Pore Characteristics in Microbial Carbonate Reservoirs*

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Abstract

Microbial carbonates are biogeochemical precipitates formed in situ directly or indirectly by benthic microorganisms. Their depositional pore characteristics are determined by biogeochemical growth fabrics constructed from microbial building blocks instead of grains or crystals as in detrital limestones and crystalline dolostones. Diagenetic alteration or fracturing may create hybrid pore types, but unless the depositional fabric is destroyed, petrophysical characteristics of microbialites depend on building blocks and their corresponding growth fabrics. The term "boundstone" is insufficient to differentiate between varieties of depositional pore geometry constructed within or around peloids, peloid clusters ("clots"), filaments, "shrubs", stromatolitic laminae, spherulites, or fossil microbes per se.

Differences in depositional pore characteristics between microbial and detrital or crystalline fabrics can impact estimates of oil in place, recovery efficiency, behavior in secondary recovery, and reservoir models. For example, depositional fabrics made of peloidal building blocks occur in modern microbial buildups at Cuatro Cienegas, Mexico. Similarities exist between the Cuatro Cienegas depositional pore characteristics and those in the Smackover (Jurassic) microbial reservoir at Little Cedar Creek field, Alabama. Modern depositional fabrics in Shark Bay microbialites exhibit fenestral and interlaminar pore types similar to some of the Cretaceous microbialites in the Atlantic off Brazil, where thrombolitic and spherulitic fabrics dictate reservoir pore characteristics. Because microbial carbonates are in situ biogeochemical accumulations such as reefs, stromatolites, thrombolites, and leiolites, the identification of petrophysical rock types and their corresponding flow units requires different approaches than those used to characterize reservoirs with interparticle porosity in detrital and crystalline carbonate or terrigenous sandstone reservoirs where particle size rather than biogenic fabric is the essential parameter. One alternative approach defines petrophysical rock types by genetic pore type instead of depositional facies.

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Pore Characteristics in Microbial Carbonate Reservoirs

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Microbial Carbonate Reservoirs

- Microbial carbonates are biogeochemical precipitates formed *in situ* directly or indirectly by benthic microorganisms [microbes]
- Their depositional pore characteristics are determined by biogeochemical growth fabrics constructed from microbial building blocks instead of grains or crystals [particles & interparticle porosity]
- Petrophysical characteristics of microbialites are influenced by microstructures and microfabrics that are insufficiently identified by macro-scale rock classifications such as boundstone, bindstone, and thrombolite, and sometimes - stromatolite.
- A genetic pore classification is better for identifying depositional, hybrid, and purely diagenetic pores in microbialites
- Petrophysical rock types and reservoir flow units can be defined more precisely with genetic pore types than with “facies”

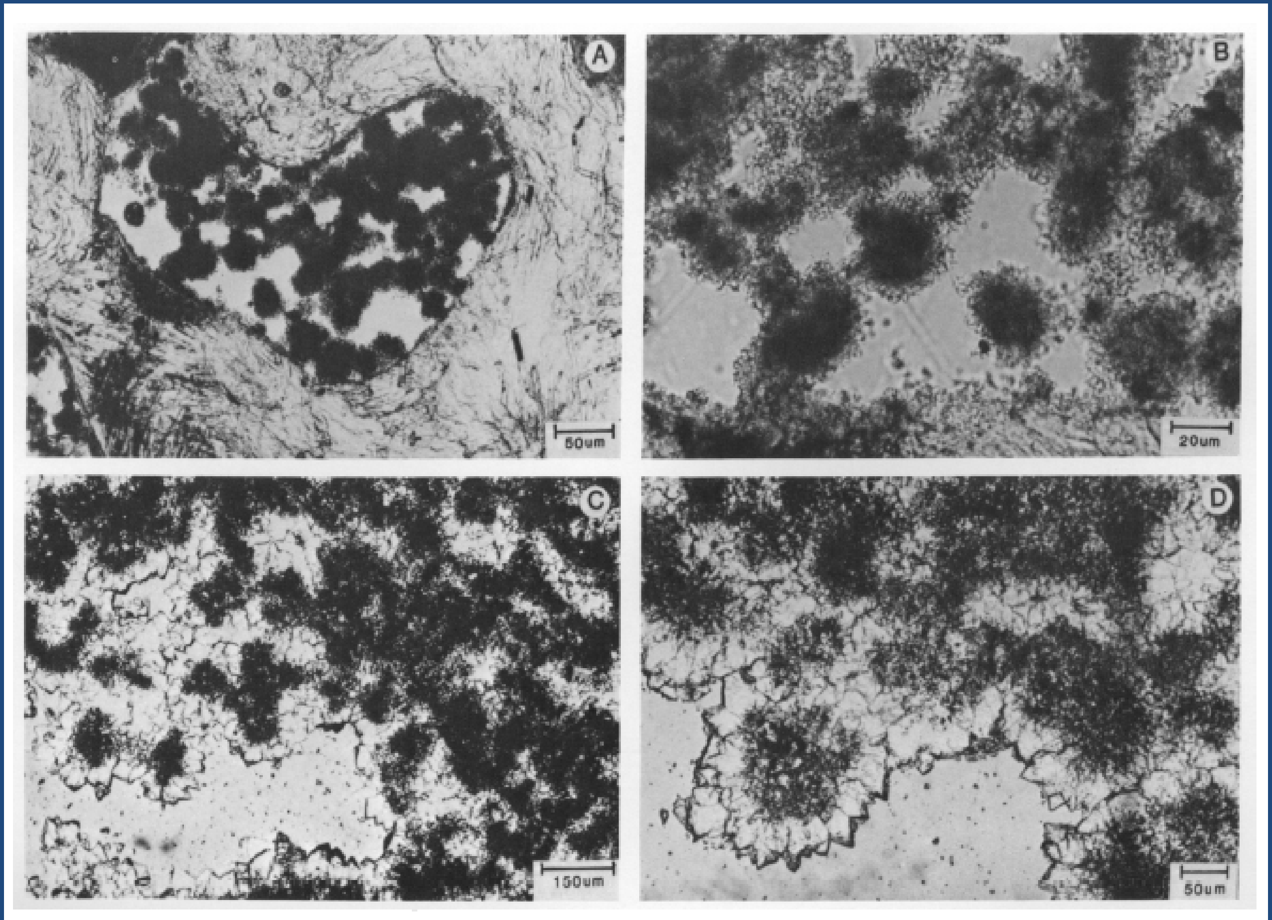
Microbial Building Blocks

Microbial building blocks are the fundamental, micro-scale constructional elements from which macro-scale features are formed; they include:

- Peloids & "Mesoclots" [Mesoclots may be compacted peloid clusters]
- "Shrubs" [Arborescent growth forms]
- "Stromatoids" [individual laminae in stromatolites]
- Filaments
- Radiaxial calcite cements*
- Recognizable calcimicrobes such as *Girvanella*, *Renalcis* and *Epiphyton*

