Reservoir Quality in Salt-Encased Microbial-Dominated Carbonates from the Late Neoproterozoic Ara Group, South-Oman Salt Basin*

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Abstract

The intra-salt carbonates of the Ediacaran-Early Cambrian Ara Group in the South Oman Salt Basin represent a self-sourcing petroleum system, which has been successfully explored in recent years. Depositional facies and carbonate/evaporite platform architecture are well understood, but original reservoir properties have been modified by diagenesis. Therefore, some of the carbonate reservoirs failed to produce at acceptable rates that triggered this study. It investigates in detail the interaction of petrography, facies and diagenetic control on reservoir properties in space and time. A number of methods were used to quantify the extent of primary porosity reduction by diagenesis. Near-surface diagenesis is dominated by early marine diagenesis and reflux-related processes leading to porosity inversion in initial highly porous facies and a patchy distribution of early cements (dolomite, anhydrite and halite). This strong diagenetic overprint of primary and early diagenetic porosity by reflux related cements leads to a reduction of stratigraphic and facies control on porosity. Calcite was identified as a burial-related cement phase that leads to an almost complete loss of intercrystalline porosity and permeability in dolomites. Microporosity forms an important component of the pore system, contributing often more than half of the complete pore space. The preservation of early diagenetic, very fine crystalline dolomite in a closed diagenetic system contributed to the relatively high microporosity values. Confocal laser scanning microscopy revealed the close association between bitumen and microporosity indicating an inhibition of recrystallization by an early influx of hydrocarbons. Reservoir bitumen was identified as important pore occluding phase and time marker of the deep-burial realm. Pressure and temperature reduction during a ‘deflation’ event at the end of salt tectonic times seems to be the most likely process leading to formation of reservoir bitumen, whereas further phases of bitumen formation, related to uplift-events, cannot be excluded. Maps confirm the heterogeneous distribution of key diagenetic phases on a field-scale. The diagenetic history within the South Oman Salt Basin is largely determined by the successive change in fluid chemistry typical for many evaporite basins. The sequence of diagenetic events established in this study can be diagnostic for other carbonate-evaporite associations worldwide.

