Porosity in Vuggy Platform Carbonates Measured Over Six Orders of Magnitude*

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Abstract

Understanding pore networks in prolific vuggy carbonate reservoirs has long been a buried treasure of hydrocarbon exploitation. Documenting porosity at four scales ranging over six orders of magnitude can provide a preliminary treasure map. Our field laboratory is the extensive quarry exposures of the mid-Cretaceous El Abra Limestone in the Sierra El Abra, San Luis Potosí State, Mexico. These expose the exhumed windward margin of the vast Valles-San Luis Potosí isolated, shallow-water platform, long recognized as the best outcrop analogue of the giant Golden Lane fields of the Tampico embayment. The platform margin consists of two distinctive facies: Rudist reefs and skeletal sand shoals of the outer margin; and inner-margin tidal deposits and sand/rubble islands. Cyclic subaerial exposure of the more elevated inner-margin sediments produced a more complicated diagenetic history and ultimately lower porosity. Both facies belts record a late, pervasive episode of dissolution, apparently in a regional meteoric aquifer, that produced molds, vugs, channels, and, rarely, caverns. Porosity in these facies was measured at four scales: Micropores (10-6-10-3 m) with standard 1-in plugs, mesopores (10-4-10-3 m) with thin-section point counts, megapores (<10-1 m) with 4-in plugs, and larger megapores with outcrop photopans. This represents a range of pore sizes spanning more than six orders of magnitude. Permeability was measured with 1- and 4-in plugs. Both inner and outer margin rocks have low matrix porosity (micropores) and permeability, 3% and 0.03 md, respectively, and negligible mesoporosity. Measured megaporosity was 9% for the inner margin and 20% for the outer margin, with maximum measured permeability of 553 md. This contrast of values between scales of measurement and between facies underscores the need to measure porosity and permeability in vuggy carbonate rocks over the widest feasible range of scales.

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Key Findings

- Porosity of vuggy carbonates of El Abra Fm. measured over 6 orders of magnitude
- Inner margin: Repeated disconformities with meteoric diagenesis, low Φ and K.
- Outer margin: Less exposure; significant Φ and K.
- Vuggy porosity can be measured in subsurface.

Significance

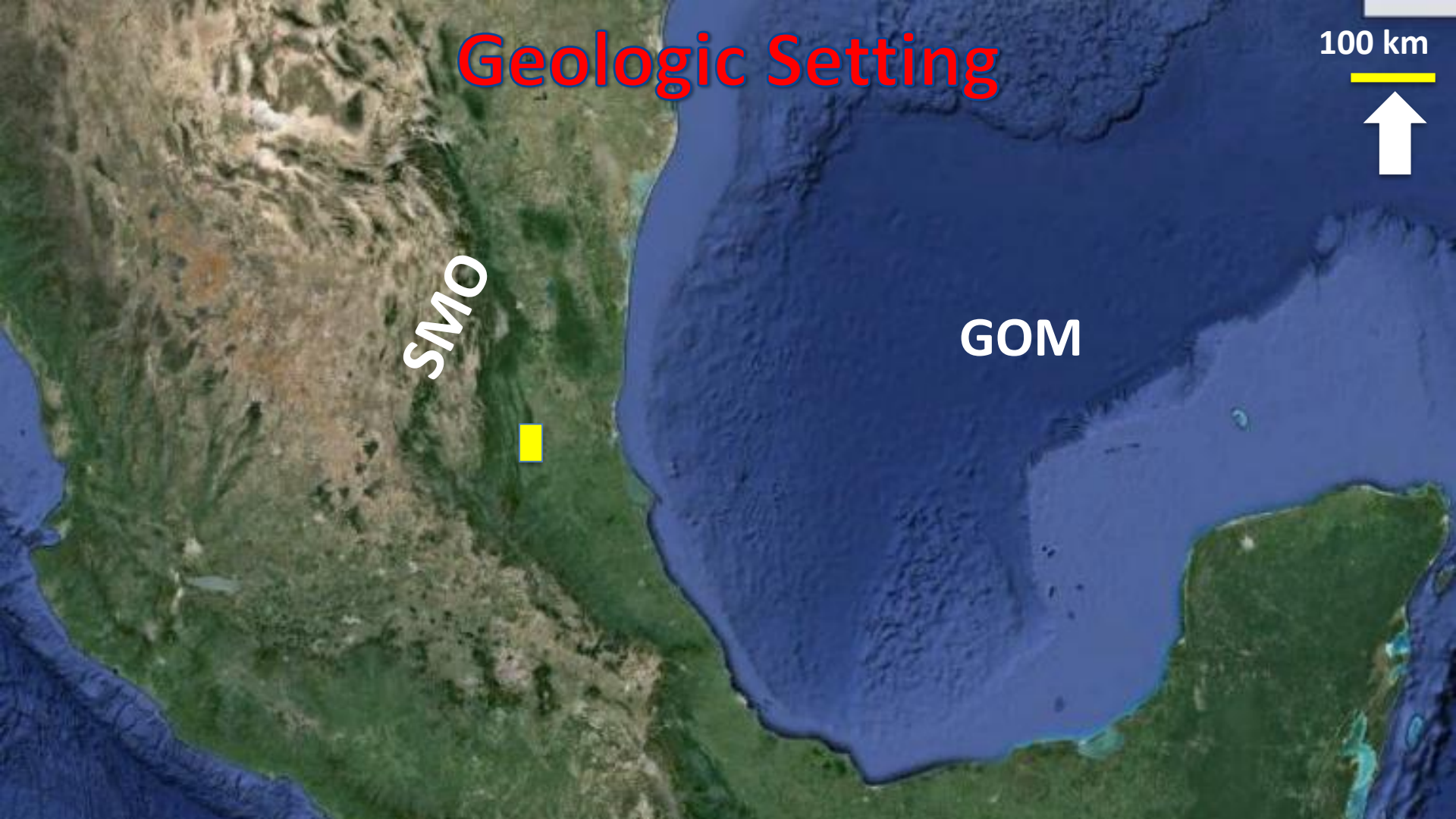
- Measurements at multiple scales reveal complete pore networks.
- El Abra: Analog for Golden Lane and some Isthmus reservoirs.
- Reservoir analog for platform-margin carbonates with large range of Φ and K.

