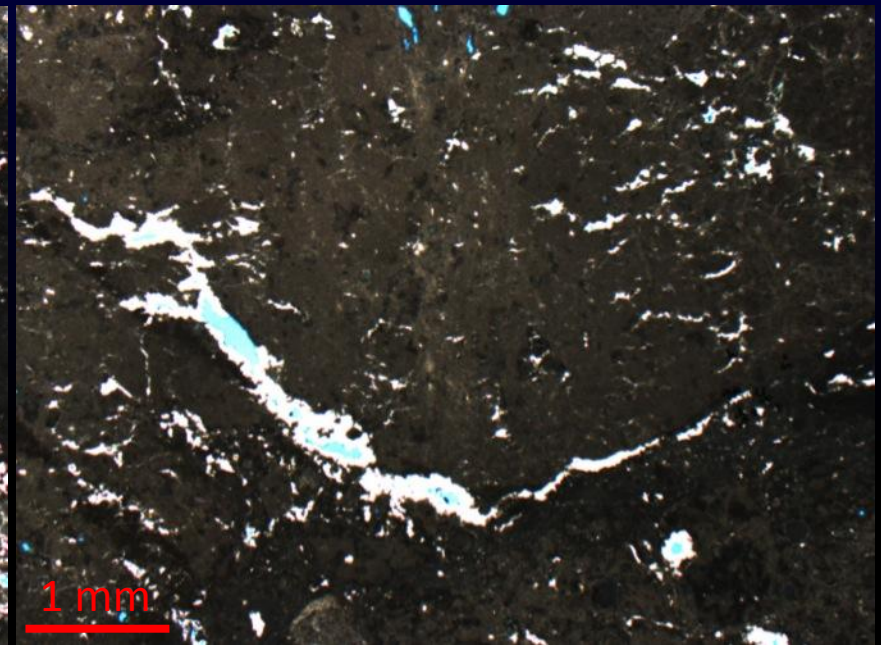
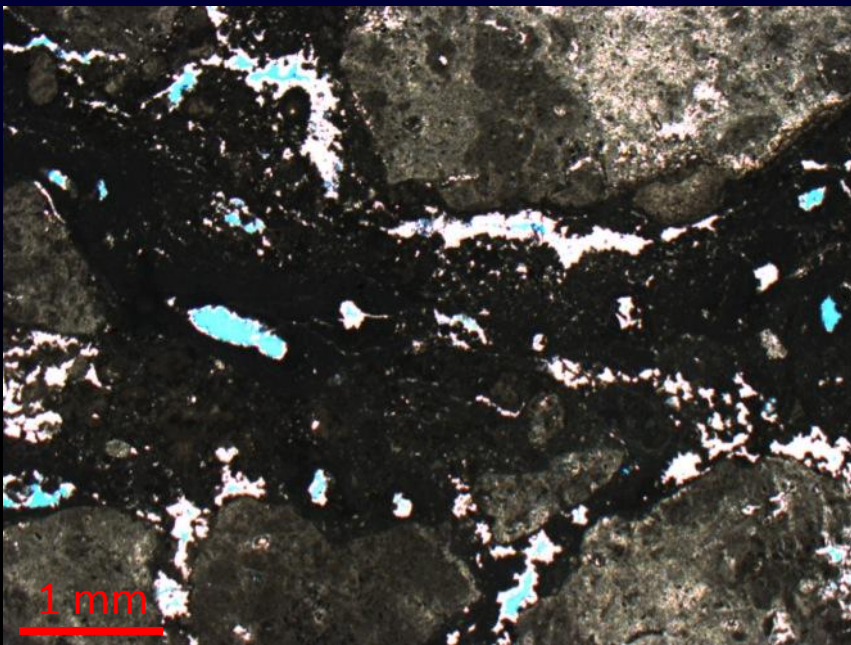
Interpretive relative sea-level curve with pinning points and fluctuation rates



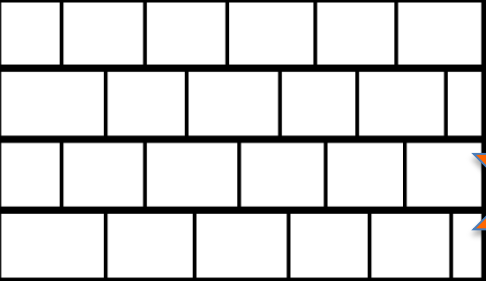


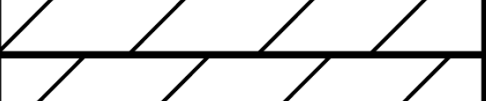









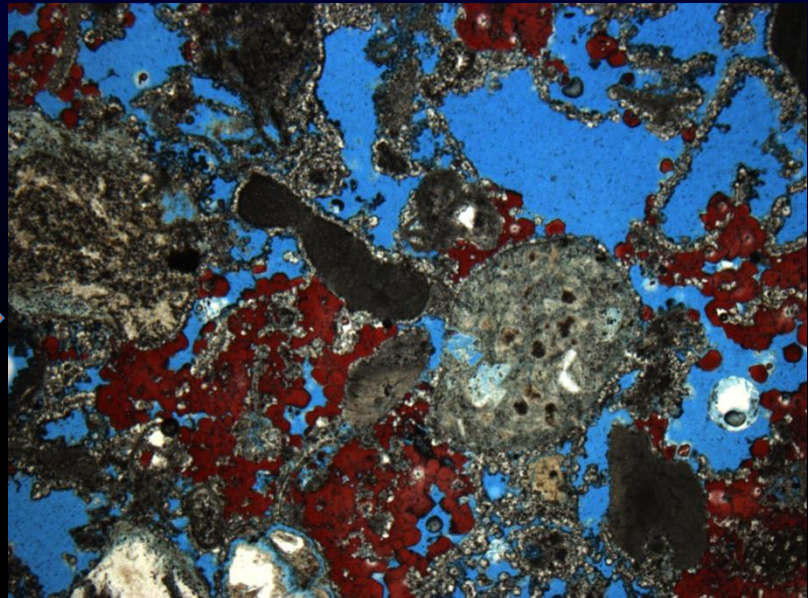
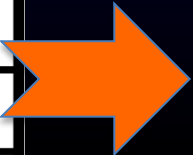
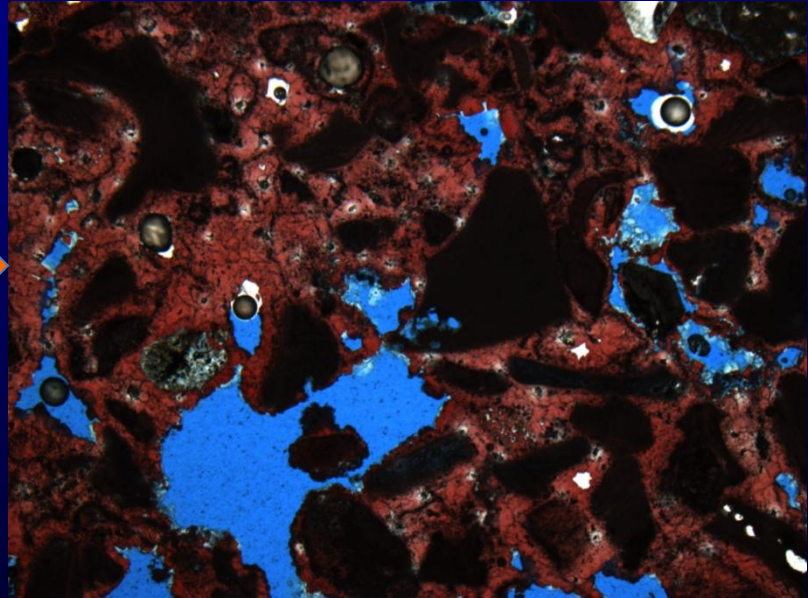
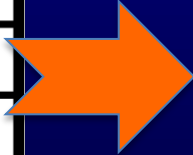
# 1. Subaerial exposure & Diagenesis

- DS1A, DS2, DS3, TCC1, 2, 3 sequences
- ✓ Neither extensive dissolution nor pervasive cementation.
- ✓ Fissures and autoclastic brecciation near surfaces.
- ✓ Vadose zone calcite cementation, and slight dissolution of aragonitic components.