** There is debate about this*

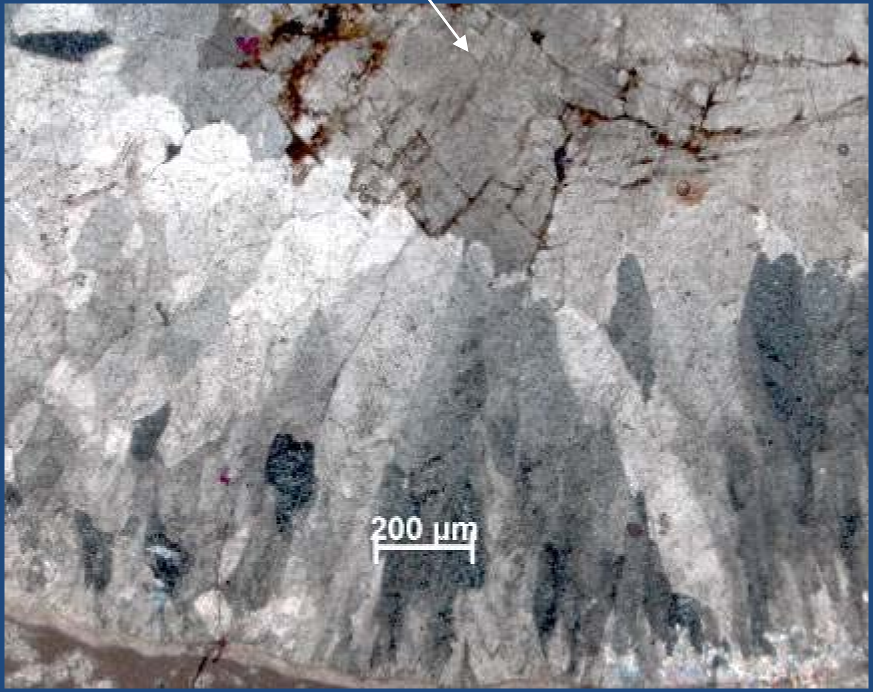
Microbial Building Blocks - Peloids



McIntyre et al., 1993

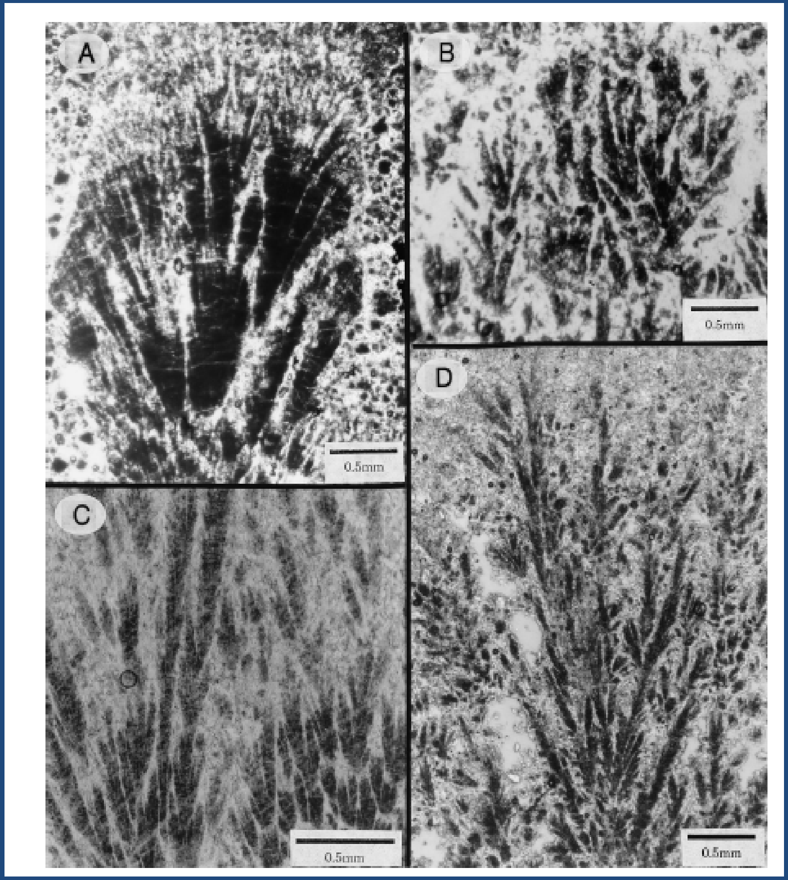
Microbial Building Blocks - Radiaxial Calcite Cement & Peloids

Saddle dolomite



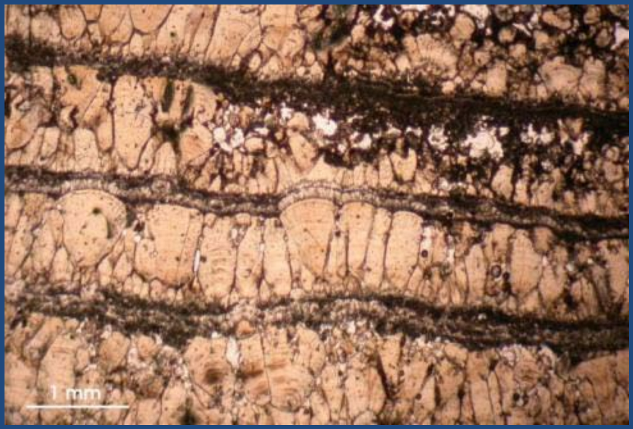
Compare with some varieties of “shrubs”

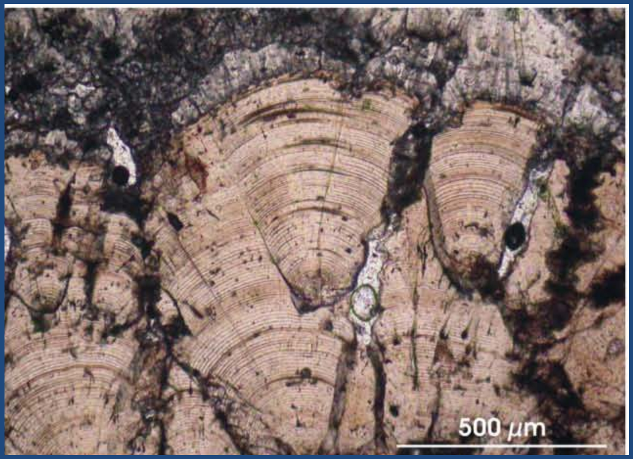
Microbial Building Blocks – Bacterial & Travertine "Shrubs"



Bacterial Shrubs

Chafetz, 1999





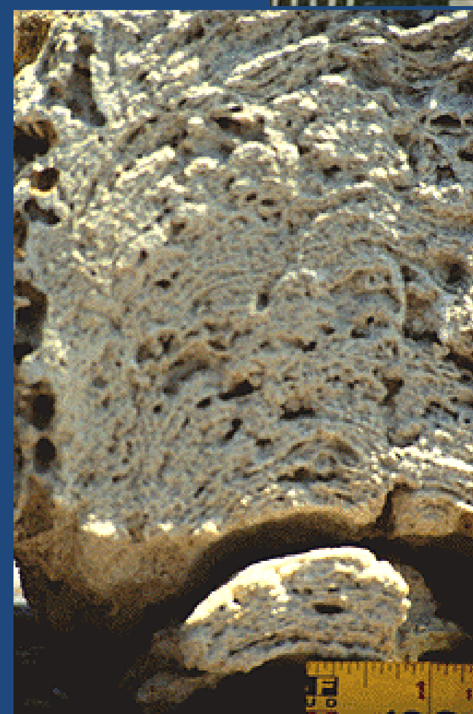
Travertine - Austria

Boch et al., 2005

Microbial Building Blocks – “Stromatoids”

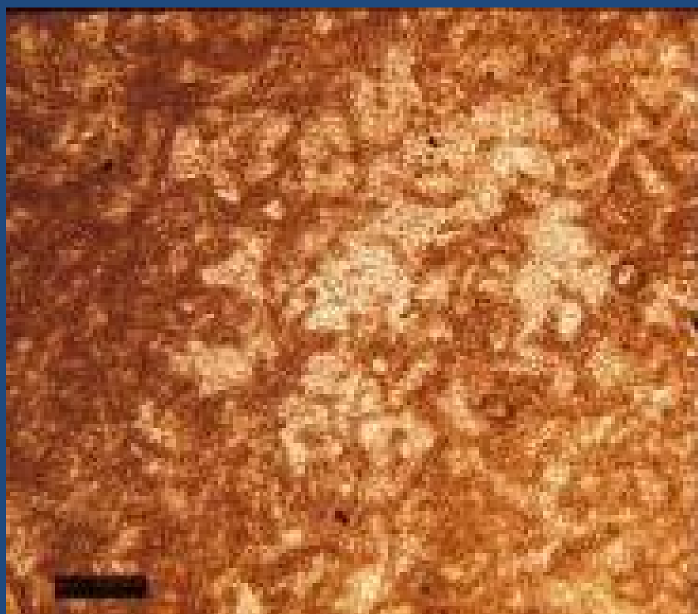
Shark Bay, W.A.