Methods

Porosity measured in:

- 56 perm plugs (micropores).
- 70 thin sections (10^{-5} to 10^{-2} m).
- 10 plugs 10-cm diameter ($<10^{-1}$ m).
- Photopans of quarry walls (10^{-1} m to 10 m).

Geologic Setting

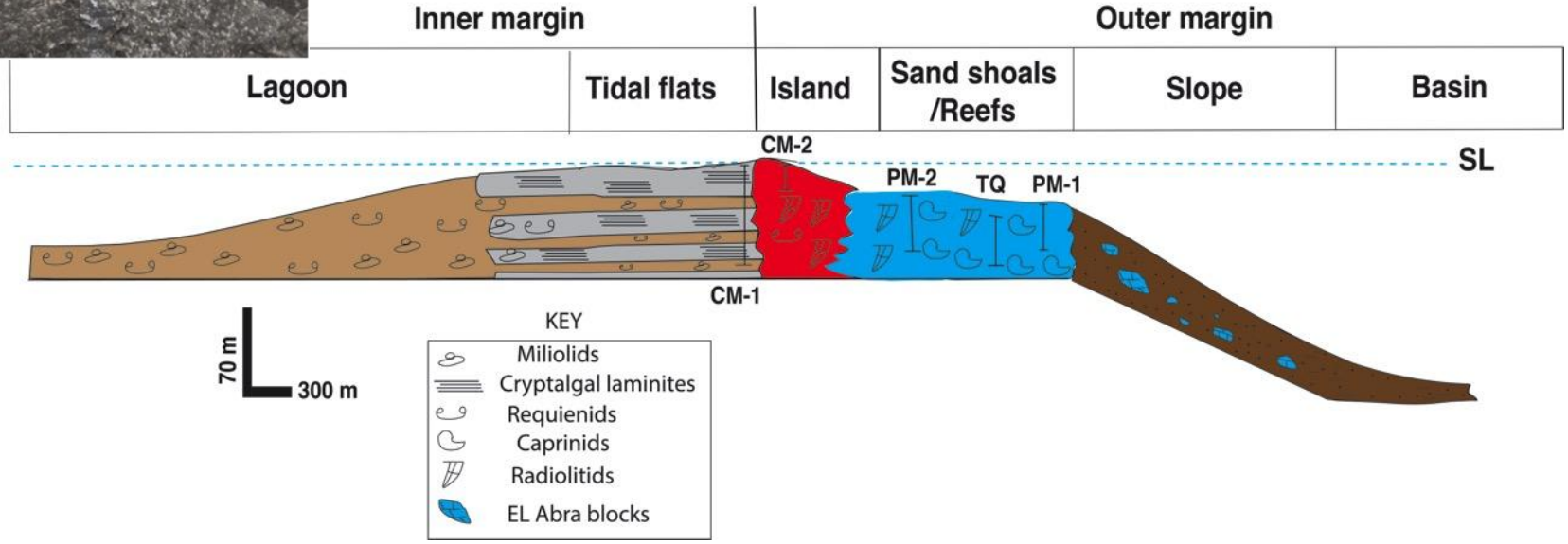

Geologic Setting
100 km
SMO
GOM


N
1 km
CM
TQ
Sierra El Abra
Slope-break
PM
CA
BP


El Abra
N
500 m
TQ
CM-1
CM-2


N
PM-2
PM-1
CA

Depositional Model Of El Abra Fm.



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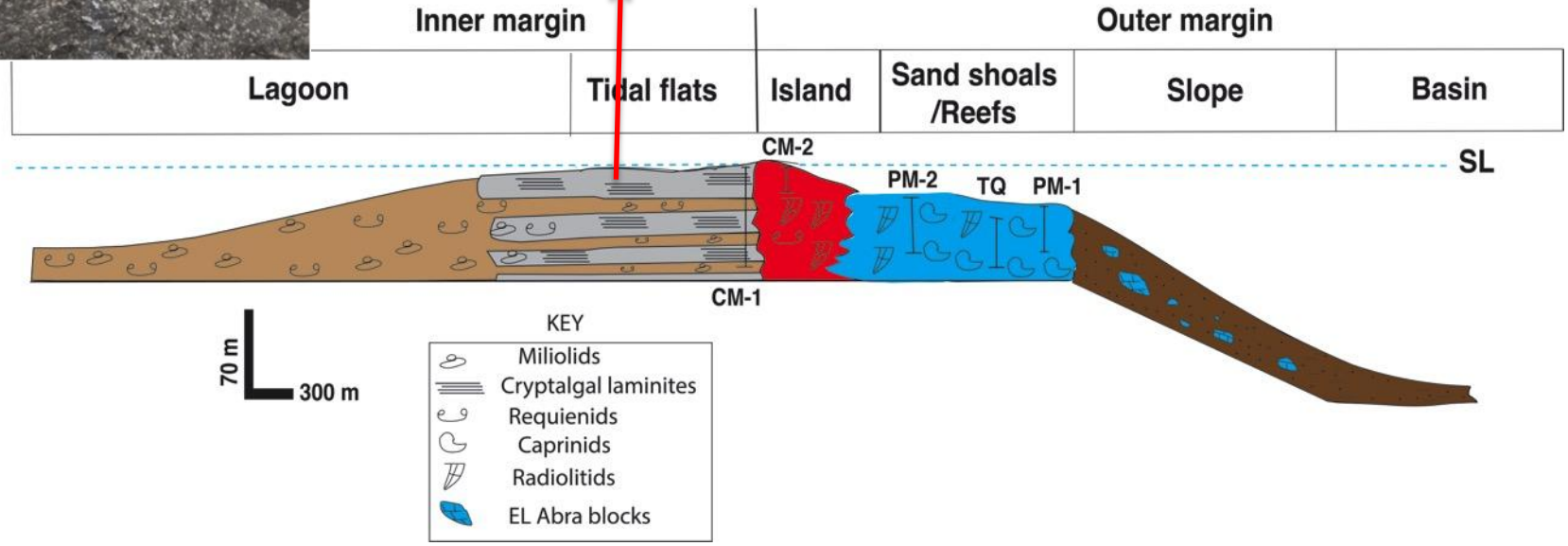