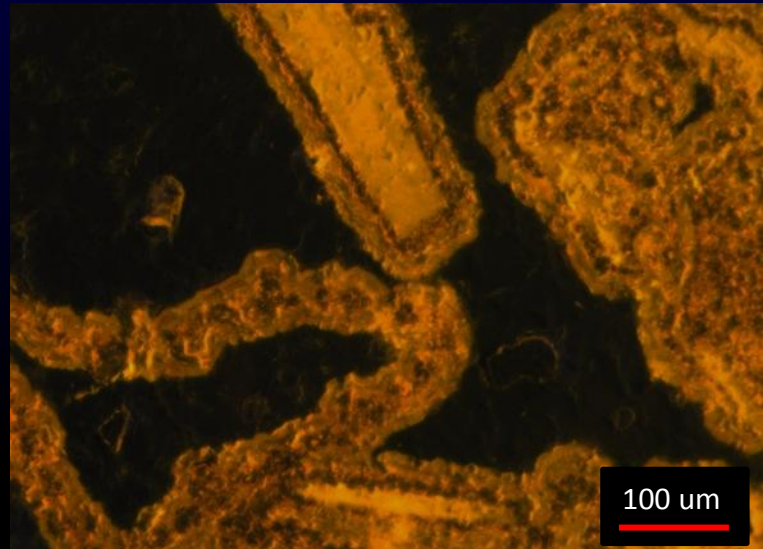
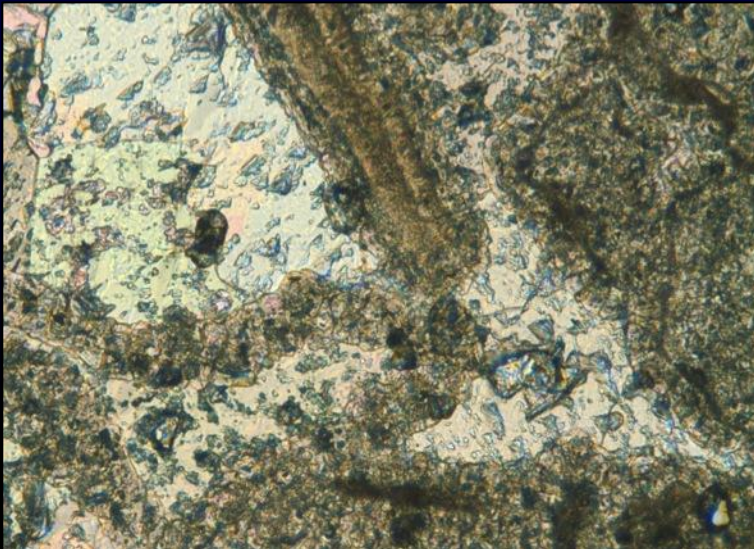
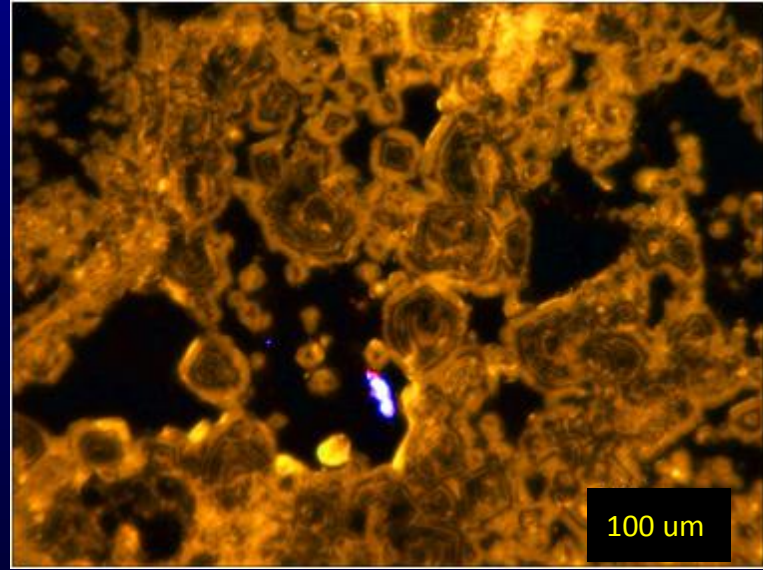
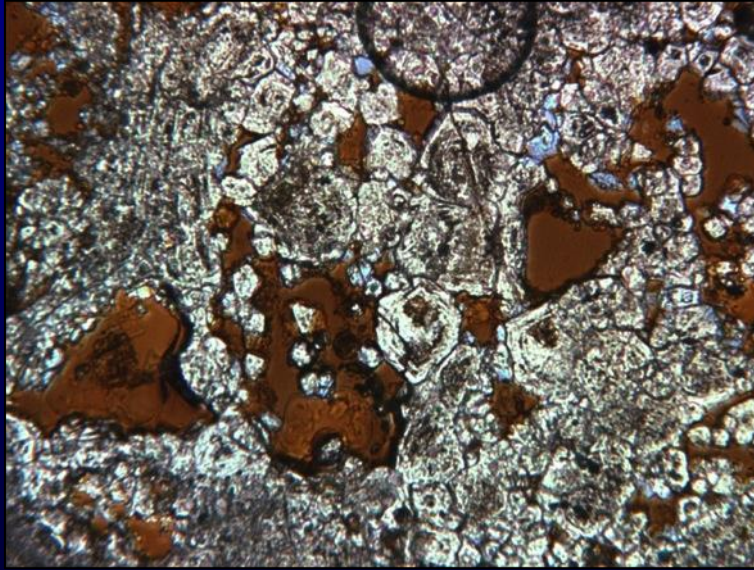
## 2. Dolomitization

AGE	STRATIGRAPHIC SECTION
PLIOCENE	
	
	
	
	
	
MIOCENE	
	
	
	
	





# Dolomite Petrography

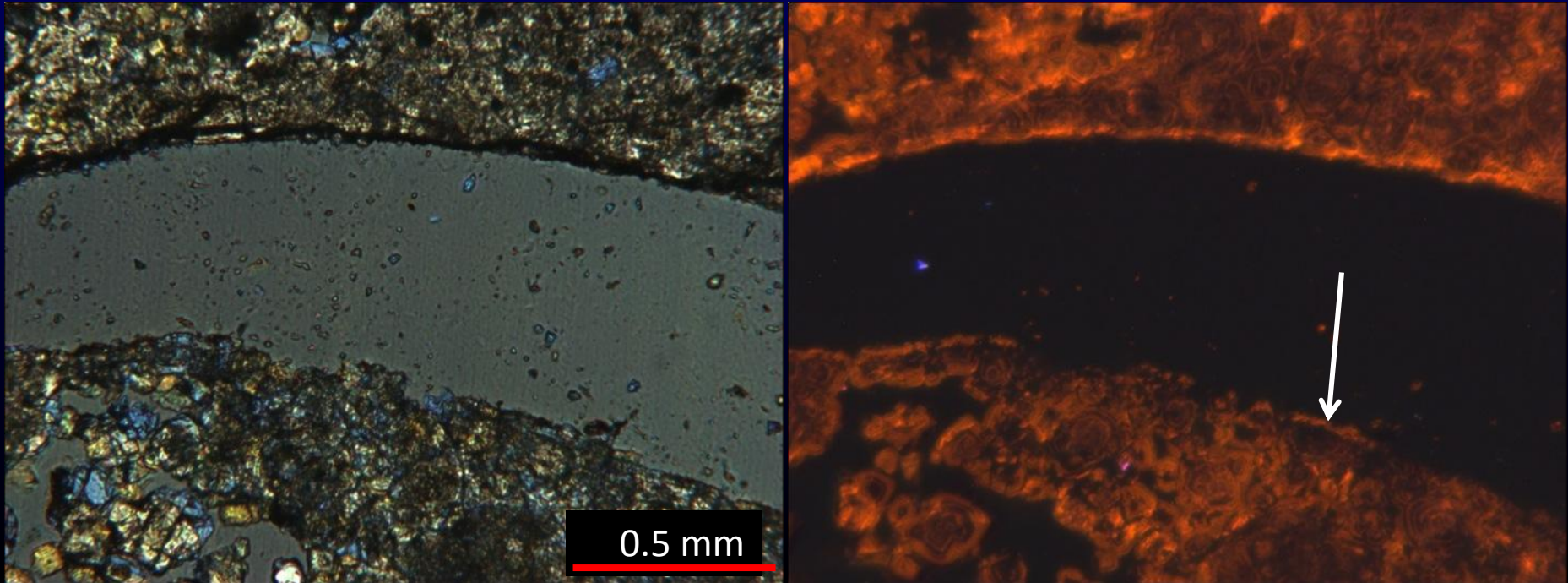


Dolomites from all sequences have similar CL characteristics.



# Dolomitization & Dissolution

Moldic and vuggy dissolution is closely associated with dolomite precipitation.