Selected References

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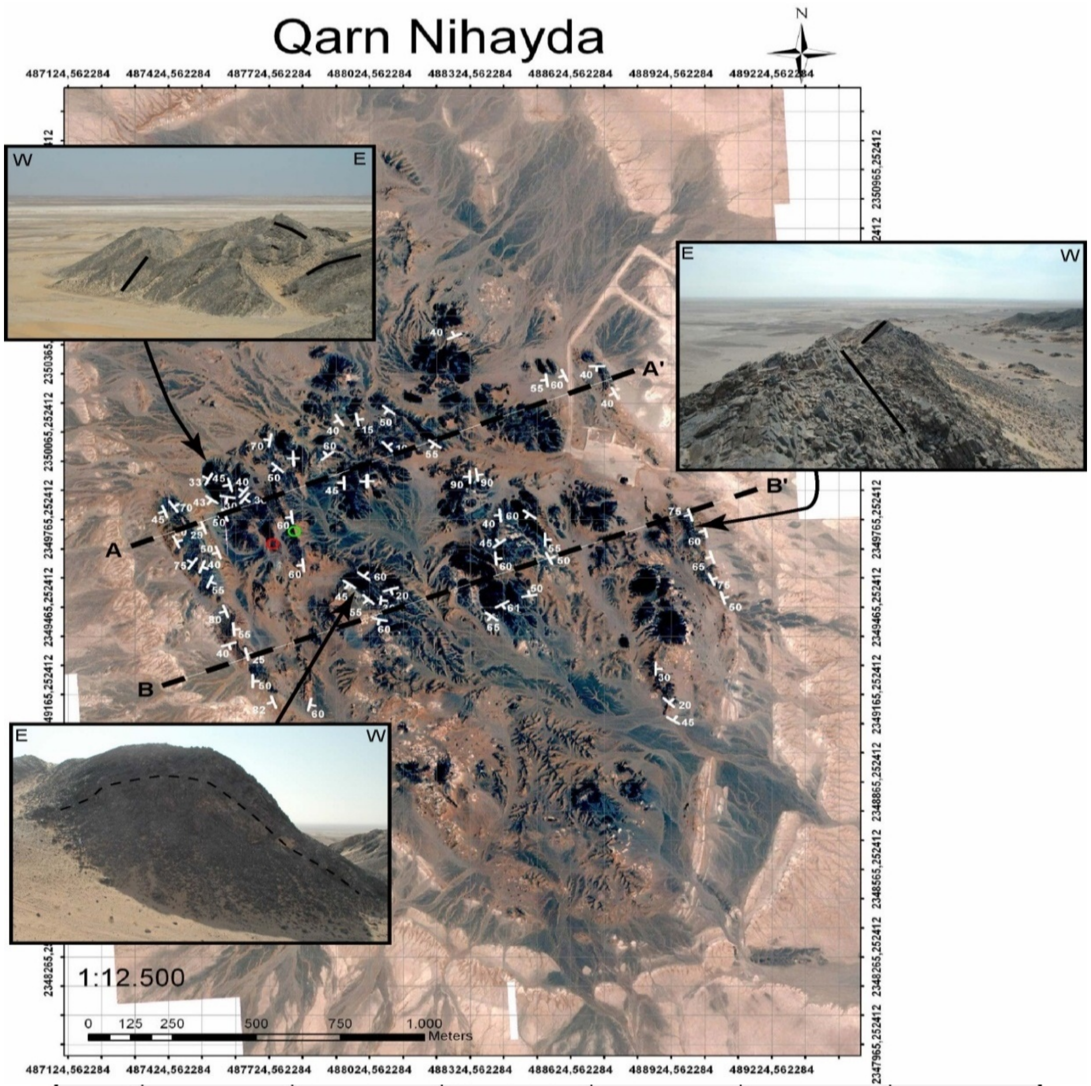