Cuatro Cienegas
Mexico

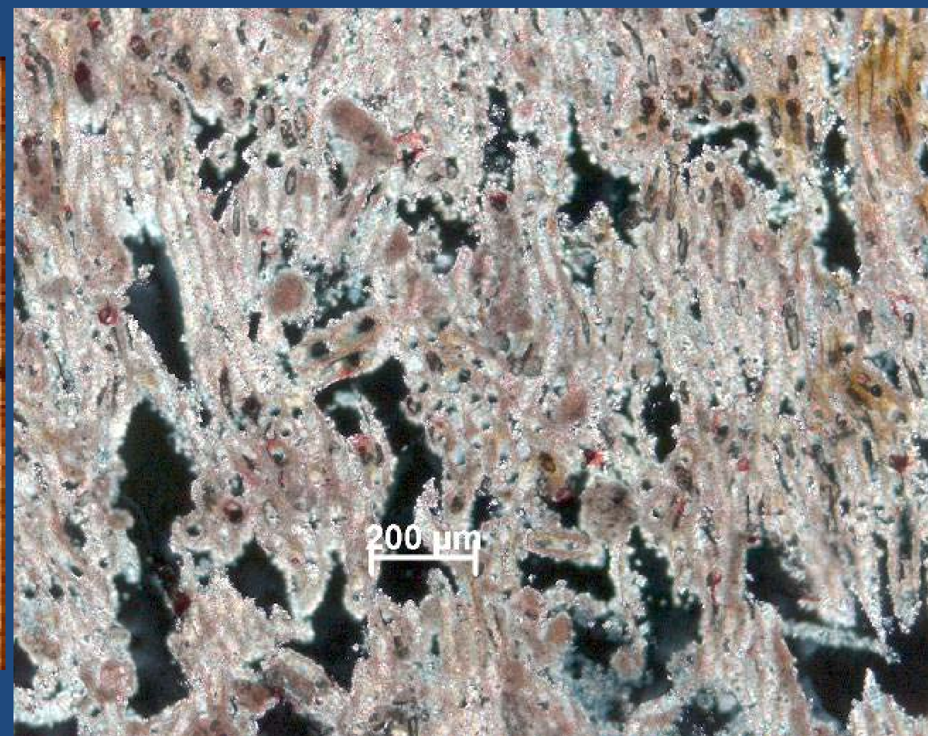


Lee Stocking Island
Bahamas

Microbial Building Blocks - Filaments



Filaments of *Girvanella* – Upper Cambrian Of Central Texas. Scale bar = 200 µm

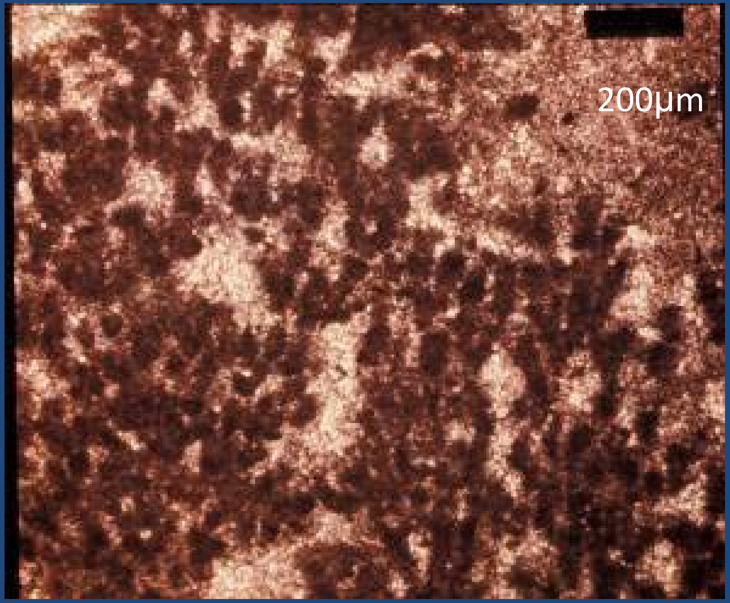


Modern filamentous "stromatolite" – Andros Island, Bahamas. Note longitudinal & transverse views of tubules [filaments] & inter-tubule cluster porosity

Microbial Building Blocks – Recognizable Fossil Microbes

Renalcis. Devonian, Canning Basin

Scholle & Ulmer-Scholle (2003)



Epiphyton Cambrian, Texas

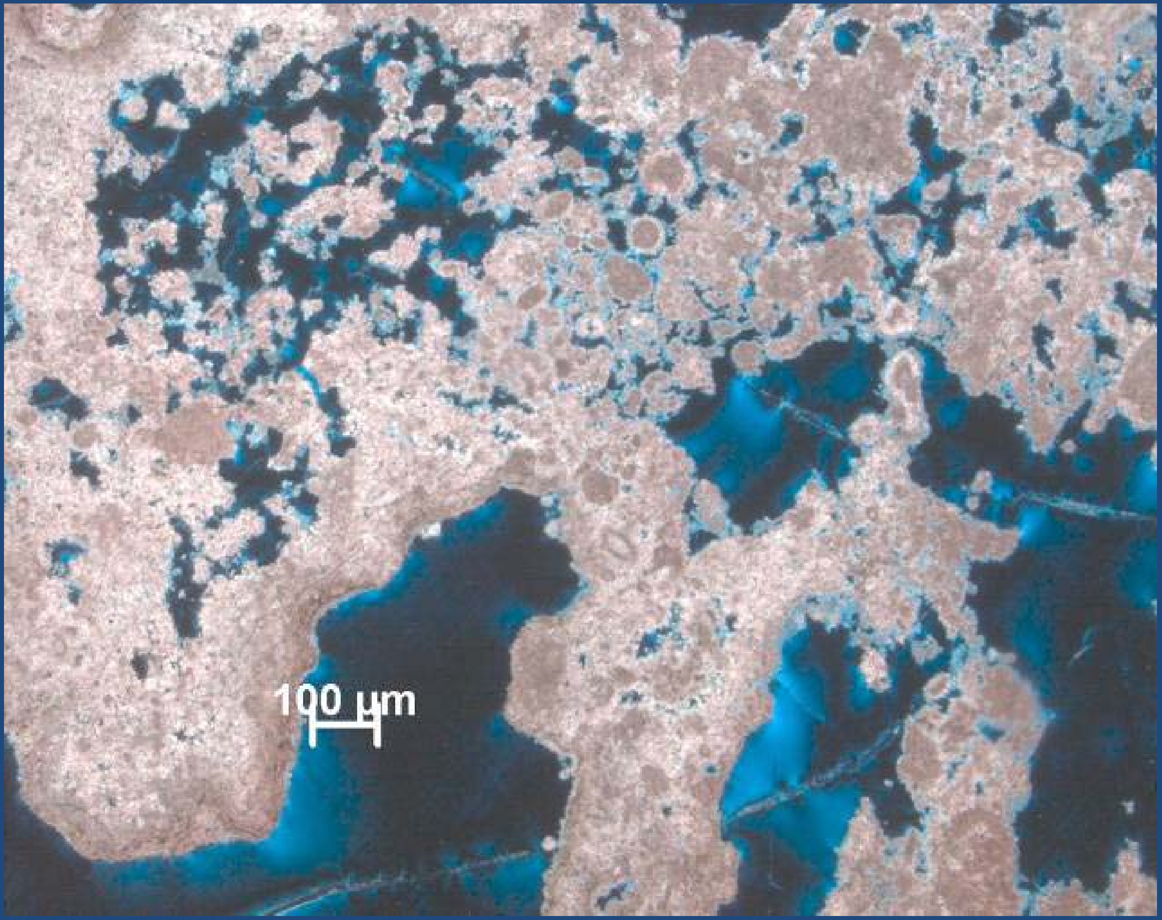
Some Modern Microbialites & Their Depositional Pore Types