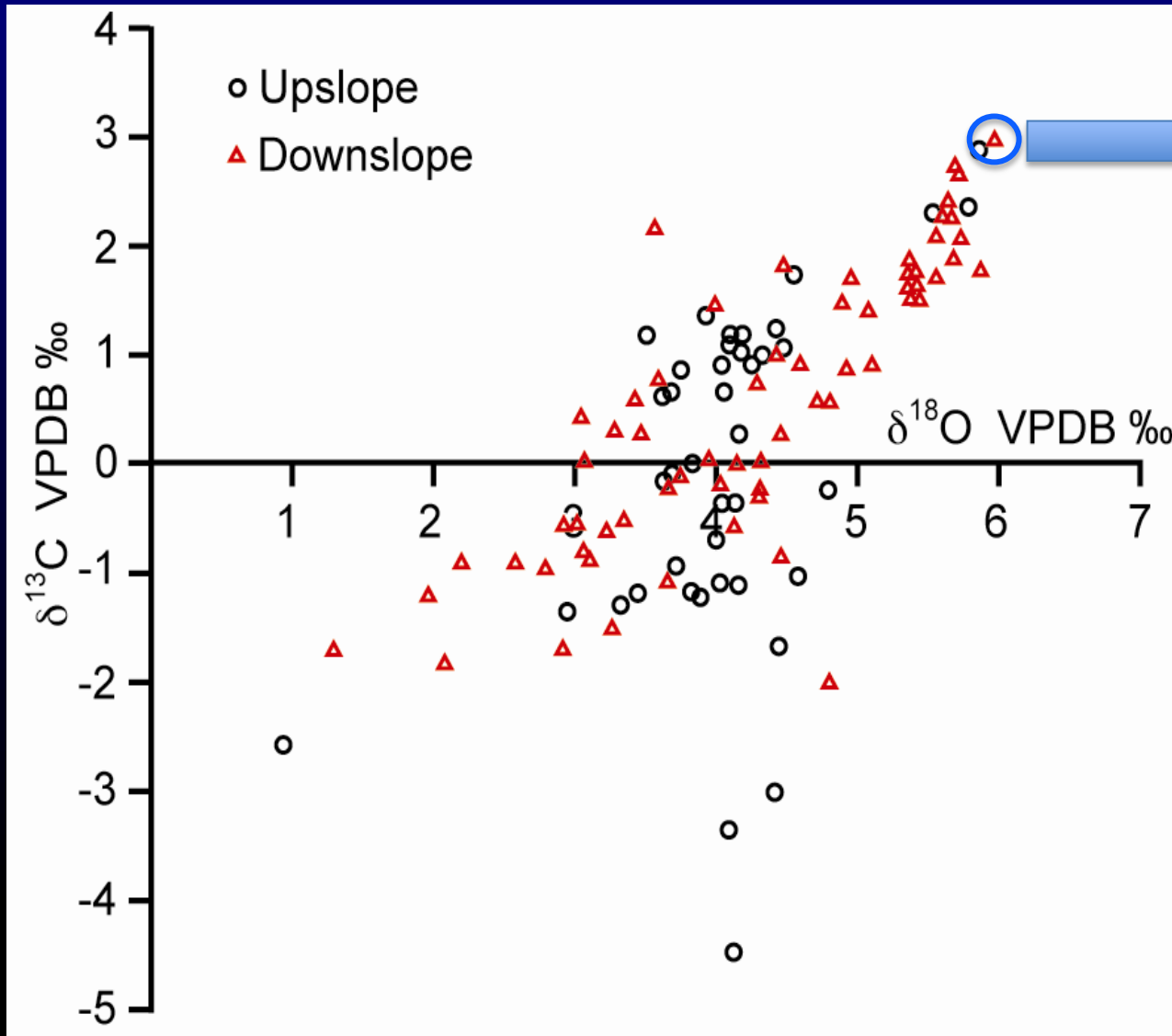


Notice only the latest growth zones of dolomite exist in moldic porosity, as seen in CL photomicrograph (arrow).



# Origin of Dolomite

## Stable Isotope Analysis

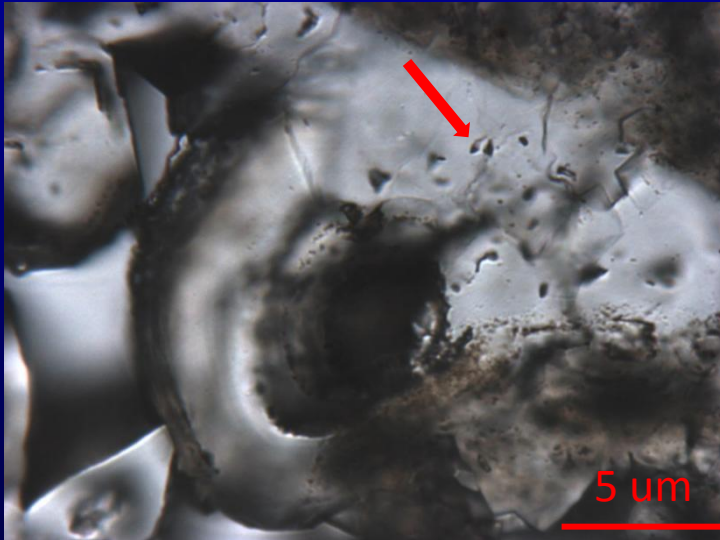


**Modeling indicates correspondence to seawater evaporated by 16%, 43 ppt salinity.**

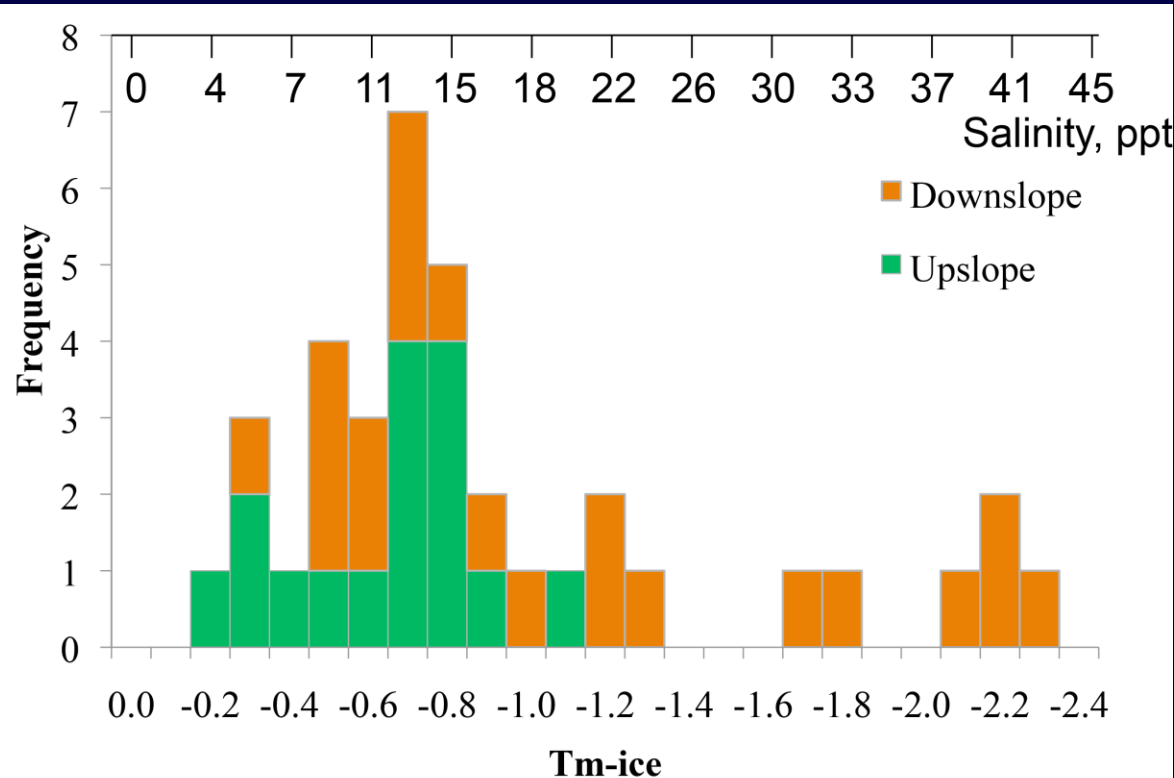
**Notice the covariation between  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  and the negative as well as positive  $\delta^{13}\text{C}$  values.**