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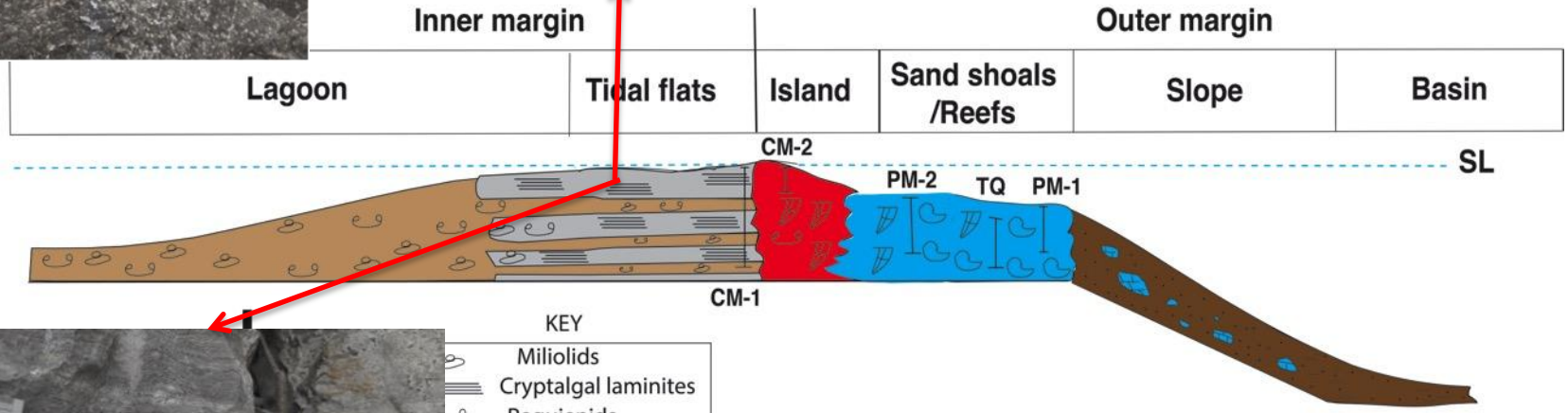

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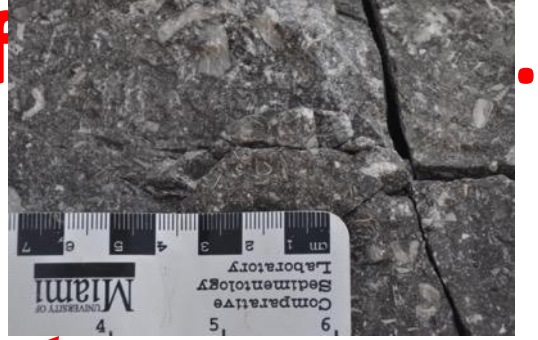