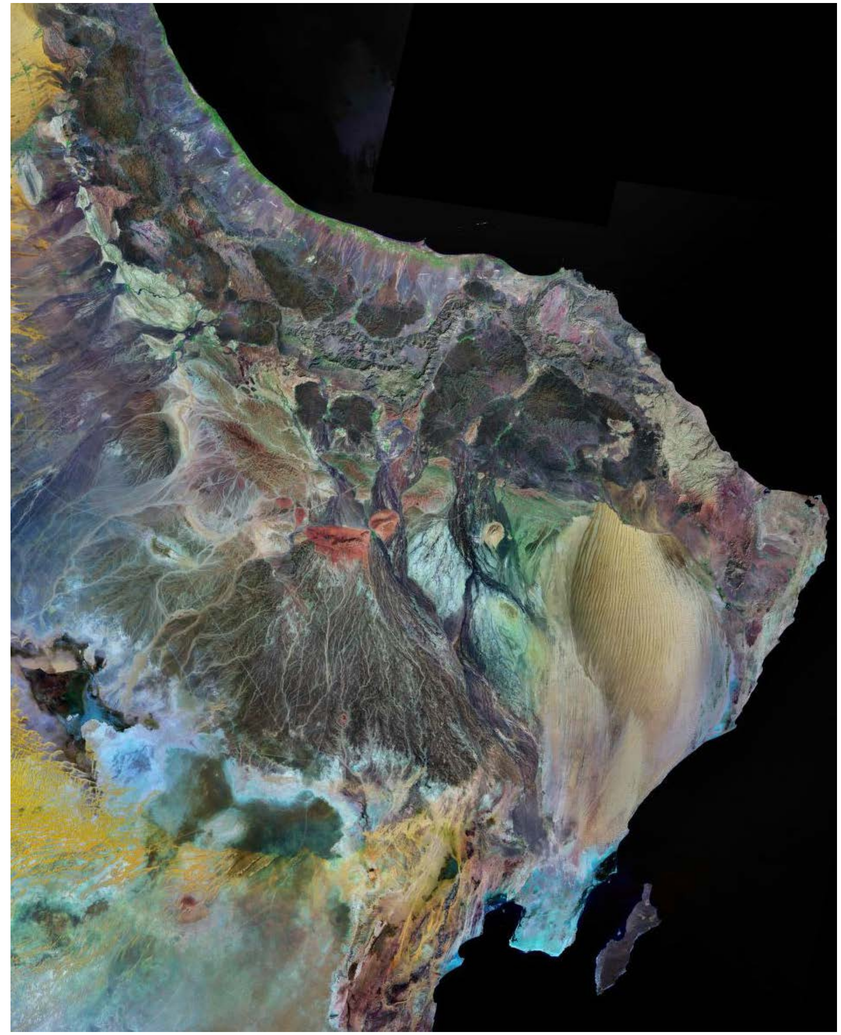
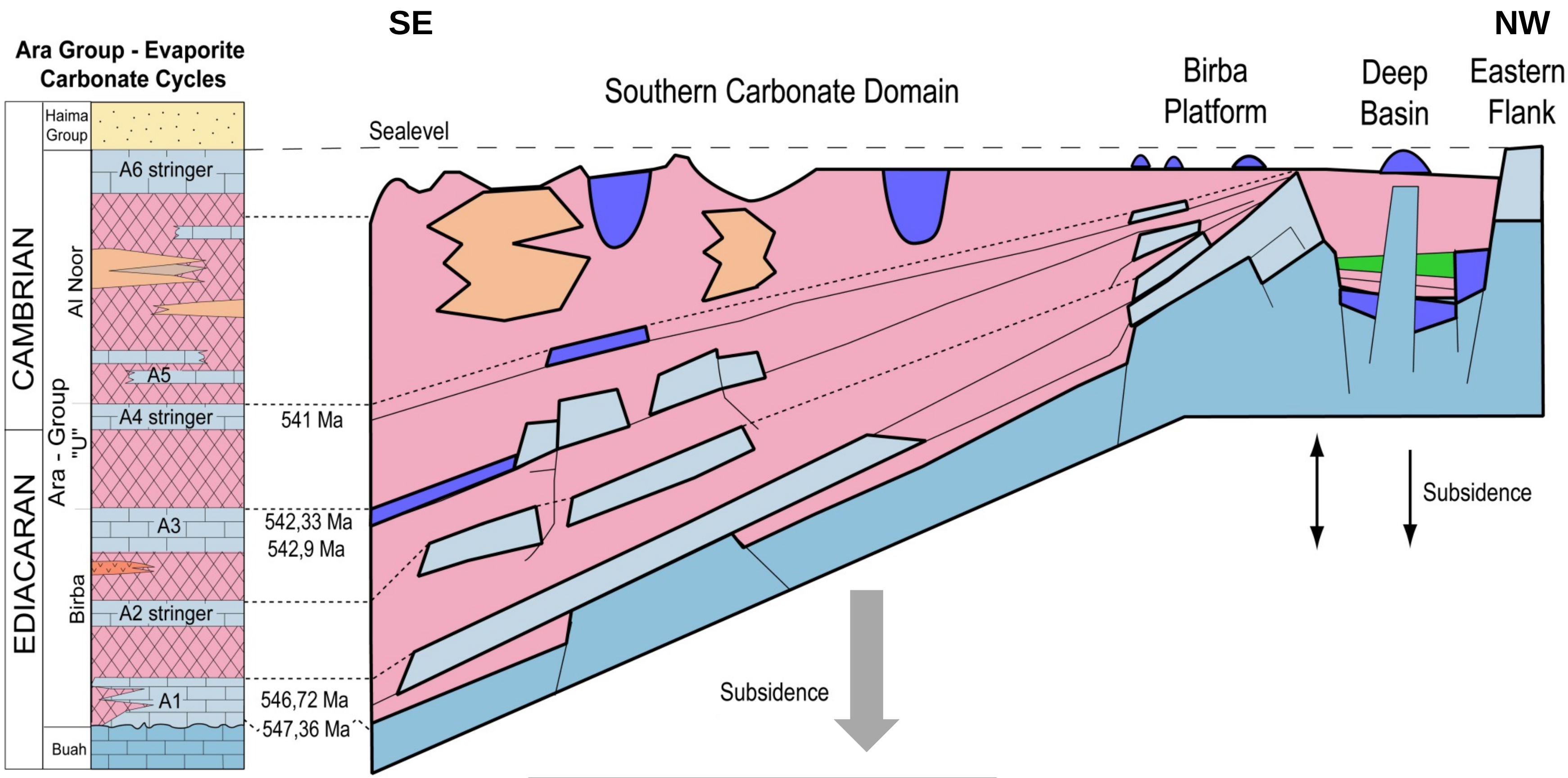
Neoproterozoic Salt Basins in Oman