# Origin of Dolomite

## Fluid Inclusion Measurement



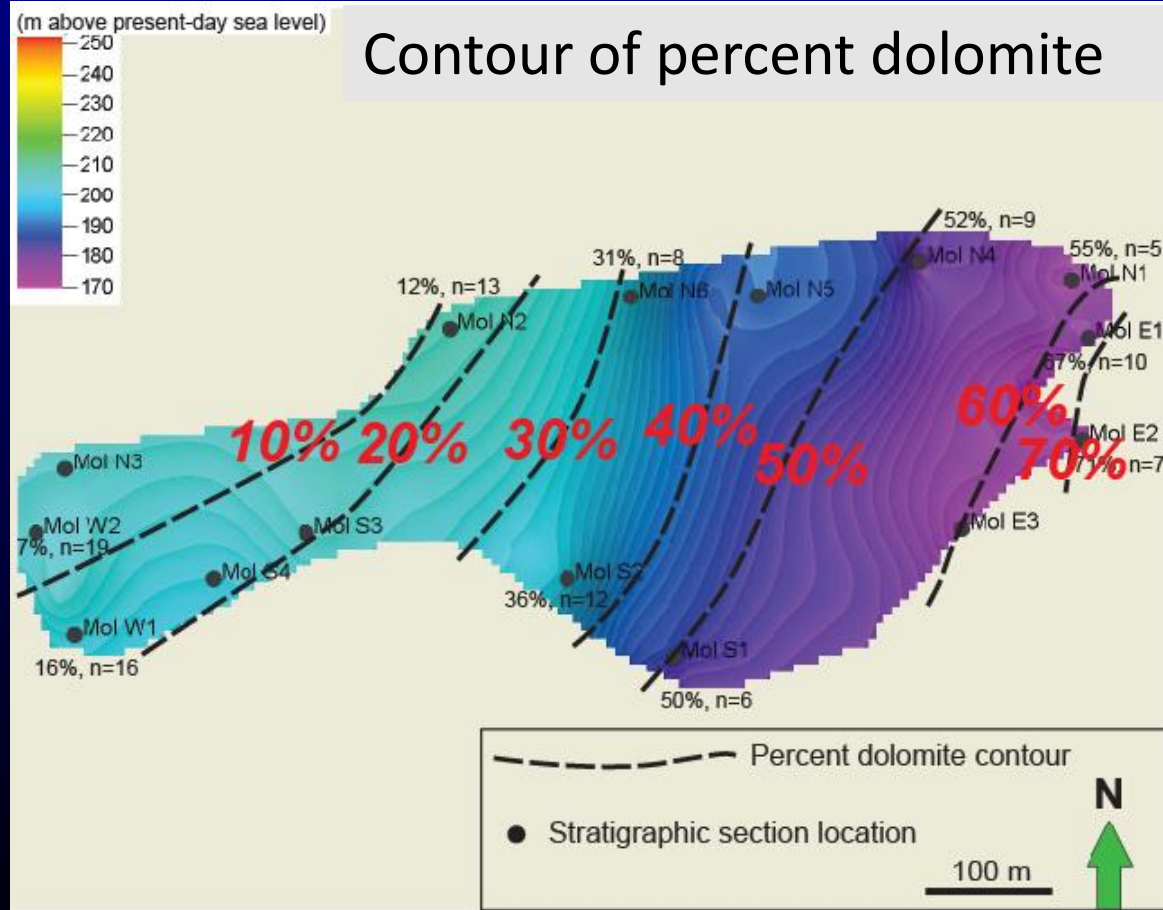
Photomicrograph showing primary fluid inclusion in dolomite (arrow).



Frequency histogram of final melting temperature of ice ( $T_{m-ice}$ ).

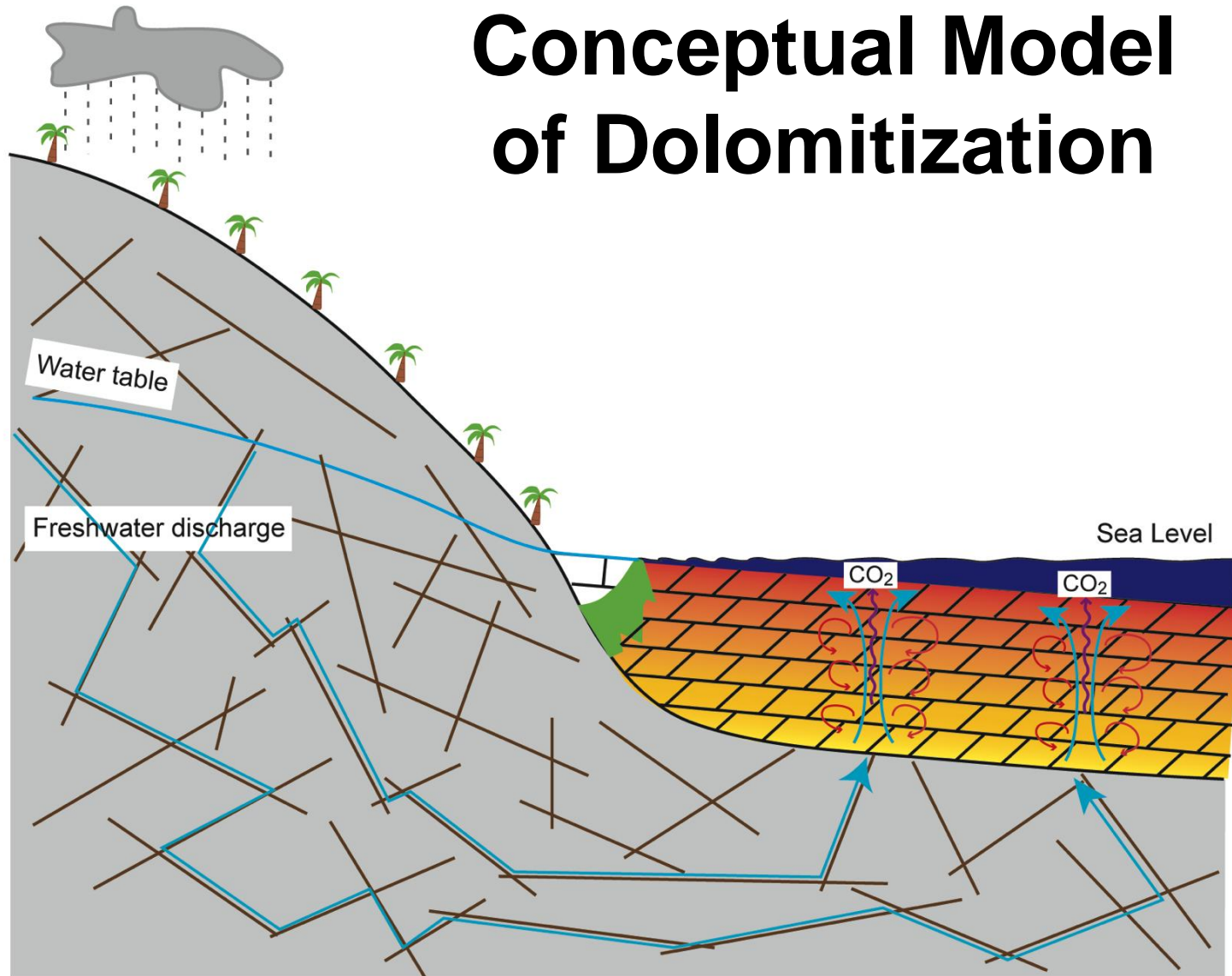
The lowest  $T_{m-ice}$  at  $-2.3$  °C correlates to salinity of 43 ppt.





# Paleotopography & Diagenesis







Contour of percent dolomite superimposed on paleotopographic map illustrating base of Terminal Carbonate Complex.