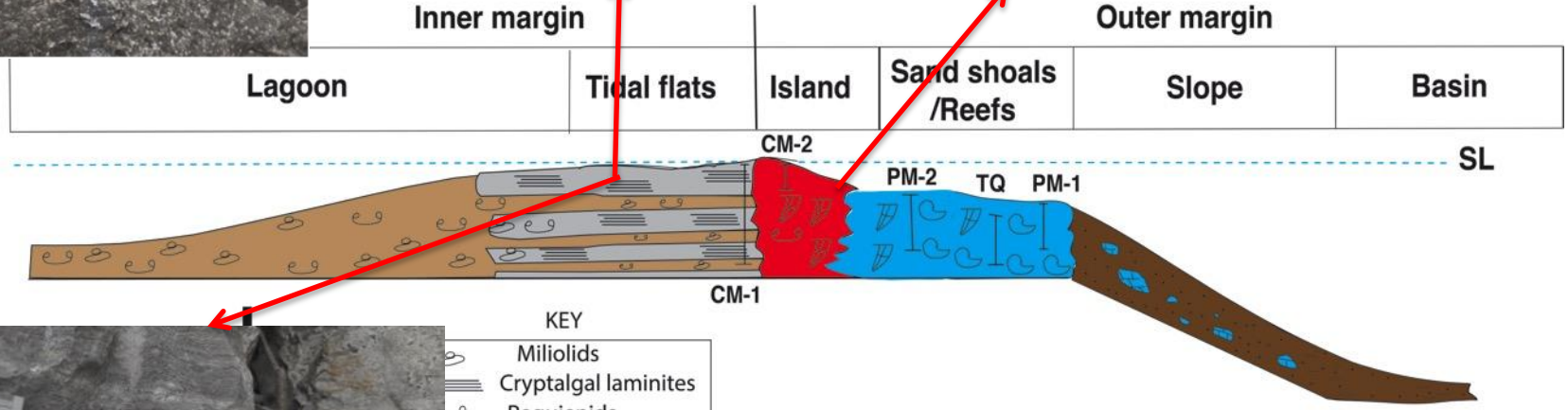

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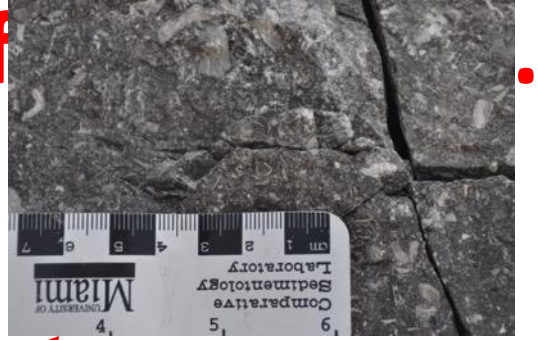
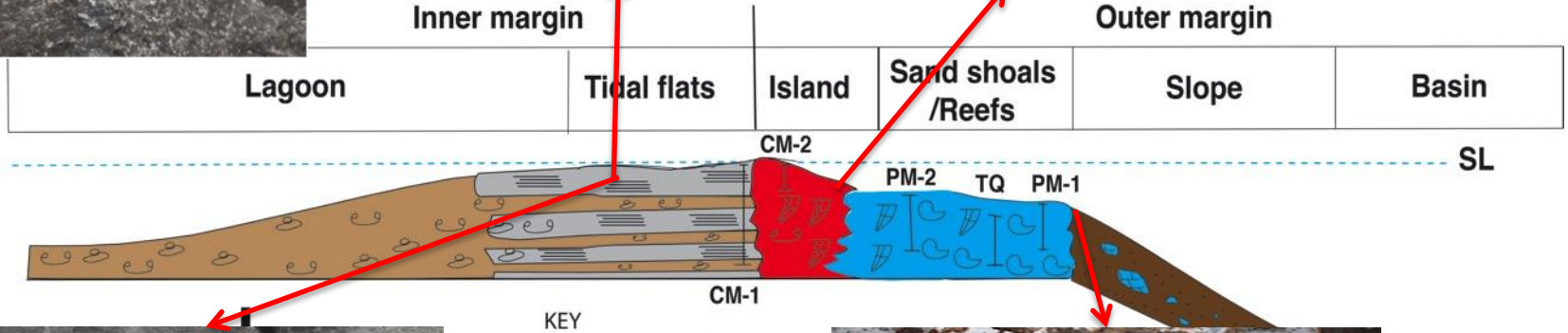
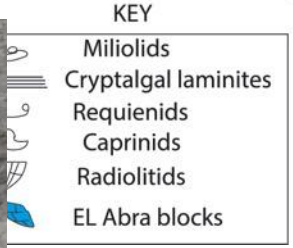
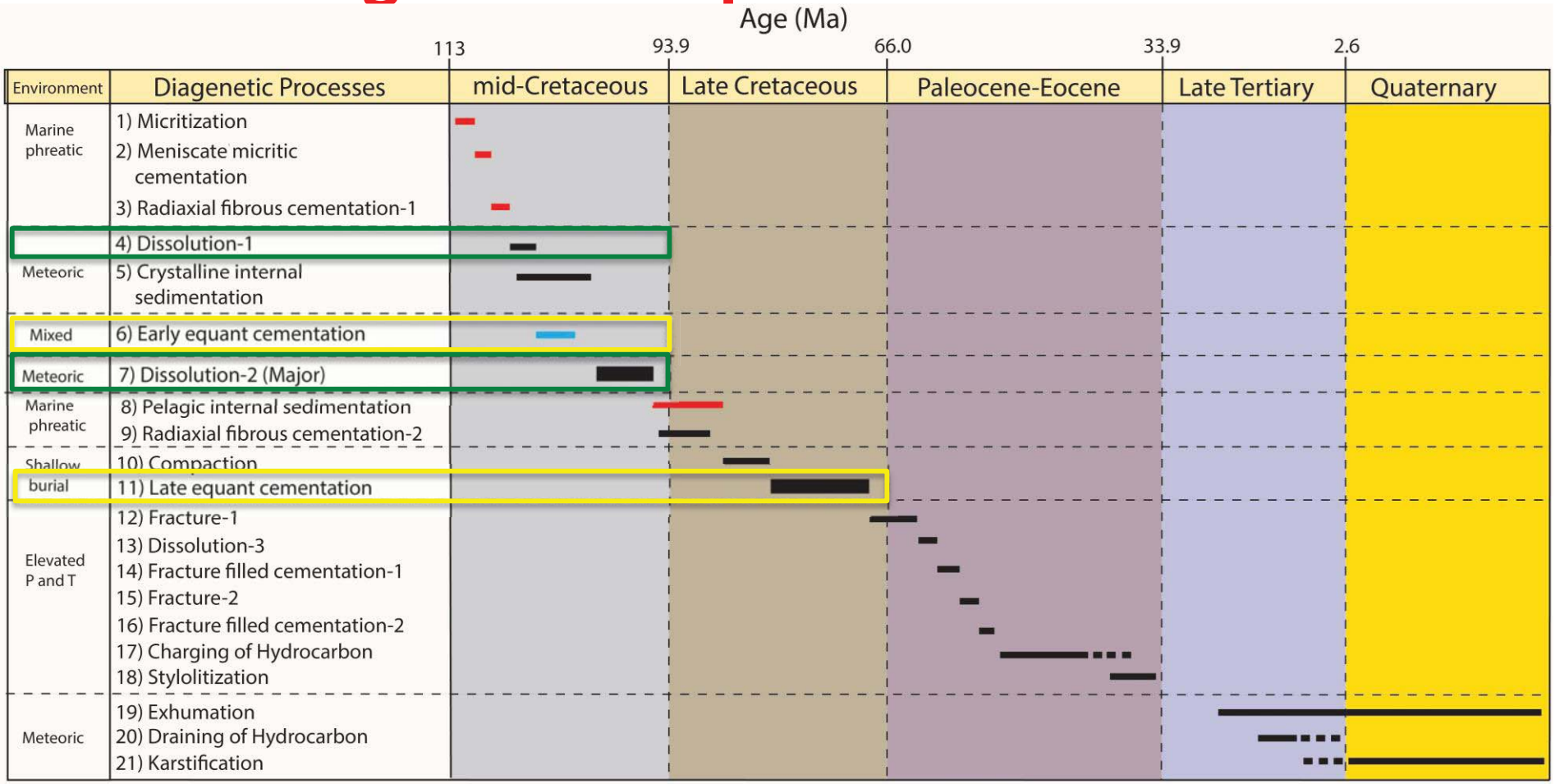