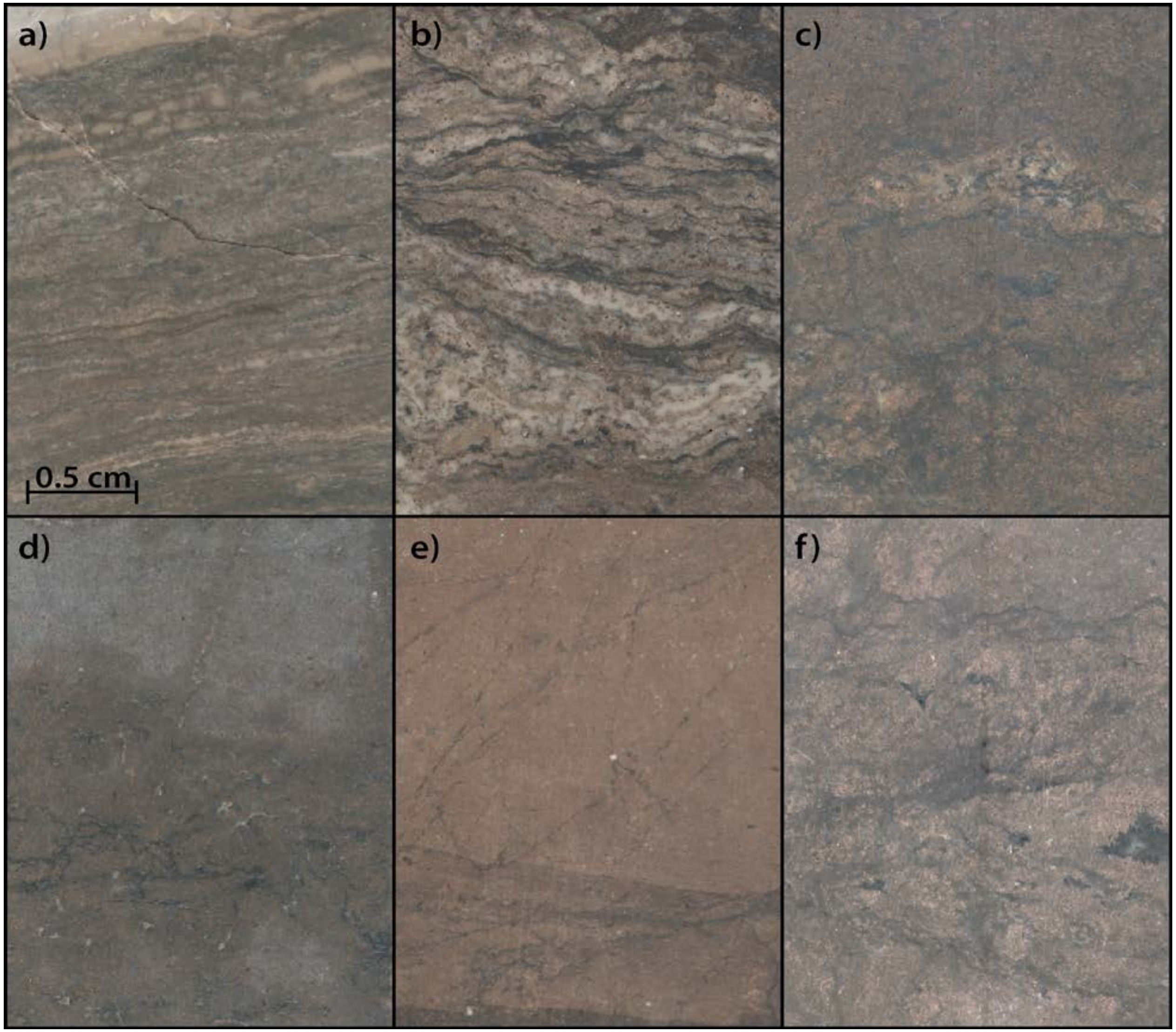
Reuning et al., GeoArabia, 2009

Stratigraphy South Oman Salt Basin (SOSB)