# Conceptual Model of Dolomitization

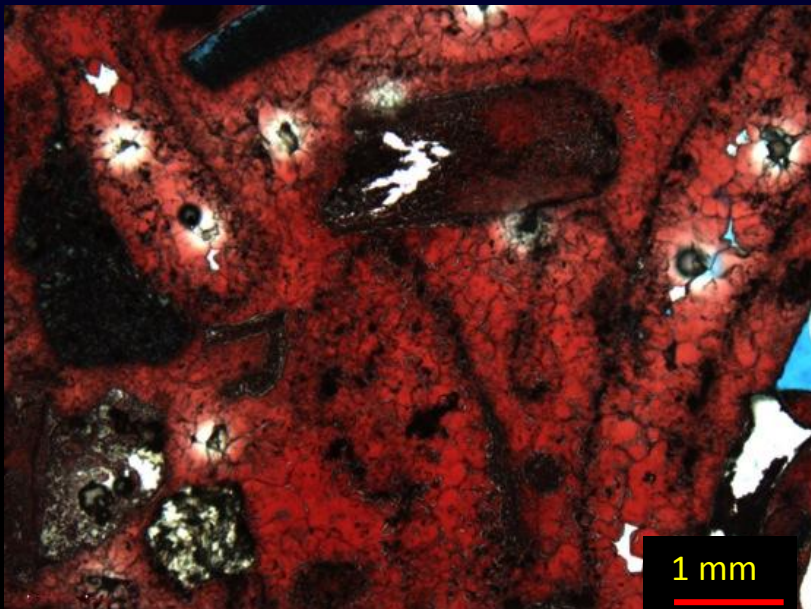
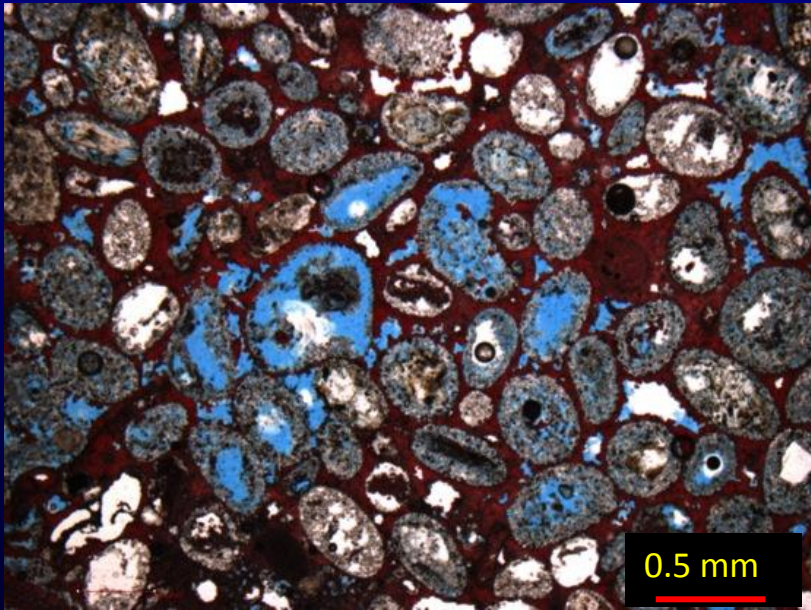


-  Freshwater flowline
-  Outward and upward eddy flow
-  High-permeability fractures in low-permeability volcanic basement
-  CO<sub>2</sub> degassing

-  Shoreline mixing zone
-  Evaporated seawater of 43 ppt salinity
-  Mixing of fluids from injection of freshwater below with gradient mixing
-  Volcanic basement

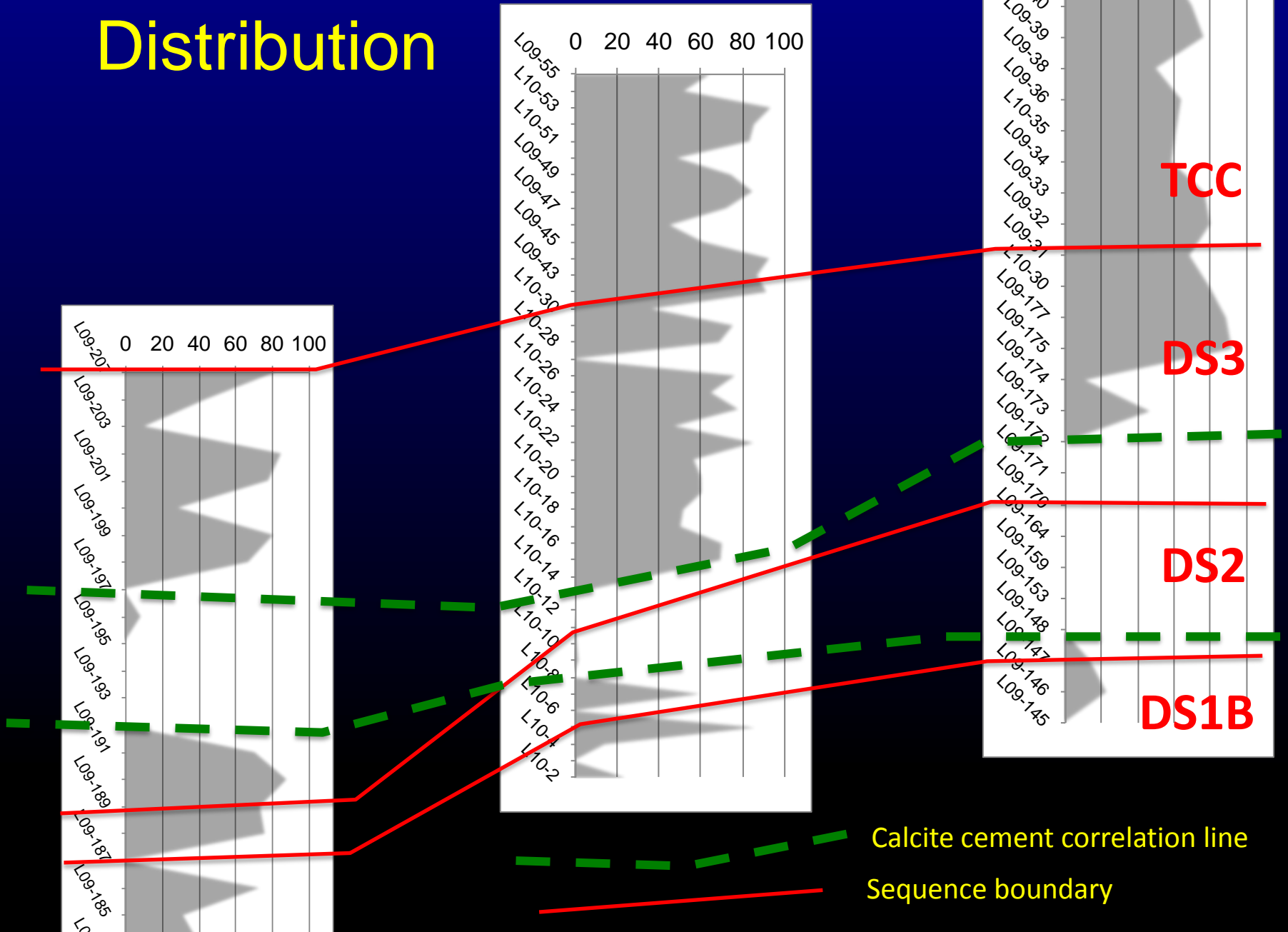


### 3. Late Calcite Cementation



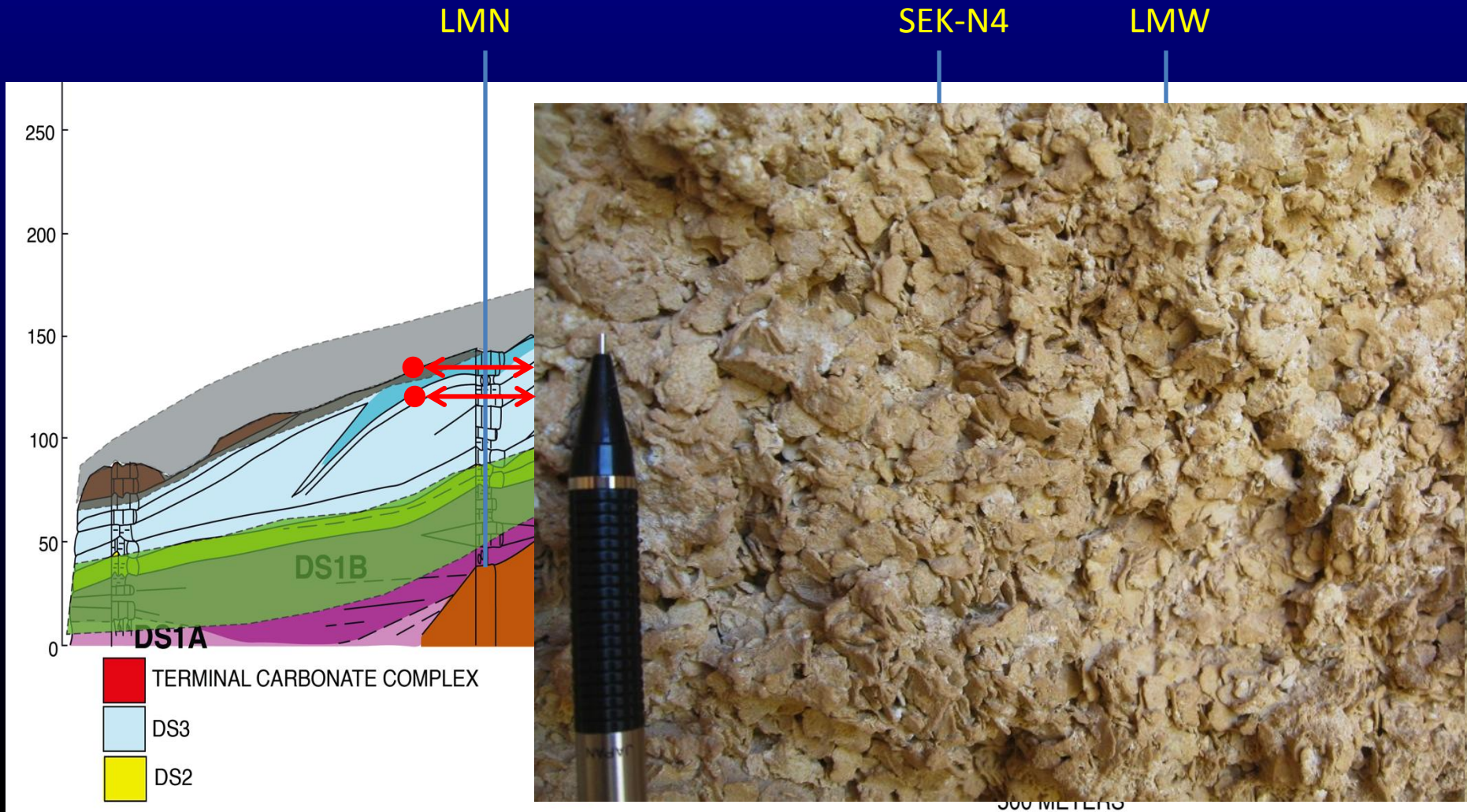
- Superpositional relationship suggests calcite precipitation postdated dolomitization.
- Calcite cements filling primary porosity as well as secondary porosity. Textures are consistent with phreatic zone.