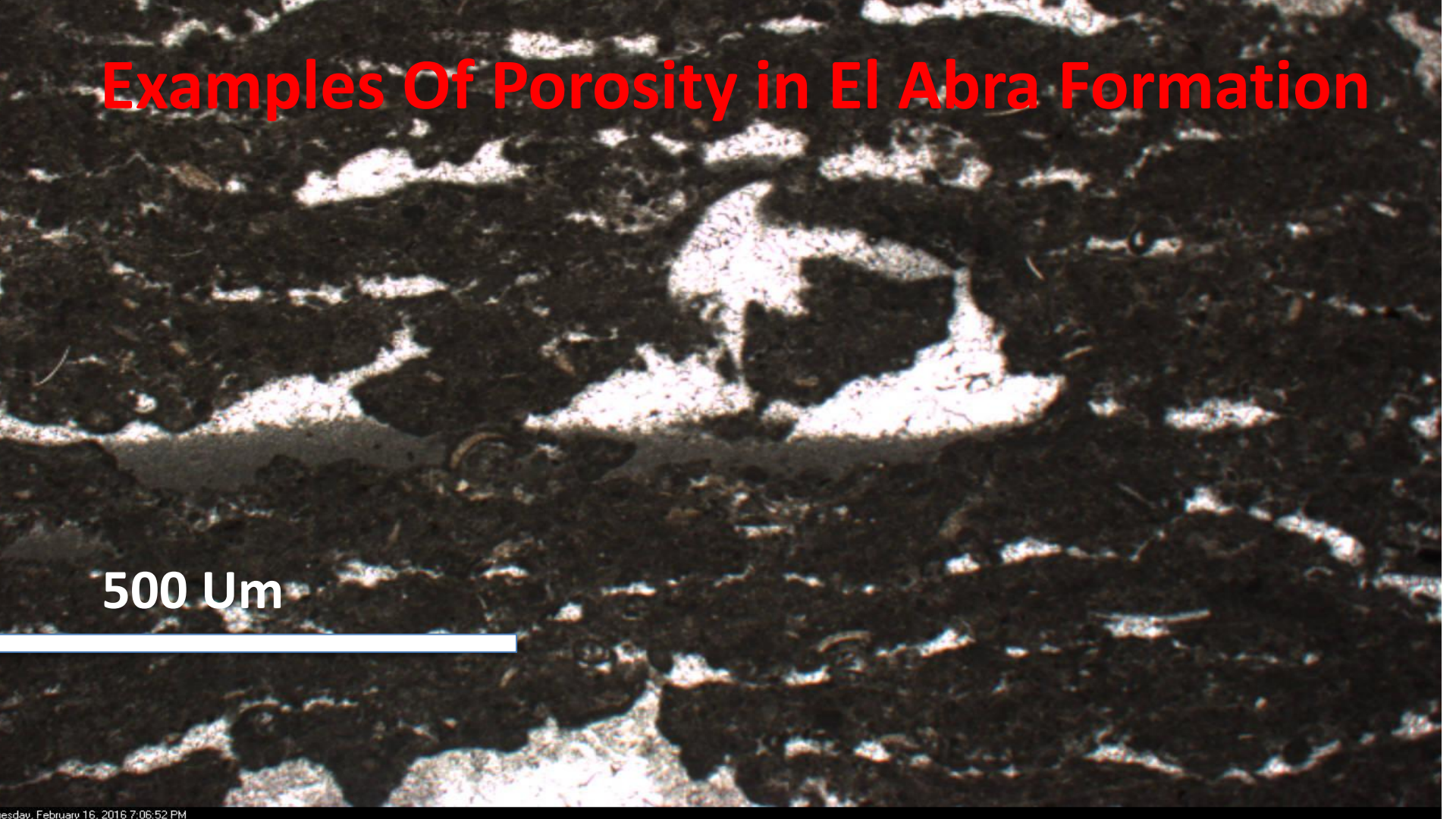




Diagenetic Sequences In El Abra



Examples Of Porosity in El Abra Formation


Examples Of Porosity in El Abra Formation
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esday, February 16, 2016 7:06:52 PM