Cuatro Cienegas, Mexico
SO_4-Rich; PO_4-Lean: Spring - Lacustrine Microbialites

Cuatro Cienegas Microbialites

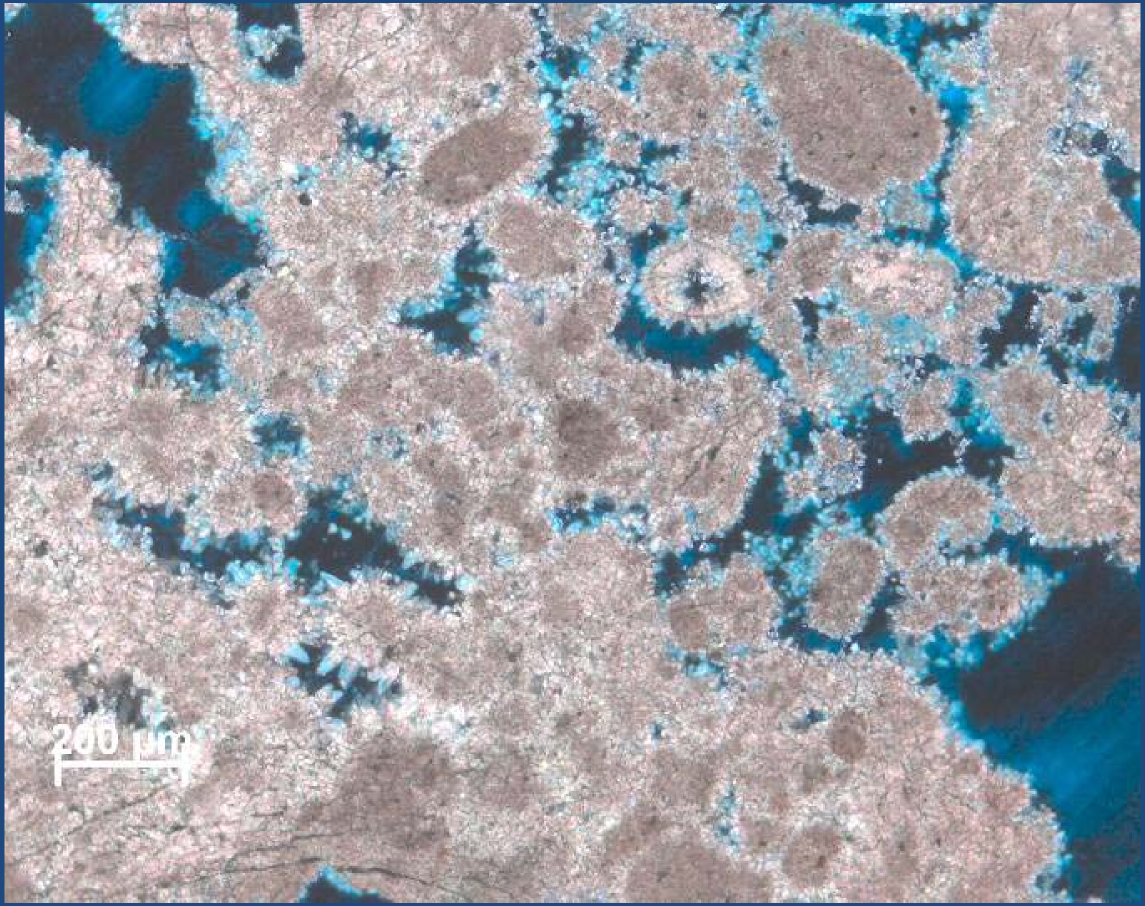
Cuatro Cienegas "Thrombolite"

Cuatro Cienegas Thrombolite in Thin Section



Note abundant peloids & peloid clusters [building blocks] & the relationship to pore structure

Higher Magnification Section, Cuatro Cienegas Thrombolite

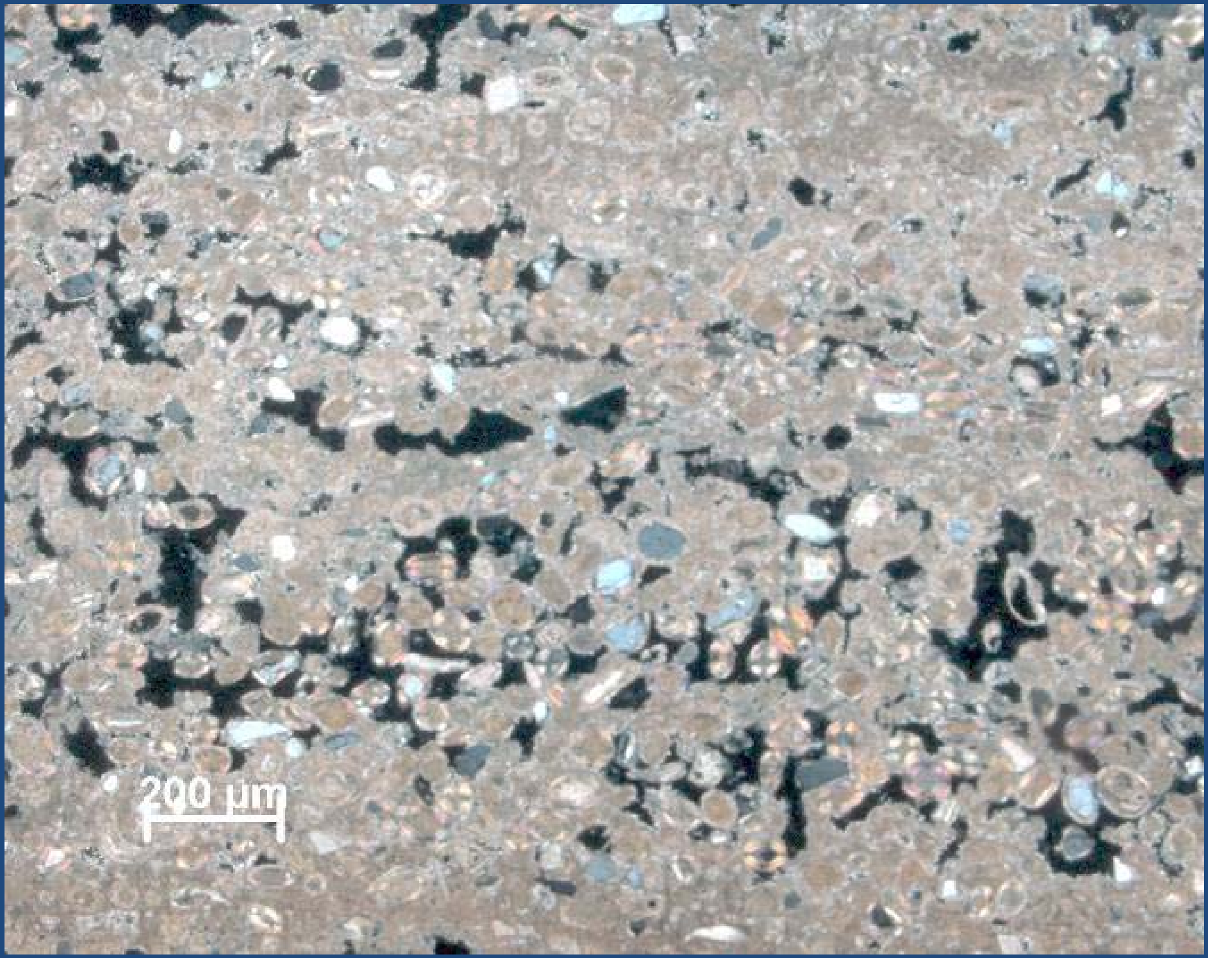


Abundant peloids, “mesoclots”, & peloid clusters with interpeloid & inter-cluster depositional porosity. Note calcite cement around peloids & pore walls

Shark Bay, W.A. – Restricted Marine Bay

Brian W. Logan and Shark Bay Stromatolites

Shark Bay Stromatolite Thin Section



Micritic layers are more microbial; grainy layers represent “trapped” sediments. Depositional porosity is Φ concentrated in grainy laminae.