# Calcite Cement Distribution



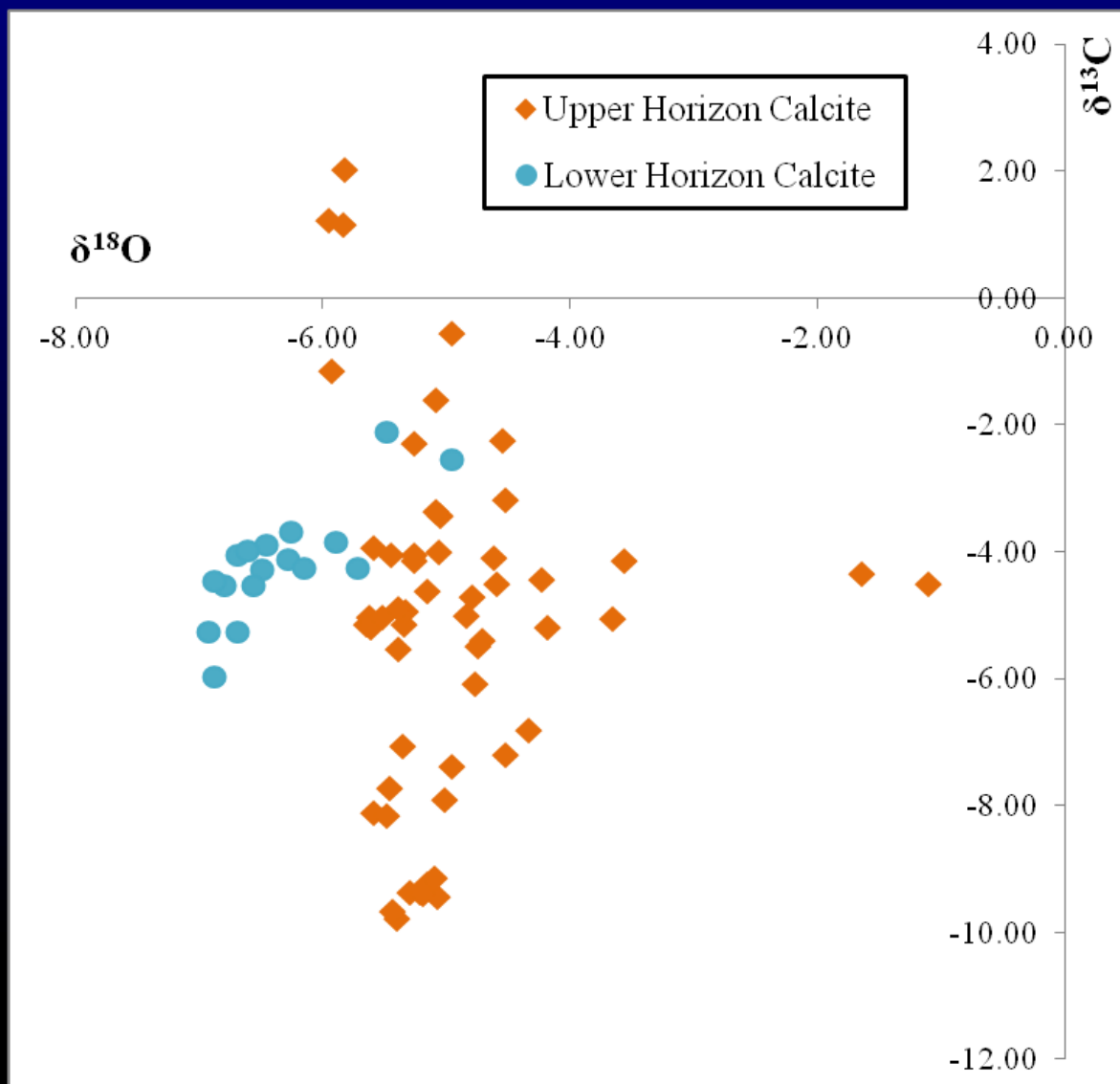


# Calcite Cement Distribution



# Origin of Calcite

## Stable Isotope Analysis

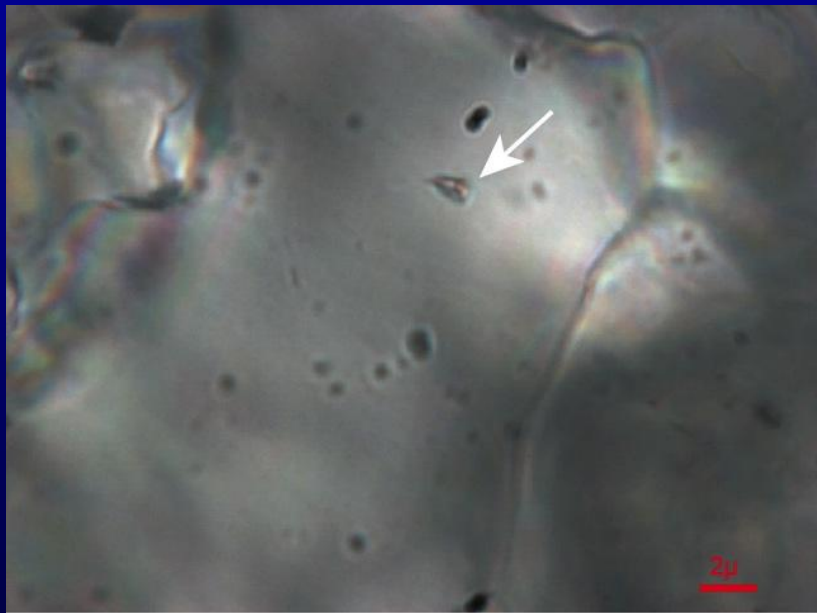


- Carbon and oxygen isotopes range from - 6.0 to - 1.1‰ PDB for  $^{18}\text{O}$ , - -9.8 to + 2.0‰ PDB for  $^{13}\text{C}$ .
- Negative oxygen and negative carbon isotope values.