Presenter’s notes: One black or white bar on the Miami scale is 1 cm.
Field notebook is 20 cm in length

MATRIX PORES: 1” PERM PLUGS

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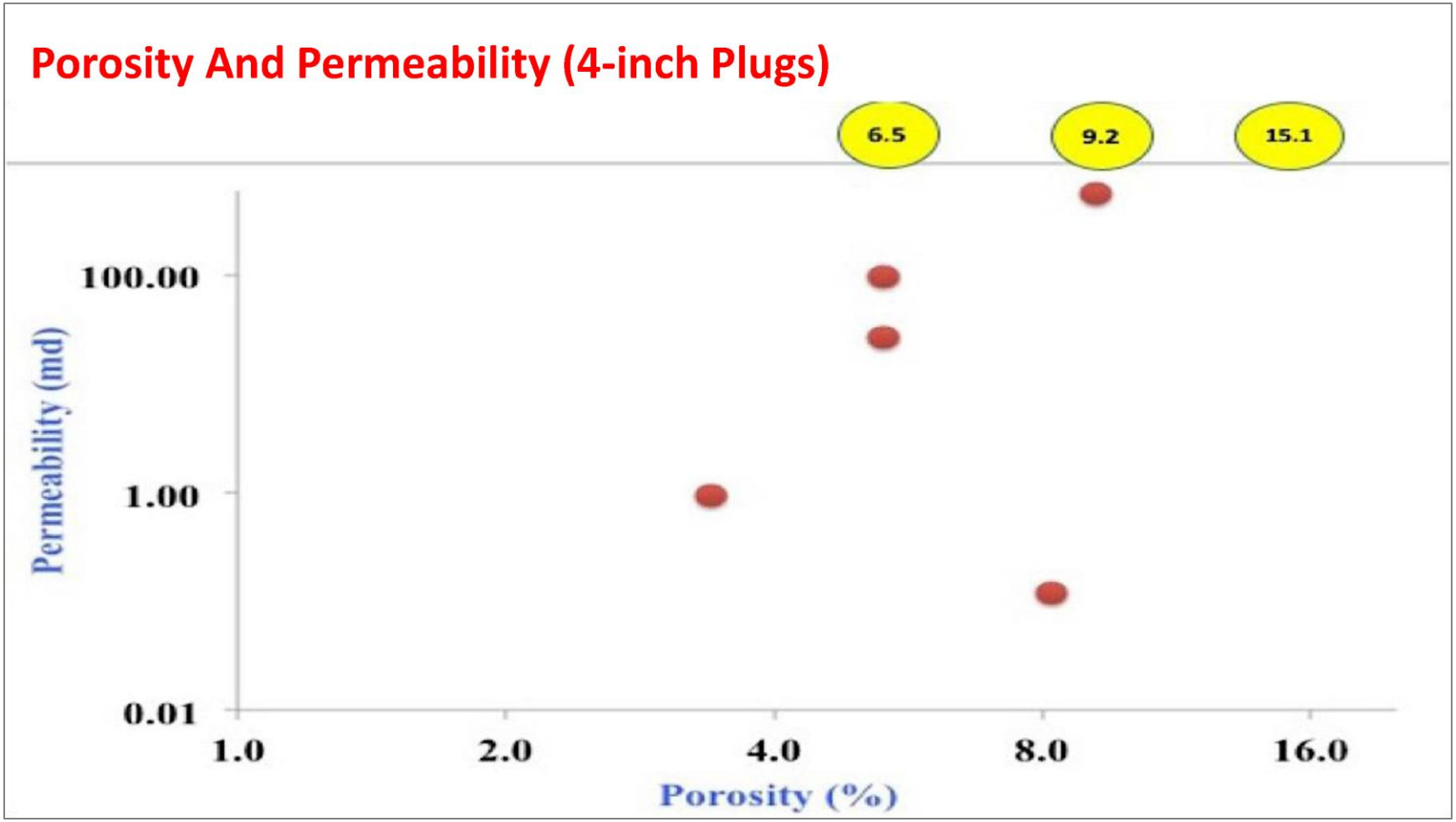
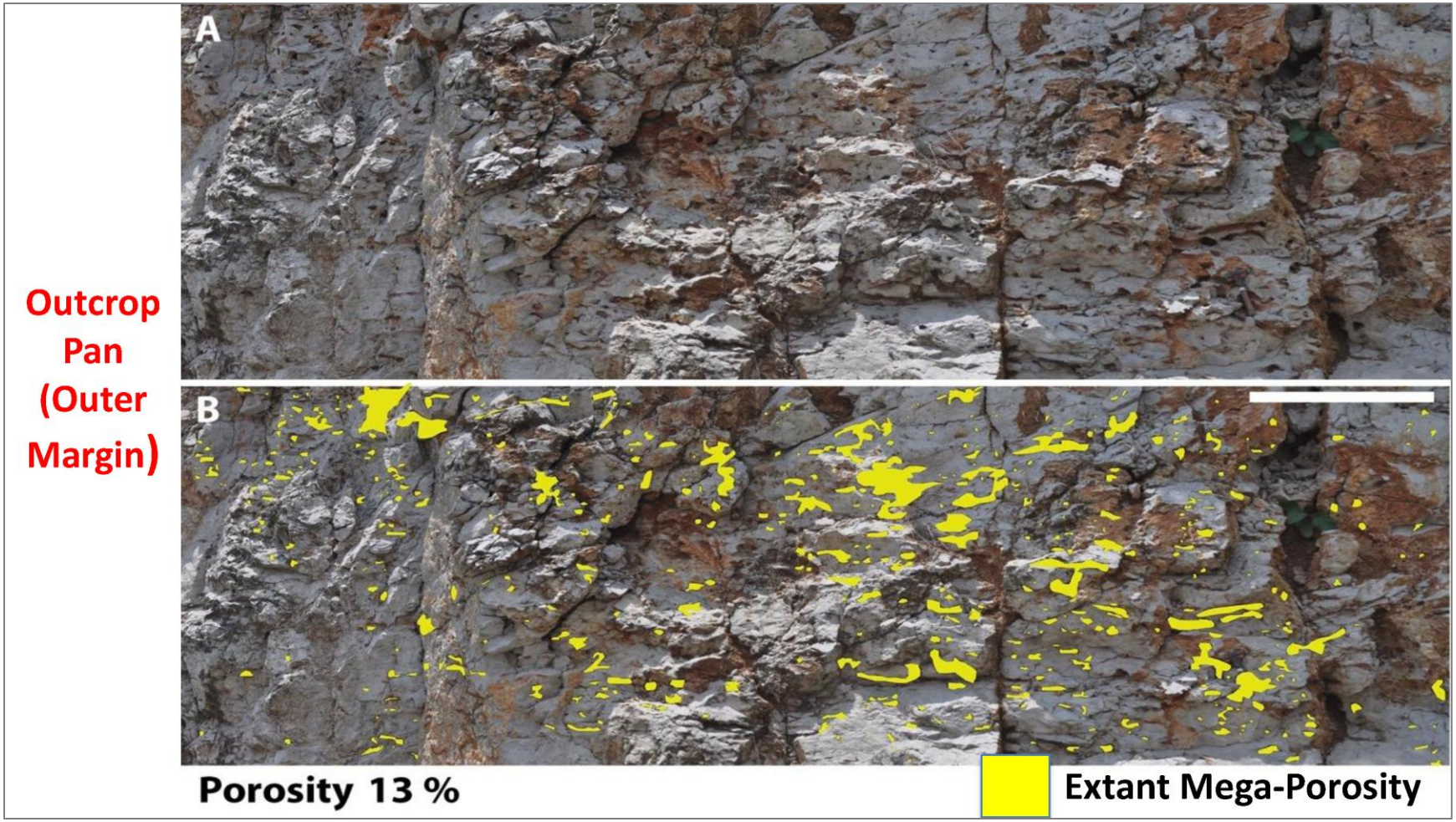
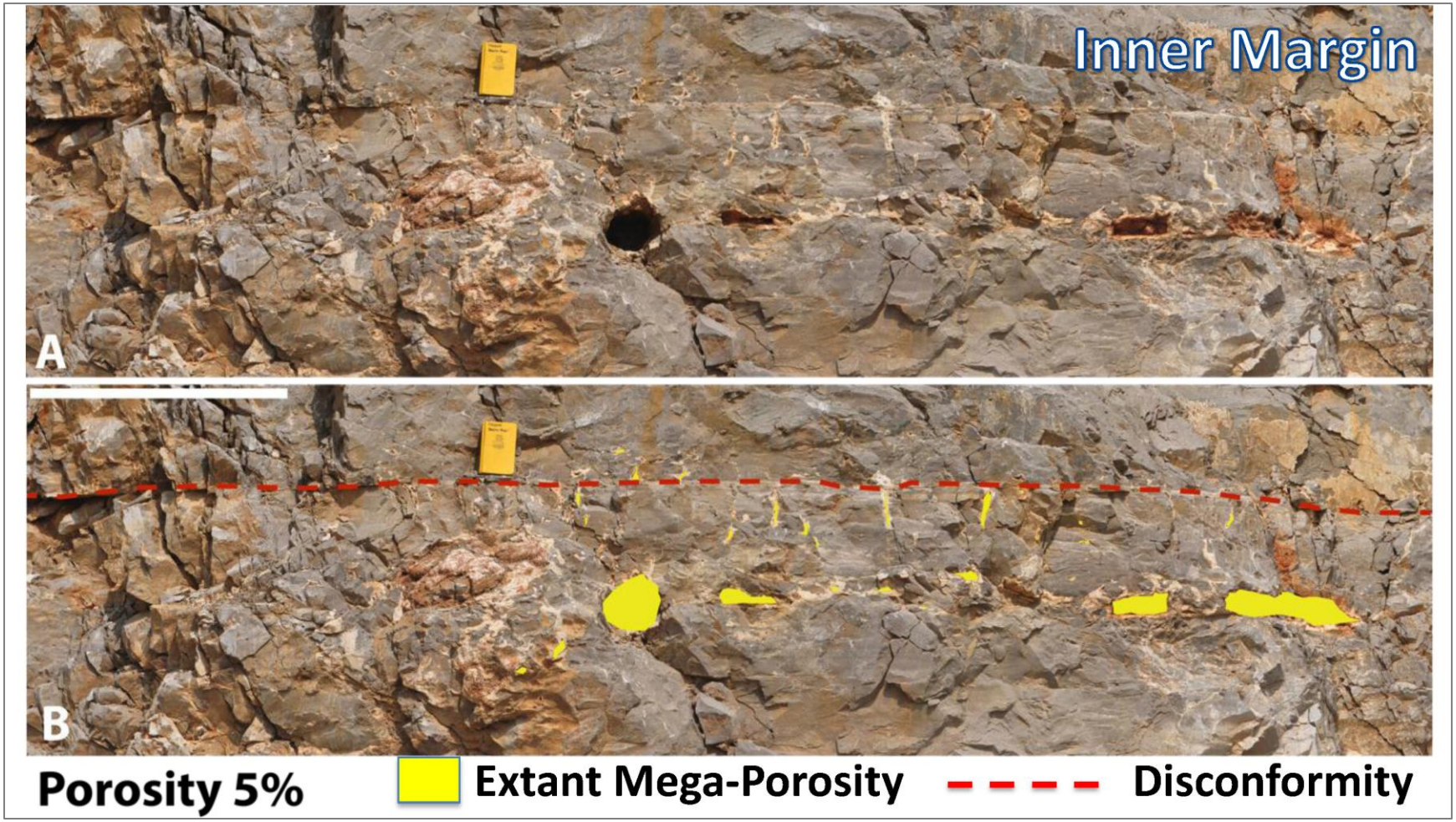