Modified from PETERS et al. (2003), AMTHOR et al. (2005) BOWRING (2007) and REUNING et al. (2009)

Facies‘



Microbial Laminites:

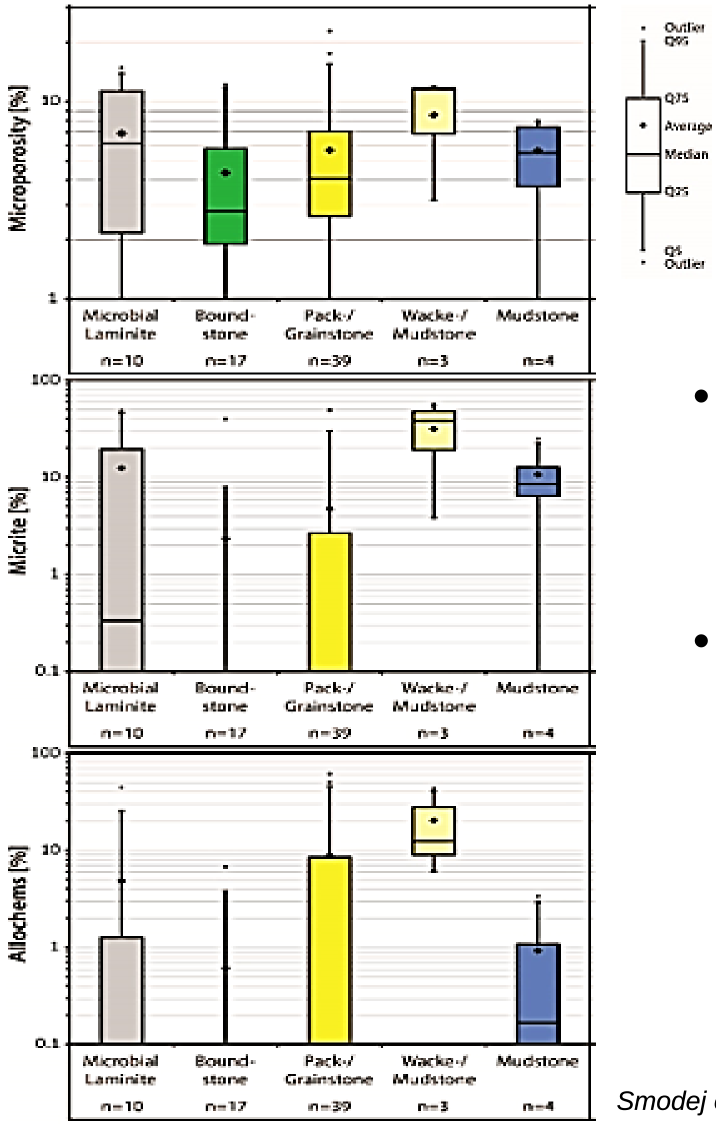
a) crinkly
b) tufted
c) brecciated

Microbial Peloids:

d, e) peloidal wacke-/mudstone

f) peloidal grainstone

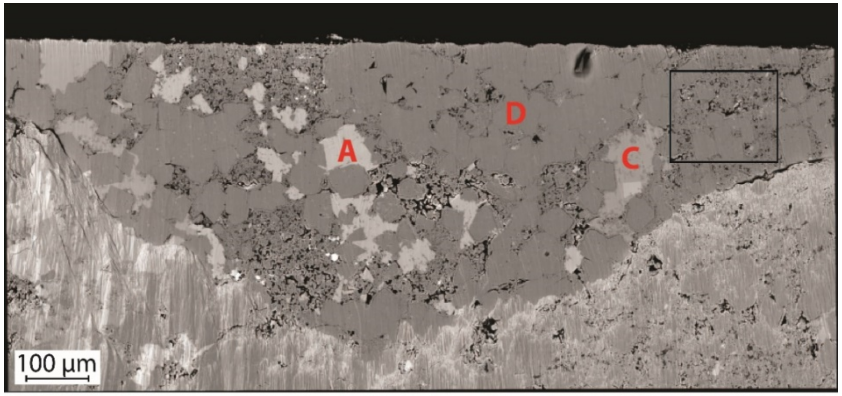
Lithotypes, Texture and Microporosity

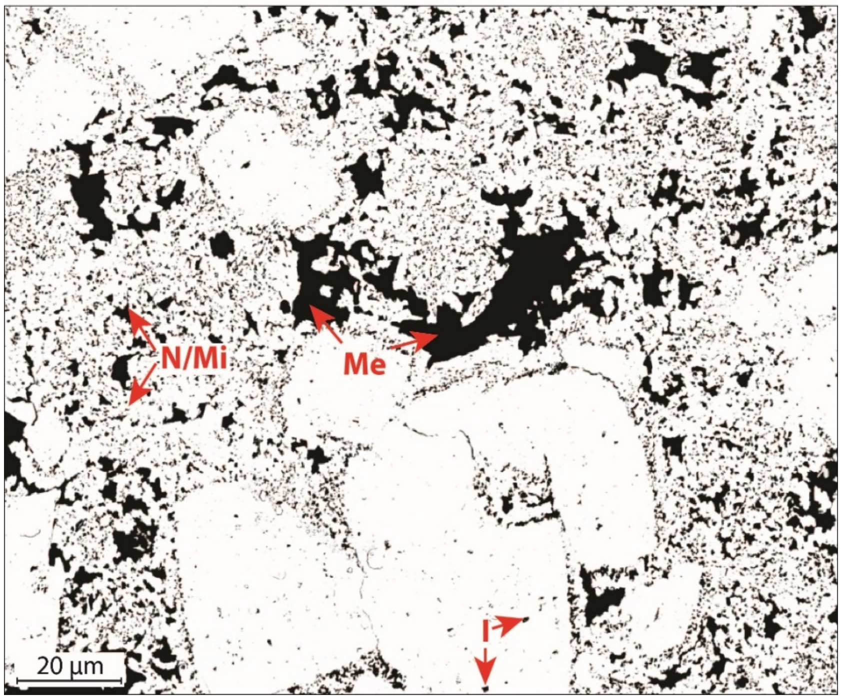


- Microporosity trends of microbial laminites and mudstones are controlled by abundance of replaced micrite
- Microporosity trends of pack-/grainstones and wacke-/mudstones controlled by abundance of allochems/grains

Smodej et al., in prep.

Microporosity in Microbial Laminite





Smodej et al., in prep.

BIB-SEM:

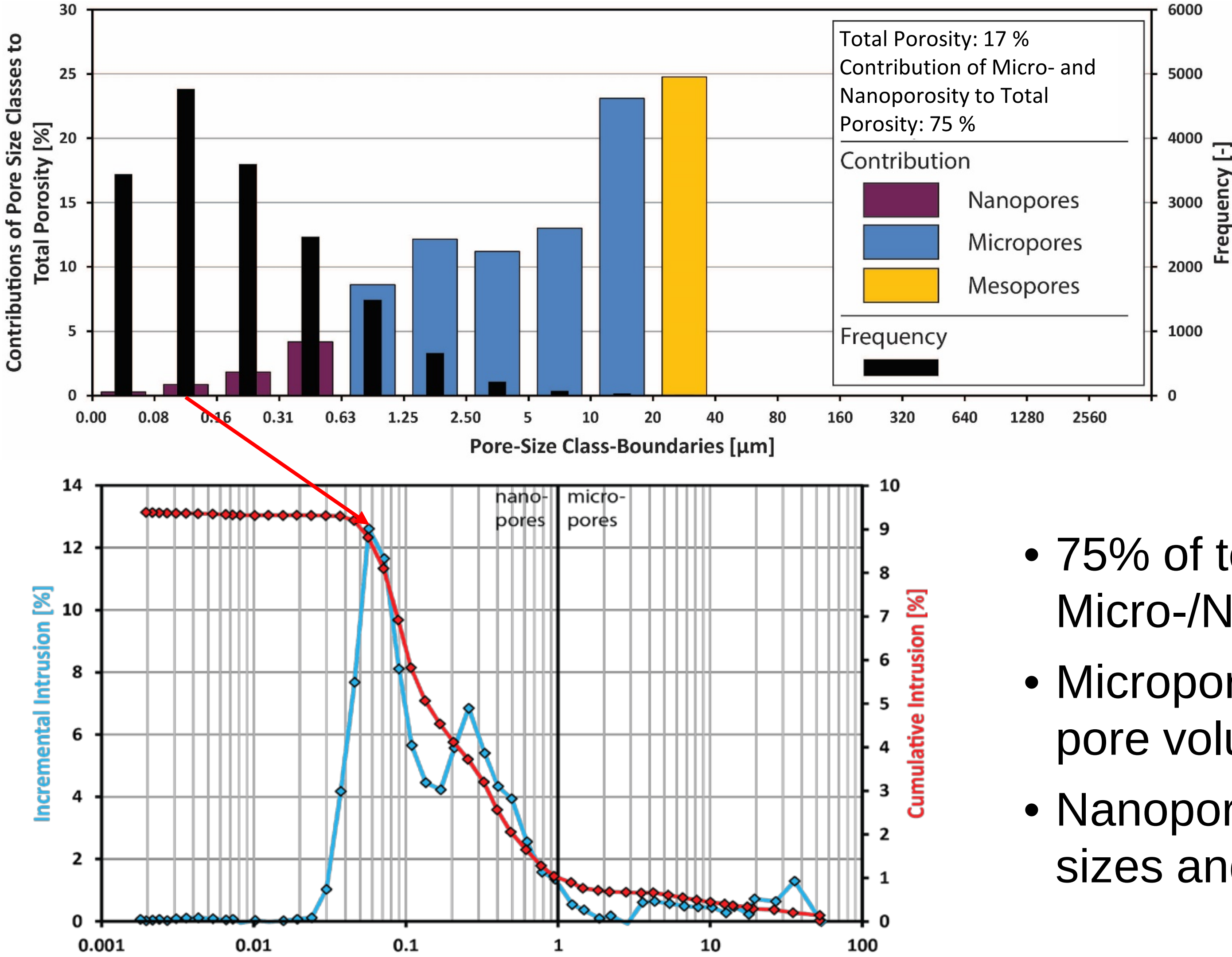
- produces smooth and planar cross-section surface
- resolves Micro-/Nanopores far below 1µm.

Microbial Laminite:

- Most of the observed Micro-/Nanoporosity is intercrystalline and hosted by aphano- and microcrystalline dolomite.