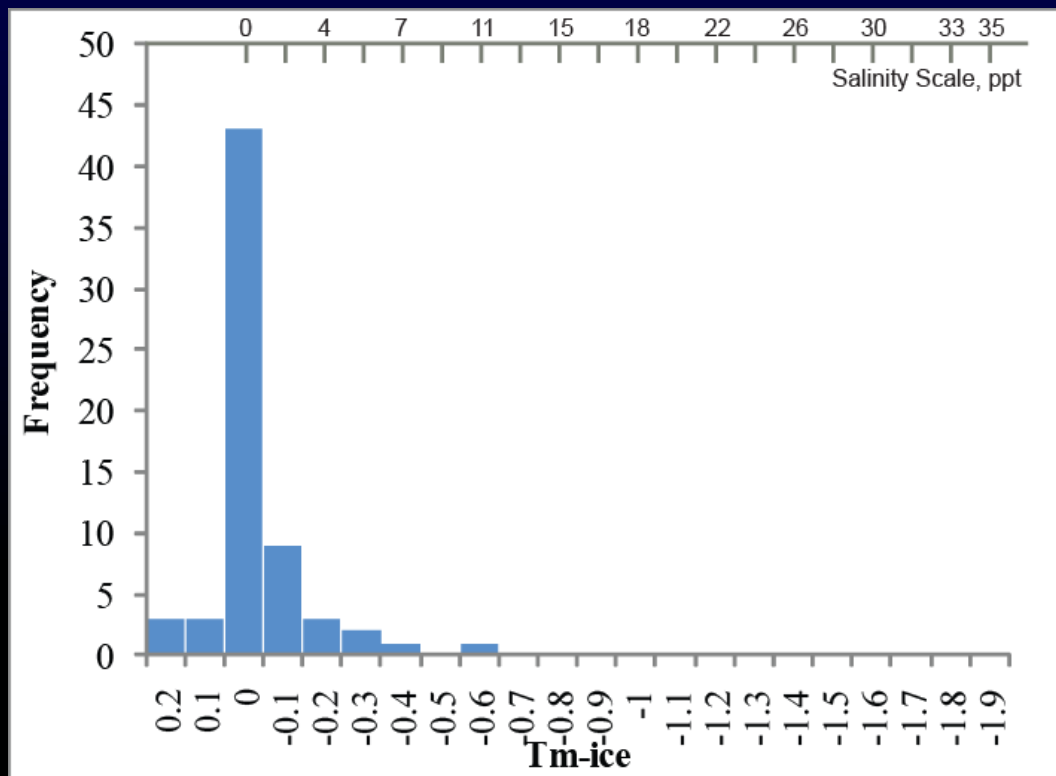


# Origin of Calcite

## Fluid inclusion data



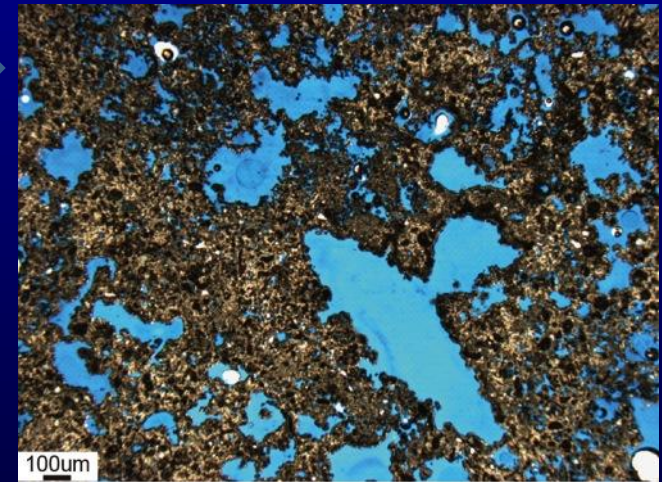
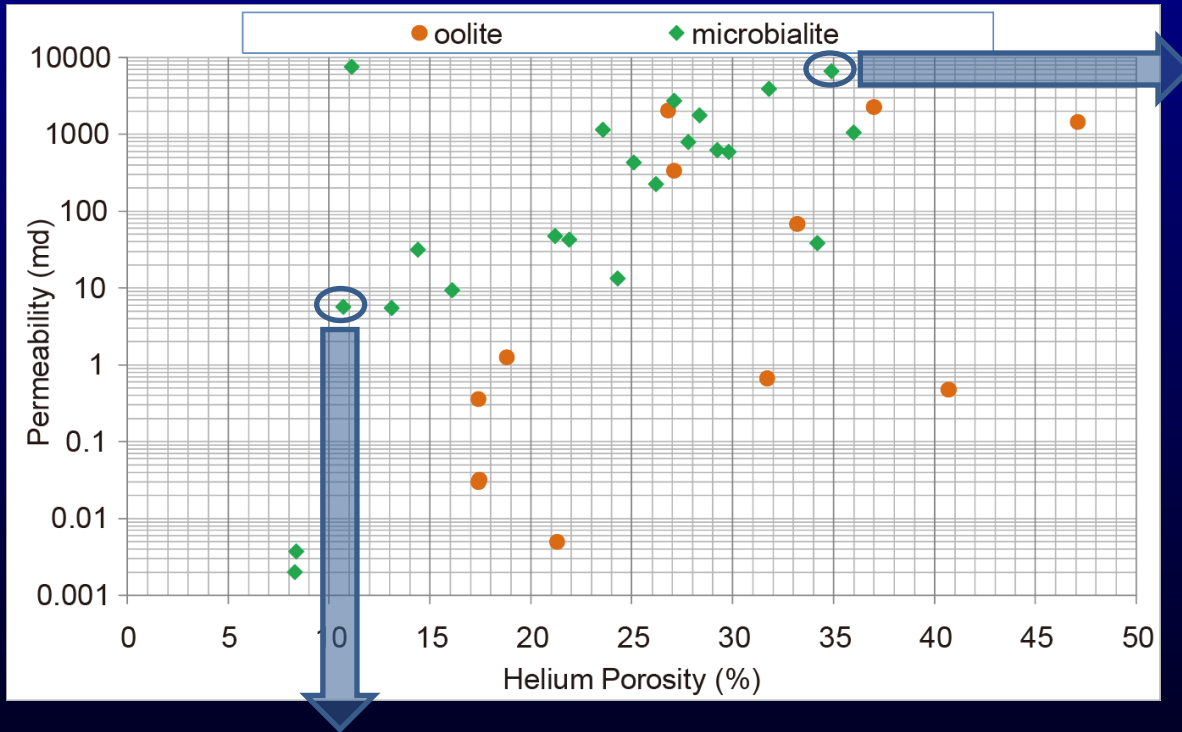
Photomicrograph of a two phase fluid inclusion in calcite cement from artificial stretching (arrow).



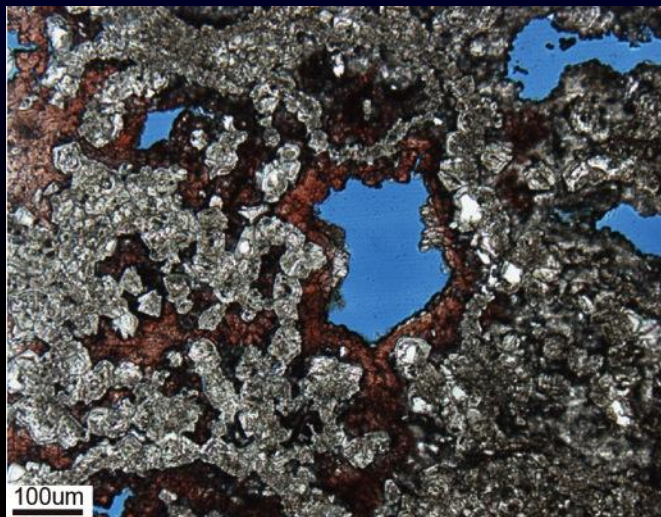
Frequency histogram of final melting temperature of ice ( $T_{m-ice}$ ).

Mode at 0.0 °C indicates calcite was precipitated from fresh water.

# Diagenetic Controls on Porosity/Permeability

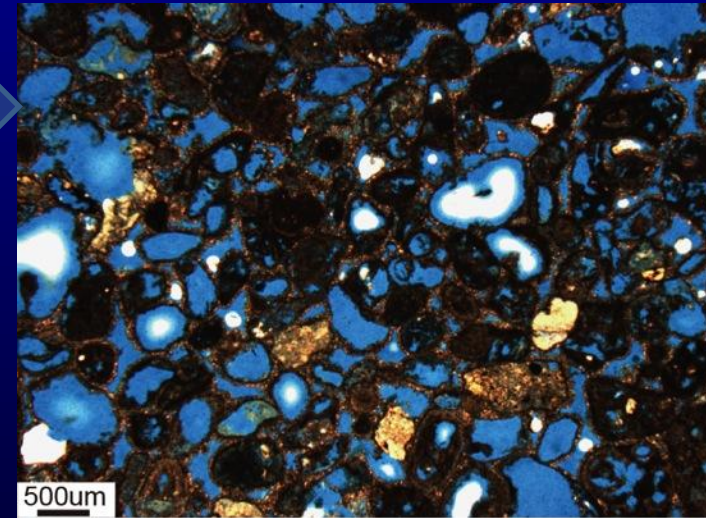
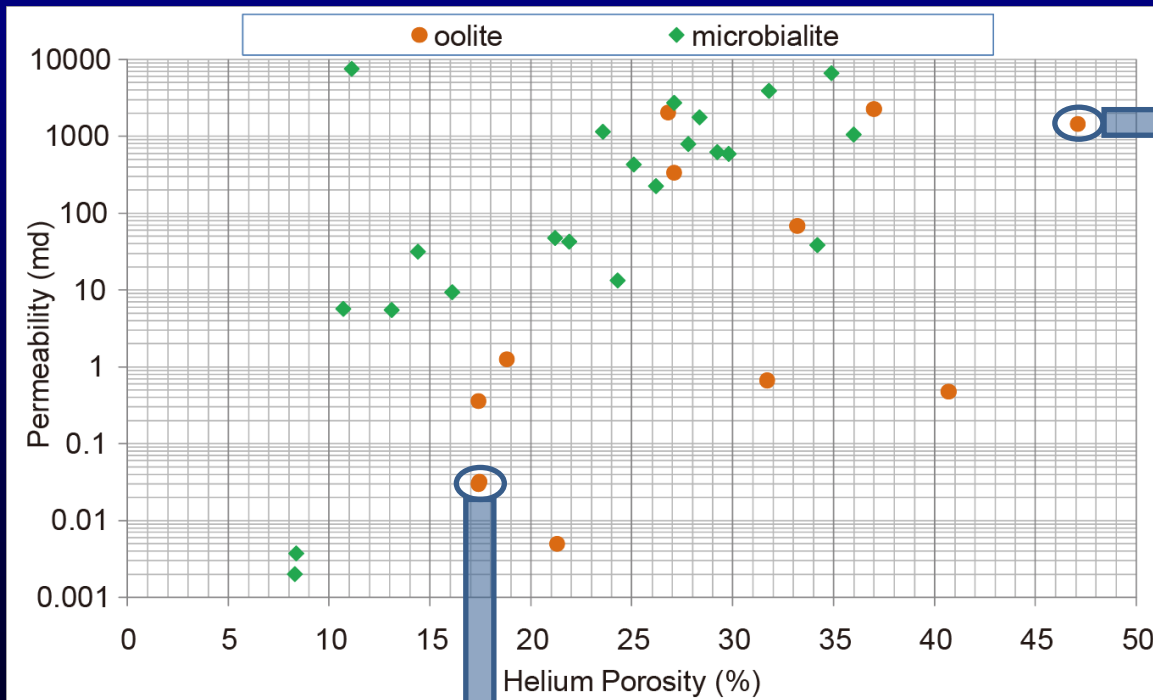