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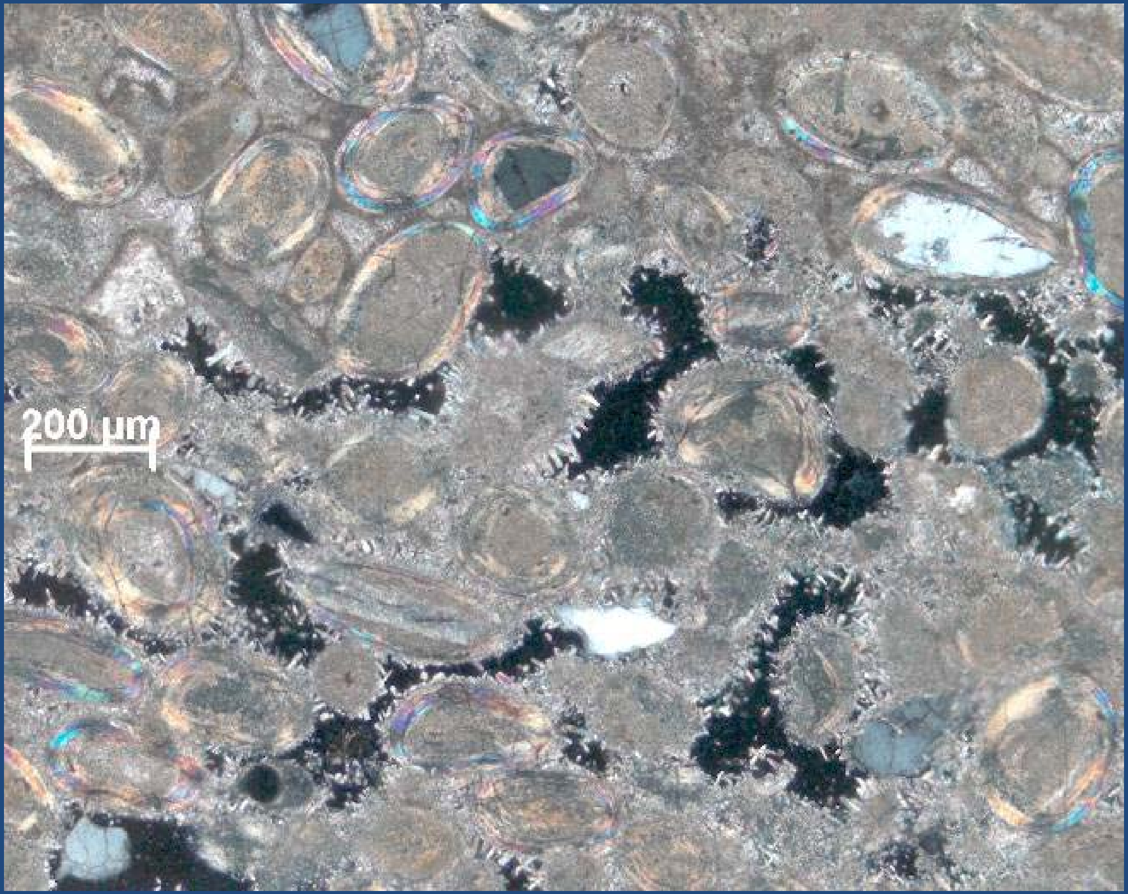
Higher Magnification – Shark Bay Stromatolite



Note abundance of ooids & inter-ooid depositoinal porosity along w/ isopacous aragonite needle cement.

Genetic Pore Types & Their Hybrids: A Classification

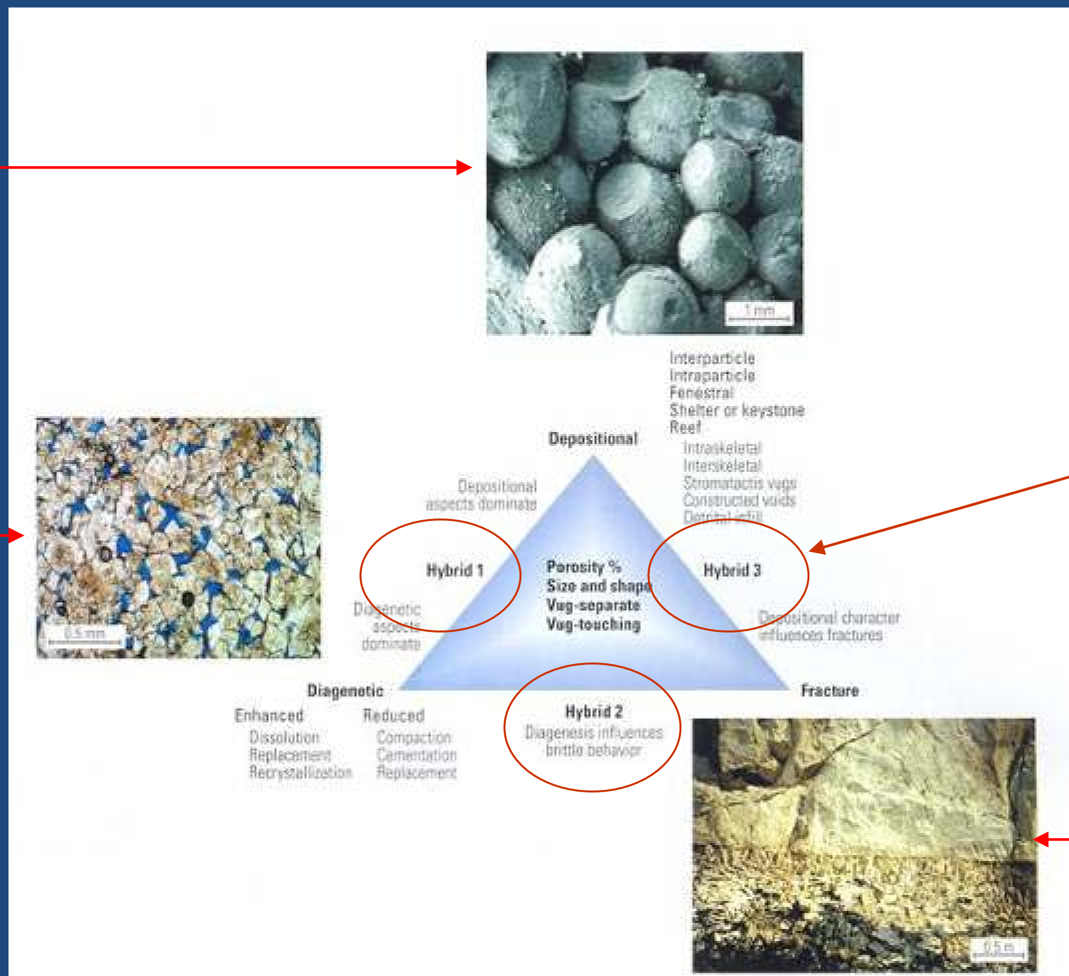
Ahr, 2005 classification focuses on 3 end-member pore types by the way they are formed in nature – and on mixtures [hybrids] of the end members

Purely Depositional

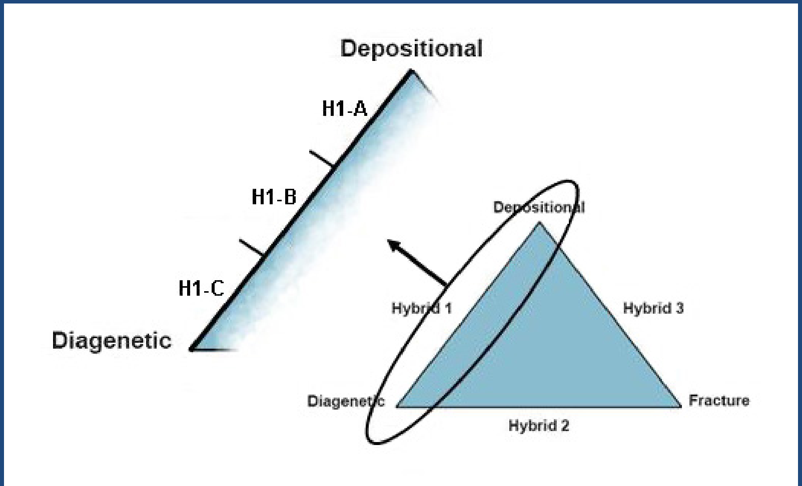
Purely Diagenetic

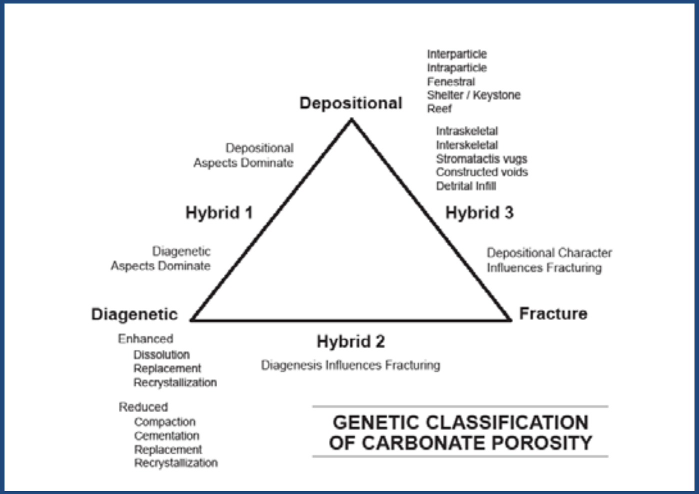
Hybrids Type 1-2-3

Purely Fracture



A modification of the Ahr porosity classification by Humbolt (2008)





Humbolt refined the scale of diagenetic alteration between purely depositional and purely diagenetic pores to more precisely define hybrid pore types for use in generating petrophysical rock types.