Presenter's notes: Outer margin only values.
Cross plot of porosity and permeability of eight core plugs (4" diameter) from the PM-1 section. Data points plotted above line (with porosity indicated) were termed "too porous for analysis." The permeability of such rocks would almost certainly be high.



Presenter's notes: Scale is 1 m.



Presenter's notes: Scale is 1 m.

Porosity and Permeability: Six Orders of Magnitude

Method	Scale	Inner margin			Outer margin		
		N	Φ (%)	K (md)	N	Φ (%)	K (md)
1-inch plugs	Micro (< 1mm)	40	2.9	0.0044	15	3.2	0.0046
Thin sections	Meso (< 1 cm)	45	0.3	---	25	0.13	---
4-inch cores	Mega (< 10cm)	---	---	---	8	7.6	0.8-553
Photopans	Mega (>10 cm)	3	6	---	3	12	---
			9.2			**19.6**	

--- denotes lack of data

Application To The Subsurface

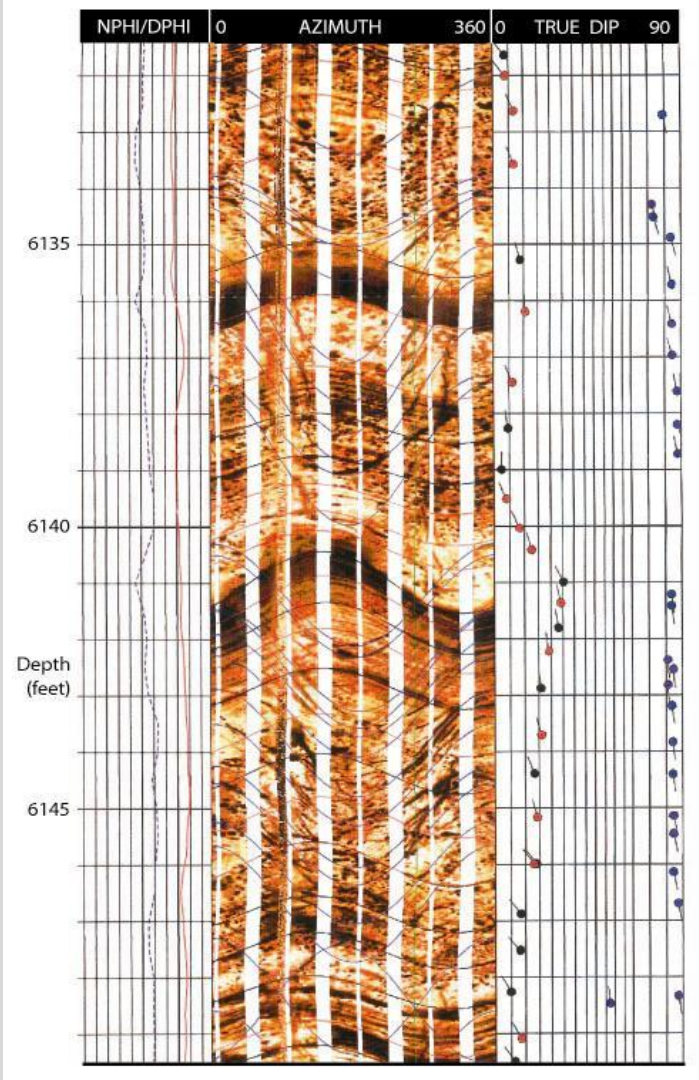
- Technique for measuring megaporosity adaptable for subsurface.
- Cores: Same as outcrop, although size restricted.

  Rotate core to increase area by π
- Open holes: Cameras or Formation MicroScanner.

FMI of an Arbuckle Group dolomite section in WECI #1, Finney County, Kansas, which was drilled about 30 degrees from the vertical.

Darker bands are shaley intervals that mark boundaries between cycles in peritidal sequences.

Note the vuggy porosity and fractures.



Conclusions

- Diagenesis was a dominant control on porosity evolution in mid-Cretaceous El Abra Formation.
- Φ and K, measured over six orders of magnitude, vary widely.
- Matrix K is nil, Φ low.
- Vuggy Φ is high (to 20%)
- ‘Touching vugs’ produce high K (>500 md)
- Repeated disconformity-related diagenesis reduced inner-margin Φ and K.
- Outer-margin reservoir quality is significantly better.

Acknowledgements

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- Special thanks to Cementos Mexicanos **(CEMEX)** and Instituto Potosino de Investigación Cientíca y Tecnológica **(IPICYT)** for support during field work.

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