Thrombolite, porosity 34.7%, permeability 6547 md. Dolomite without any calcite cement. Dolomitization was penecontemporaneous with vuggy, moldic, and intercrystalline porosity.

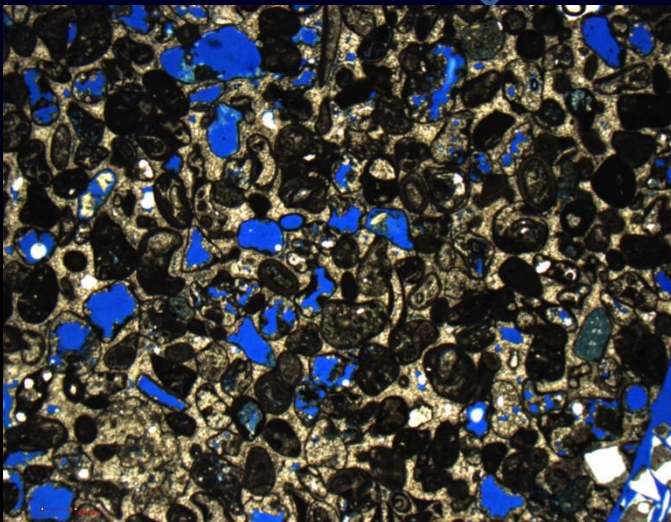


Thrombolite, porosity 10.7%, permeability 5.64 md. Early dolomite and later calcite cement, shown by staining with Alizarin Red S, occluded much of the porosity.

# Diagenetic Controls on Porosity/Permeability



Oolite, porosity 47.1%, permeability, 1443 md. Dolomite crystals coat interparticle pores, followed by extensive leaching of ooids. Lack of calcite cement leads to high permeability.



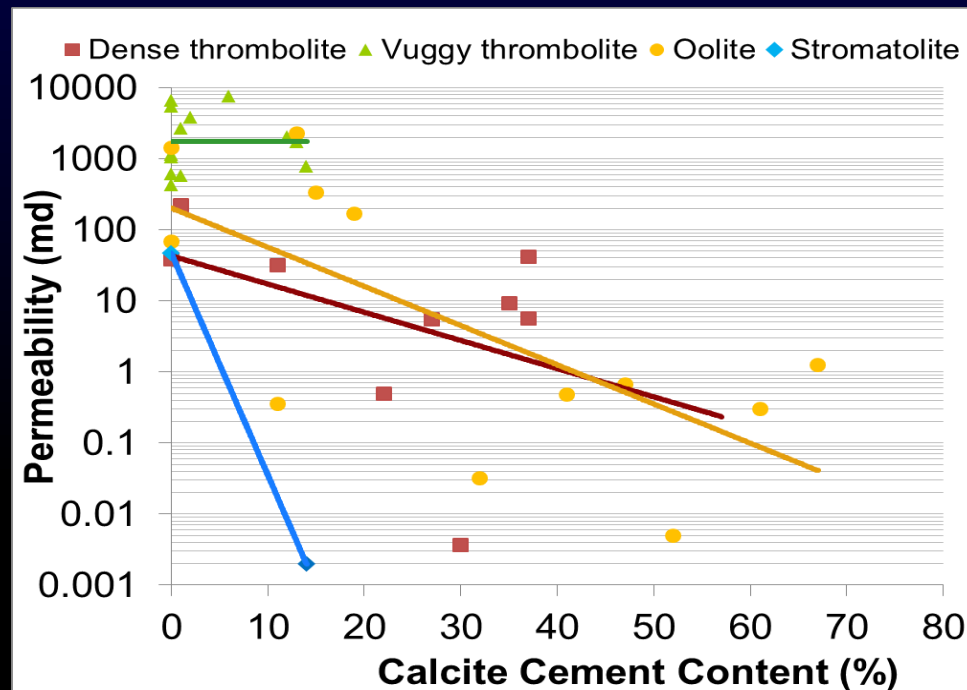
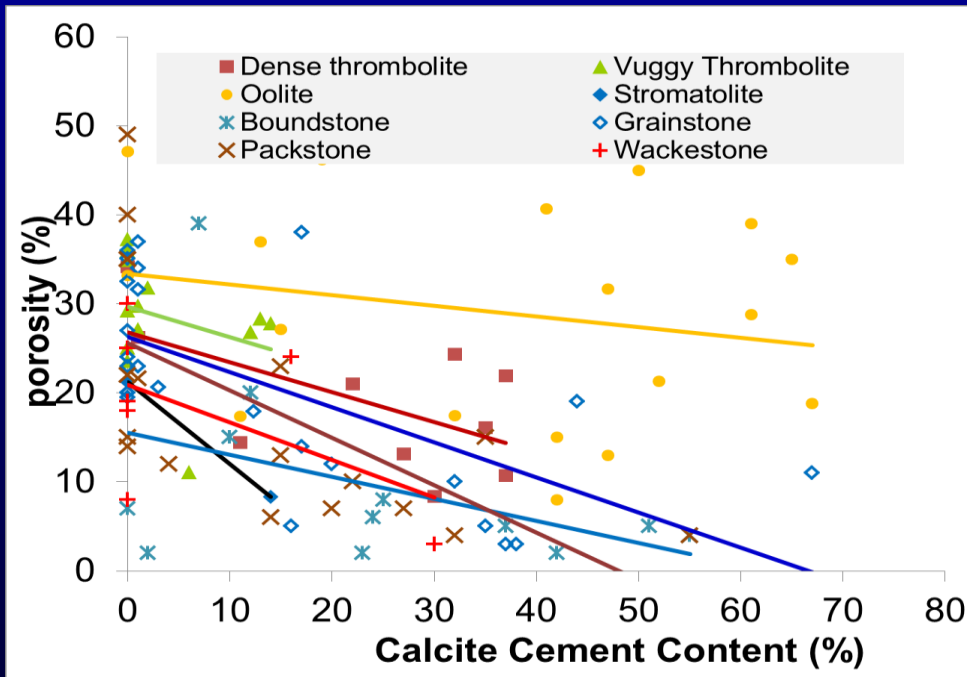
Oolite, porosity 17.4%, permeability 0.03 md. Leaching of ooids created secondary porosity, but calcite cementation substantially reduced permeability.



# Diagenetic Controls on Porosity/Permeability

## Porosity & Calcite Cement

Good correlation -  
Porosity decreases as  
calcite cement increases.



## Permeability & Calcite Cement

Good correlation -  
Permeability decreases as  
calcite cement increases.



# Conclusions

1. Only minor dissolution and cementation during short-lived and/or arid subaerial exposure, but extensive cementation during long-lived subaerial exposure in a wetter climate. Calcite cement was precipitated from fresh water at two different levels, and had a major impact in reducing porosity and permeability. Its impact was facies specific.
2. Dolomitization is due to ascending freshwater-mesohaline mixing. Dolomitization enhanced porosity and permeability, and its distribution may be predictable on the basis of understanding the hydrogeology and paleotopography.

**Thank you very much!**