One must know the difference between diagenesis and Diogenes to understand carbonate porosity !

Genetic Pore Types in Some Microbial Reservoirs

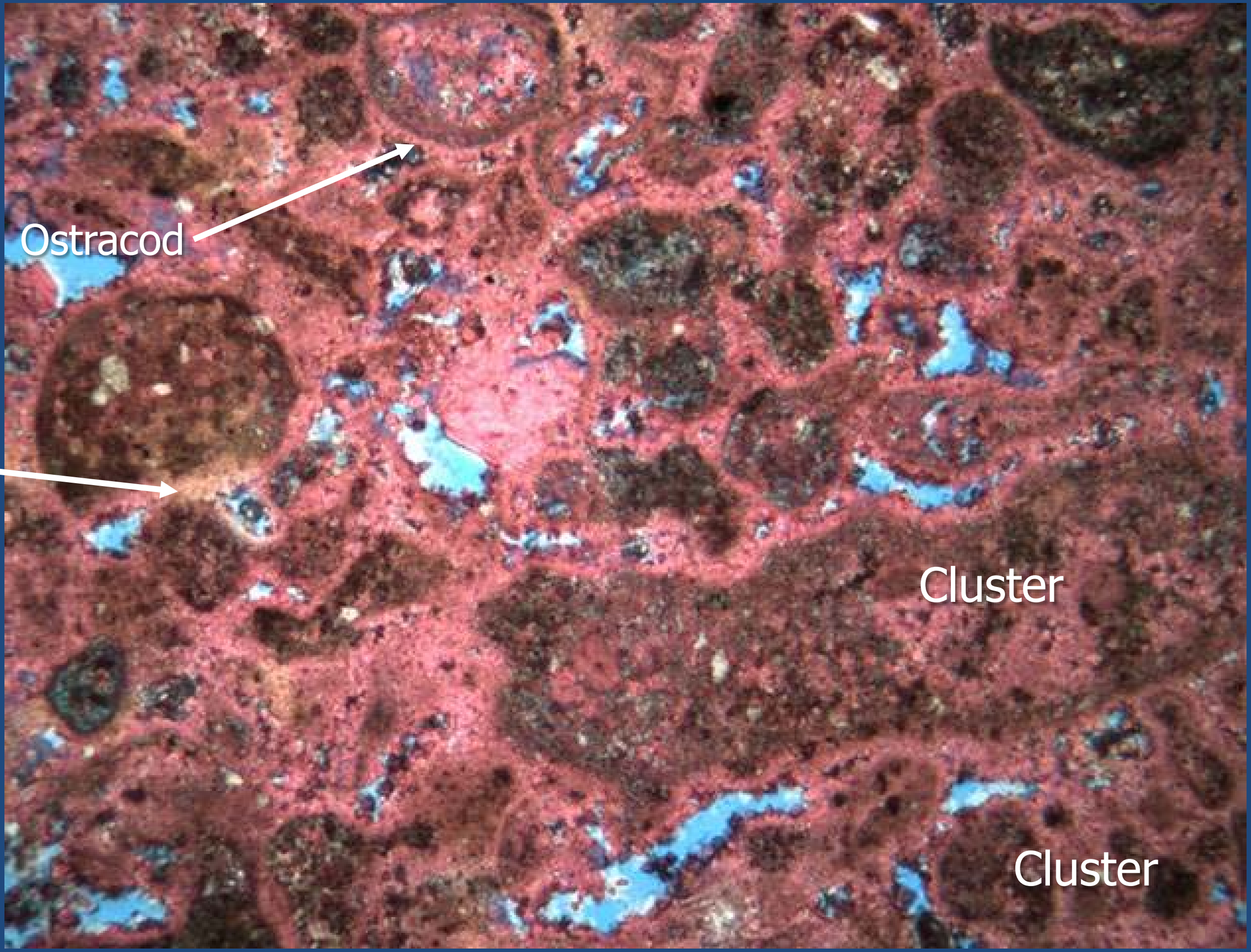
Subtidal Peloidal Thrombolite, Little Cedar Creek (Smackover) Field, Alabama

Average Φ = 10.8 -> 22.2 %
Average K = 196 -> 2834 md

Permit 12872; 11,880 feet

Photo: E.A. Mancini

Thin Section – Little Cedar Creek field.



Solution-enhanced interpeloid and peloid cluster porosity

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Appleton Field Alabama (Smackover)Thrombolitic Reservoir Facies

Reticulate thrombolite

“Dendroidal” thrombolite

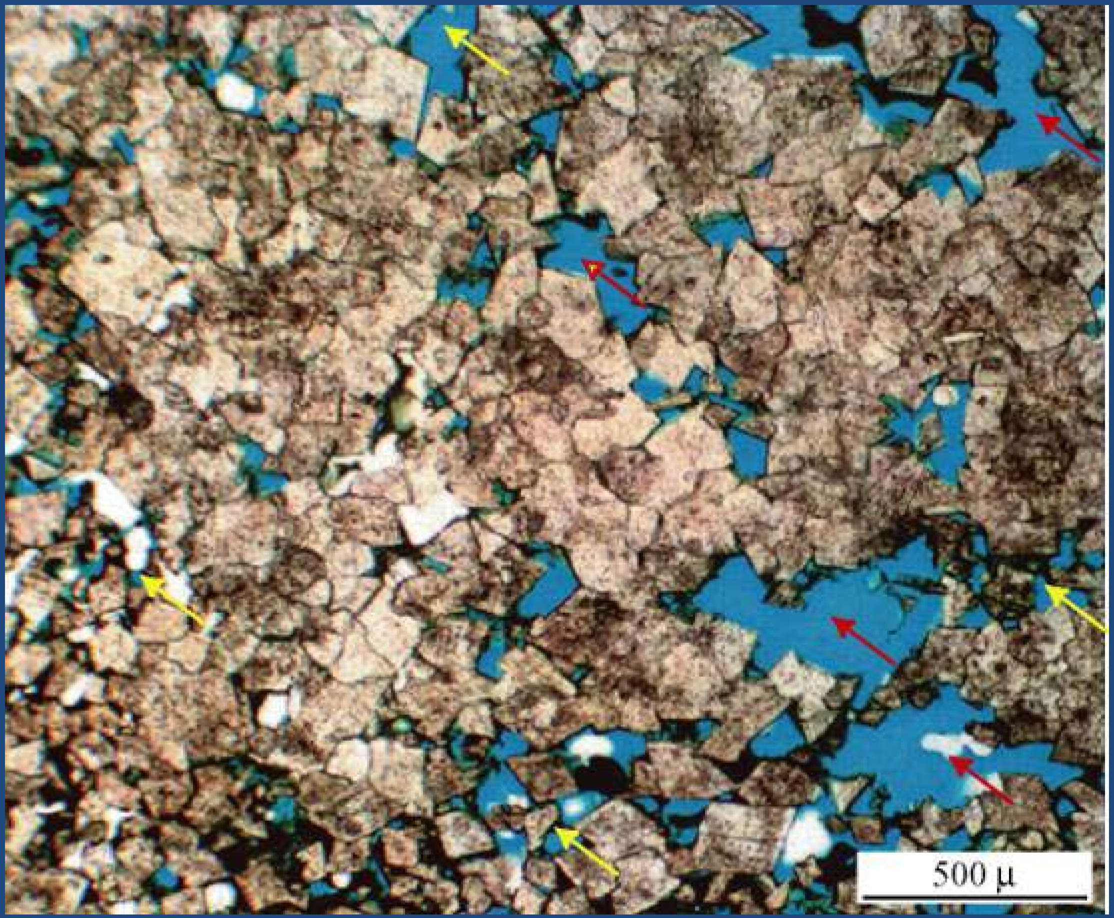
Laminated thrombolite

Terminology of Parcell (2002)