A Anhydrite
C Calcite
D Dolomite
I Intraparticle pores
Mi Micropores
Me Mesopores
N Nanopores

Pore Size Distributions in Microbial Laminite

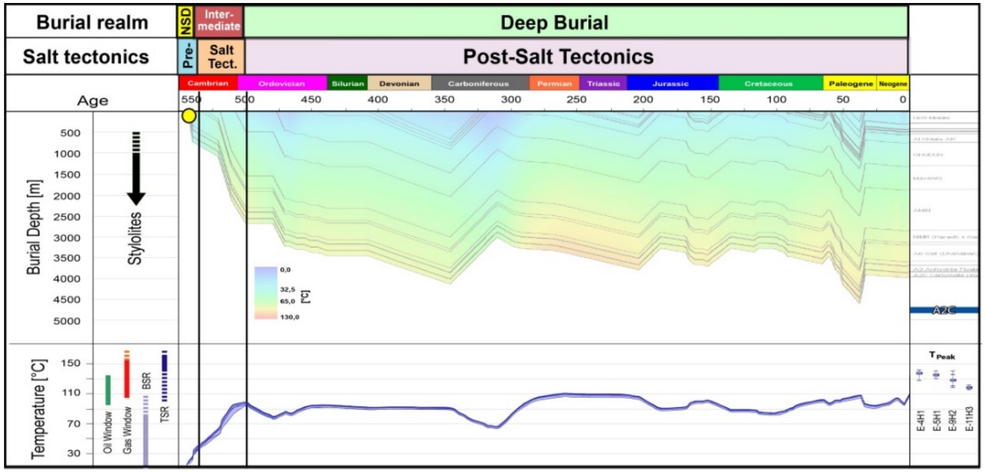


Smodej et al., in prep.

- 75% of total porosity is Micro-/Nanoporosity
- Micropores provide most of the pore volume
- Nanopores control pore throat sizes and therefore permeability

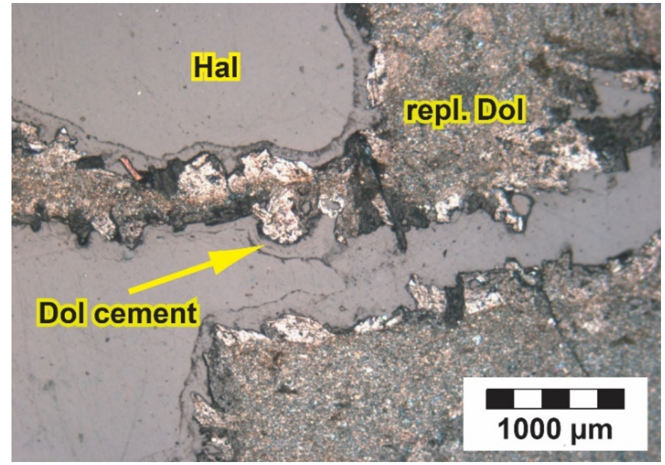
Near-surface diagenesis – carbonates completely encased in salt

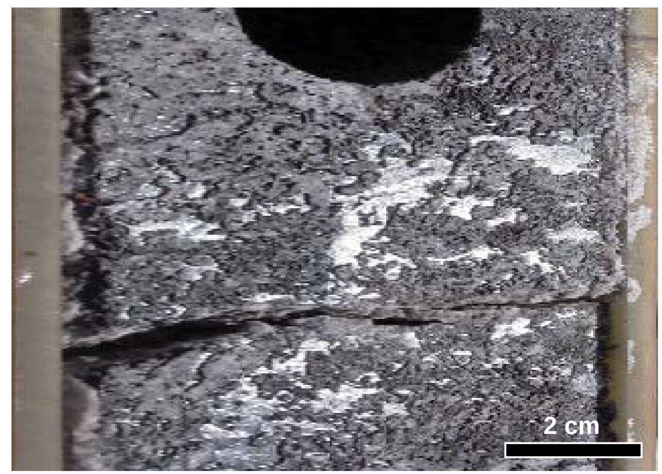
- What preserves Micro-/Nanoporosity ?



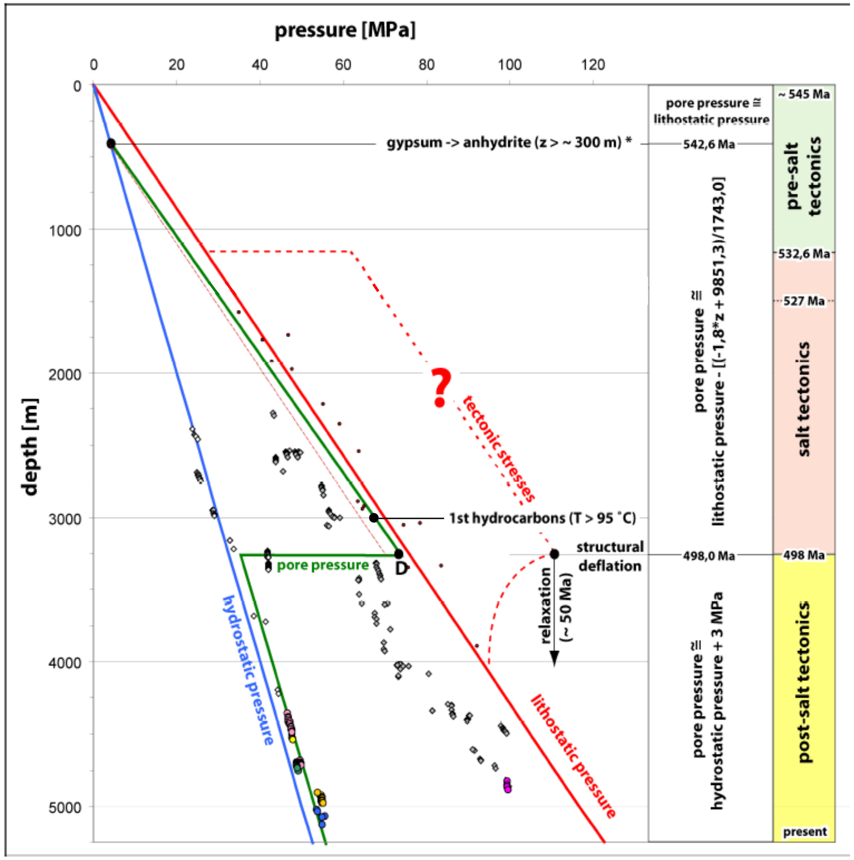
	Near-Surface	Intermediate	Deep Burial	
Product/Process	Pre-Salt Tect.	Salt Tectonics	Post-Salt Tectonic.	Effect on PoroPerm
micritisation				+/-
early marine cementation				–
(over-)dolomitisation				+/-
anhydrite replacement/cementation				–
halite cementation				–