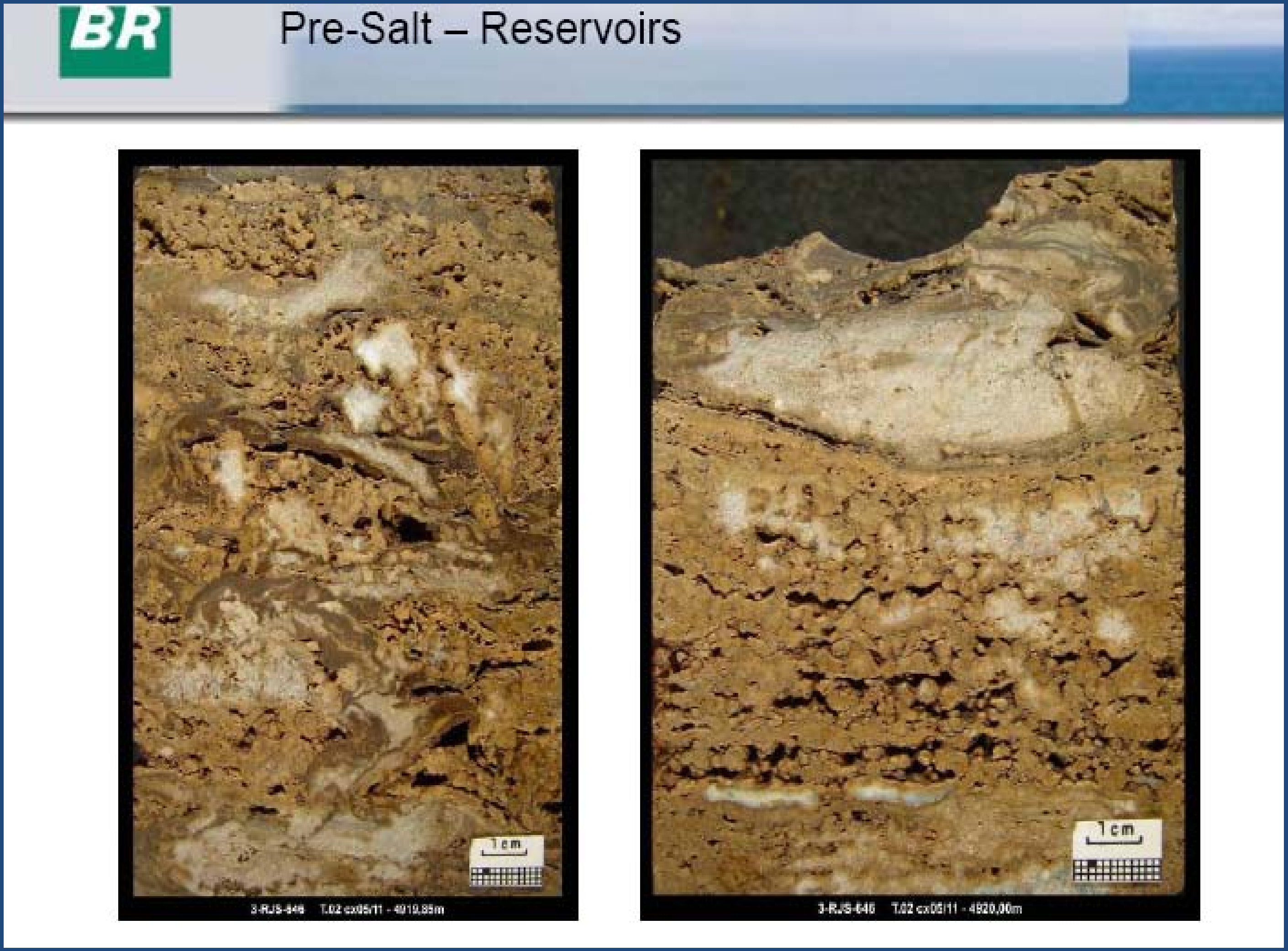
Thin Section: Dendroidal Thrombolite - Appleton Field Reservoir: Hybrid Pore Type H1C

Sample from well 3984, 12,970 feet depth

Extensive replacement by dolomite with faint “ghosts” of peloids and peloid clusters. Red arrows = vugs; yellow = intercrystallie pores.



Mancini et al. (2006)

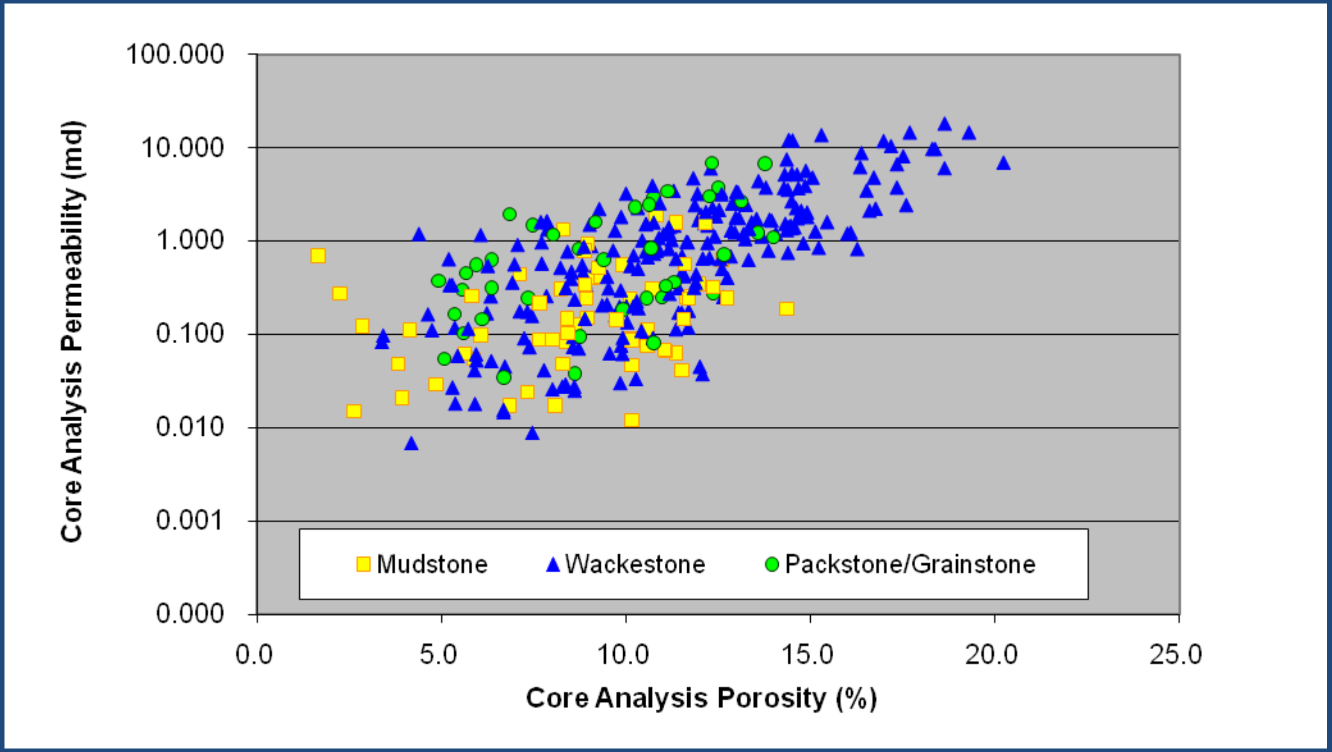


Lula field, Aptian, offshore Brazil. Microbialites with solution-enhanced fenestral and inter-fabric pores

Formigli, 2008. Rio O&G web

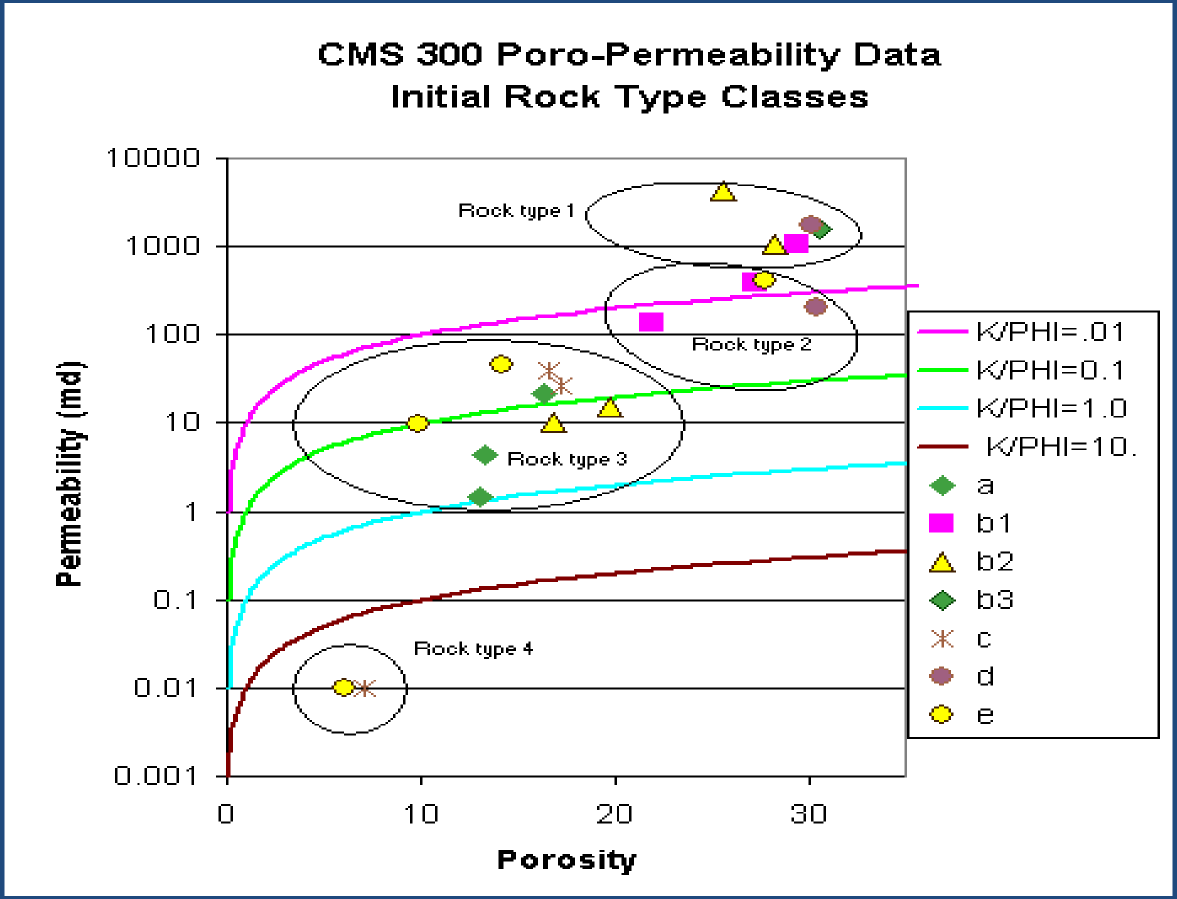
Petrophysics & Microbialite Reservoirs

Depositional facies are poor indicators of reservoir petrophysical properties

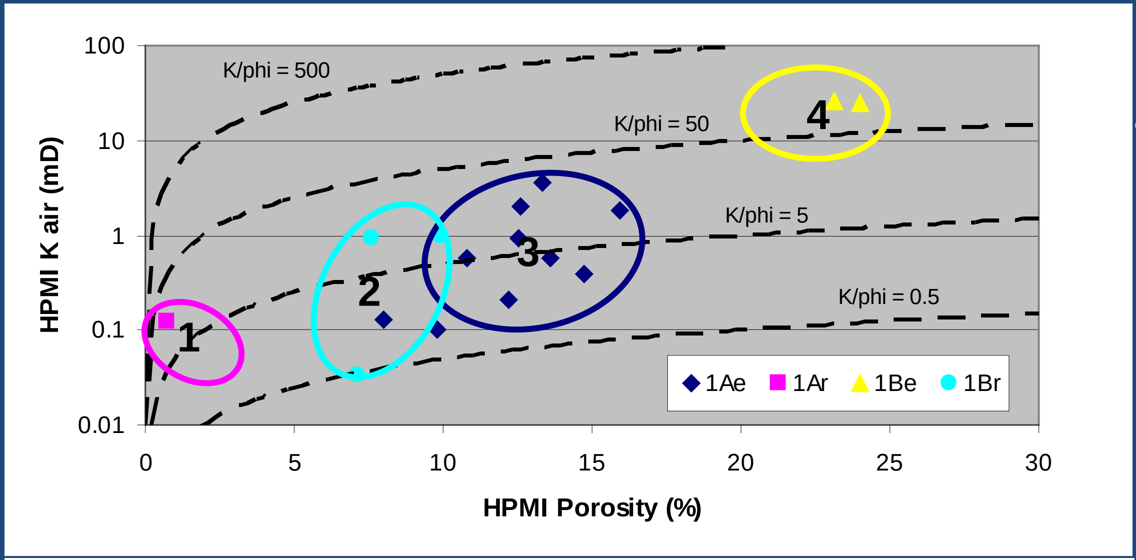


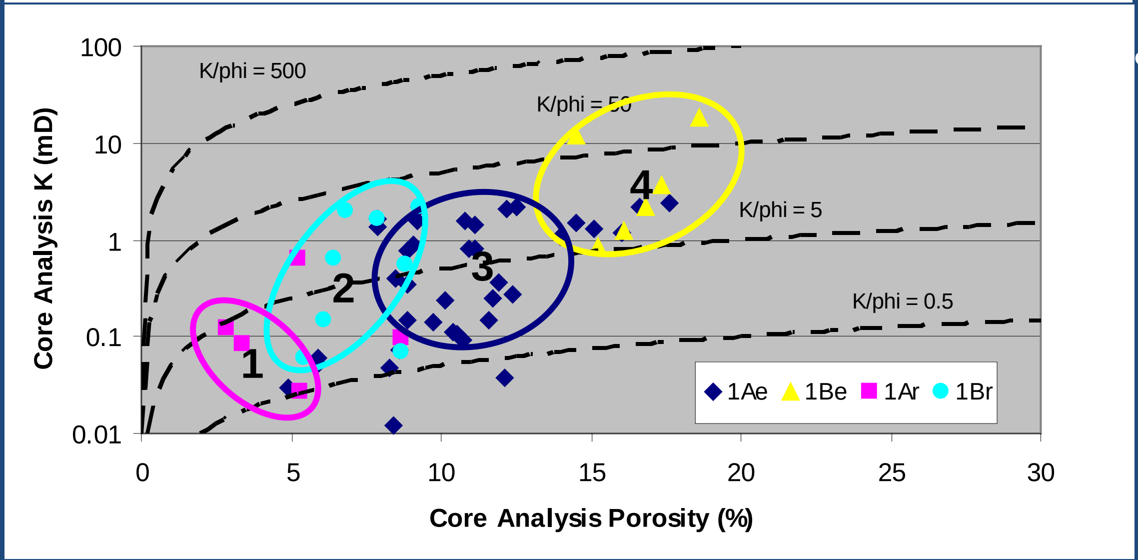
Humbolt (2008)

For example, this is a k/Φ plot to define petrophysical rock types but it is based on facies. Note that several rock types exist within one facies



Petrophysical Rock Types Based on Genetic Pore Categories





- Petrophysical rock types are classified according to the attributes that influence reservoir performance: porosity, permeability, capillary pressure, saturation, etc.
- *Petrophysical rock types in carbonates are usually independent of facies.*

Humbolt (2008)

Summary

Microbial carbonates are in situ biogeochemical accumulations such as reefs, stromatolites, thrombolites, and leiolites.

They are built from a variety of building blocks such as peloids, peloid clusters, stromatolitic laminae, filaments, and fossil microbe bodies

Depositional pore and pore throat geometry are first determined by the texture and fabric of the building block array

Most reservoir porosity has been modified by diagenesis to varying degrees that can be identified in a genetic porosity classification

The identification of petrophysical rock types and their corresponding flow units requires different approaches than those used to characterize reservoirs with interparticle porosity in detrital and crystalline carbonate or terrigenous sandstone reservoirs where particle size rather than biogenic fabric is the essential parameter.