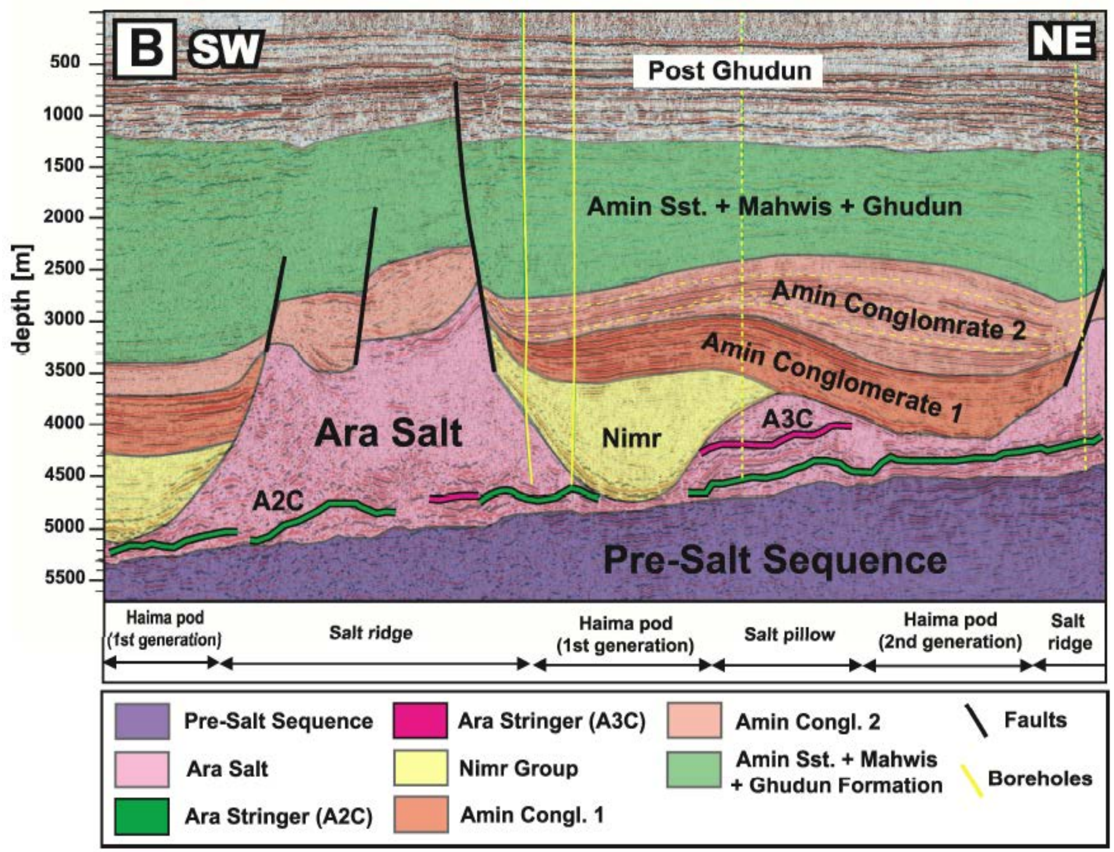
Becker, 2013





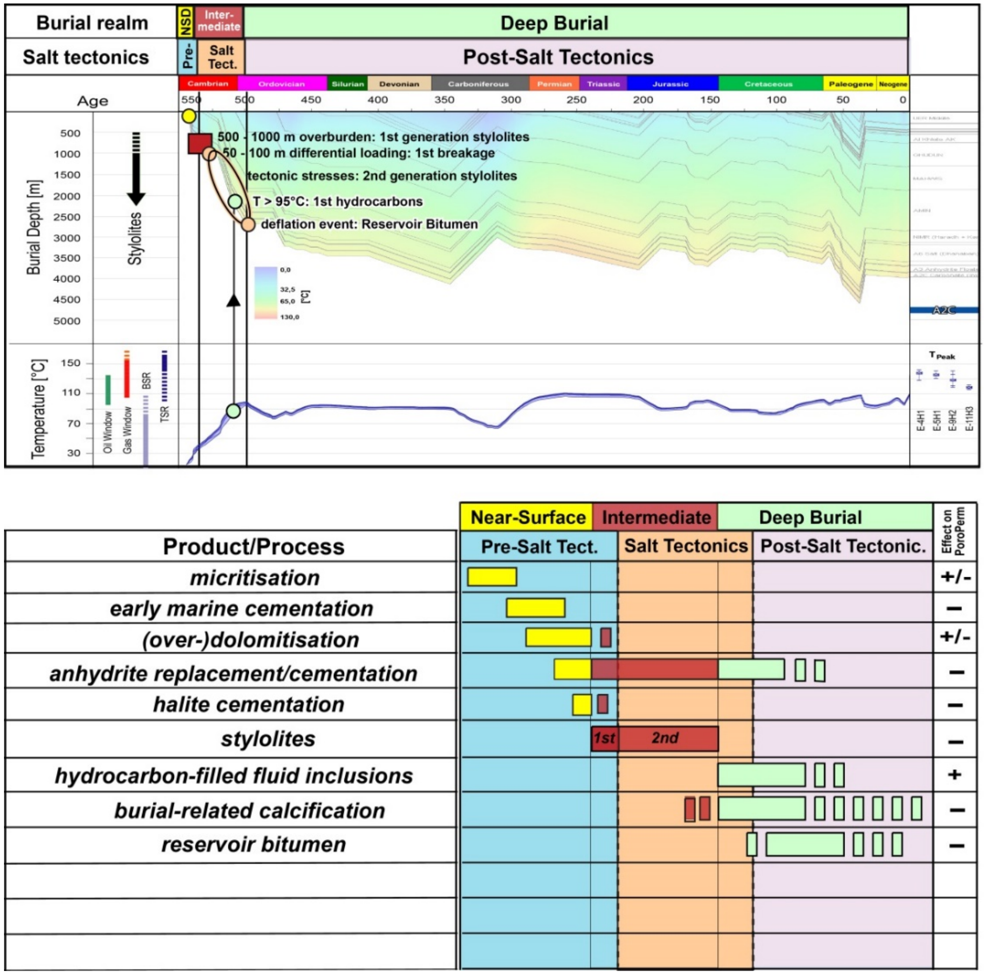
Overpressures & Hydrocarbons



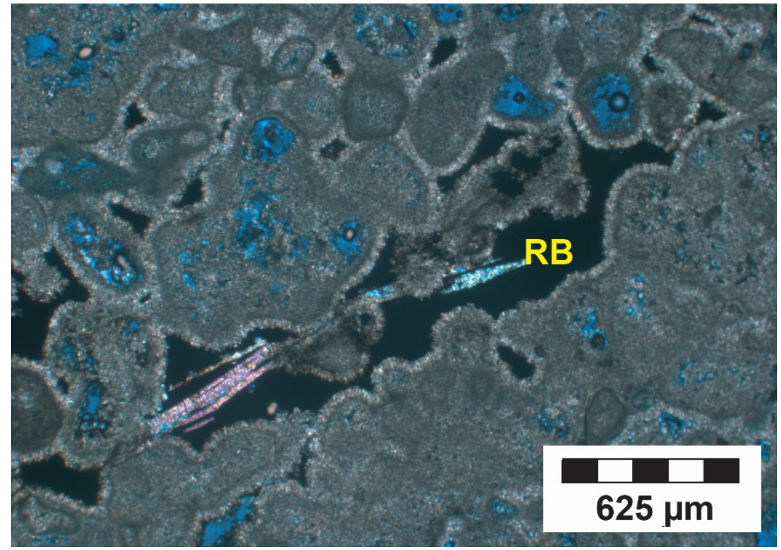


after Kukla et al., 2011

Deep burial Diagenesis – preservation of Micro-/Nanoporosity



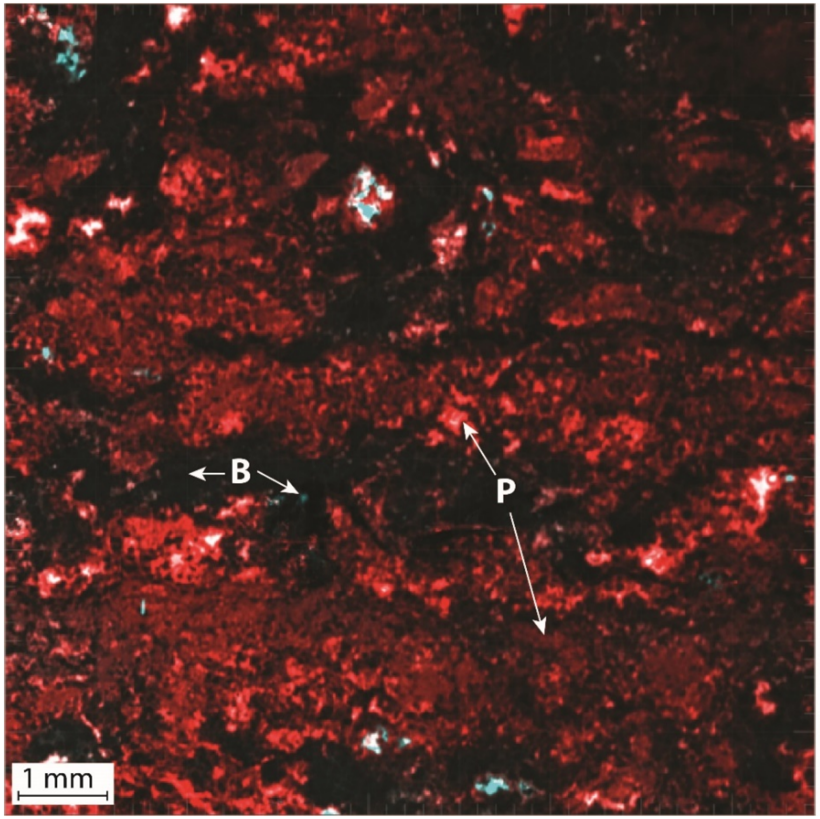
Becker, 2013

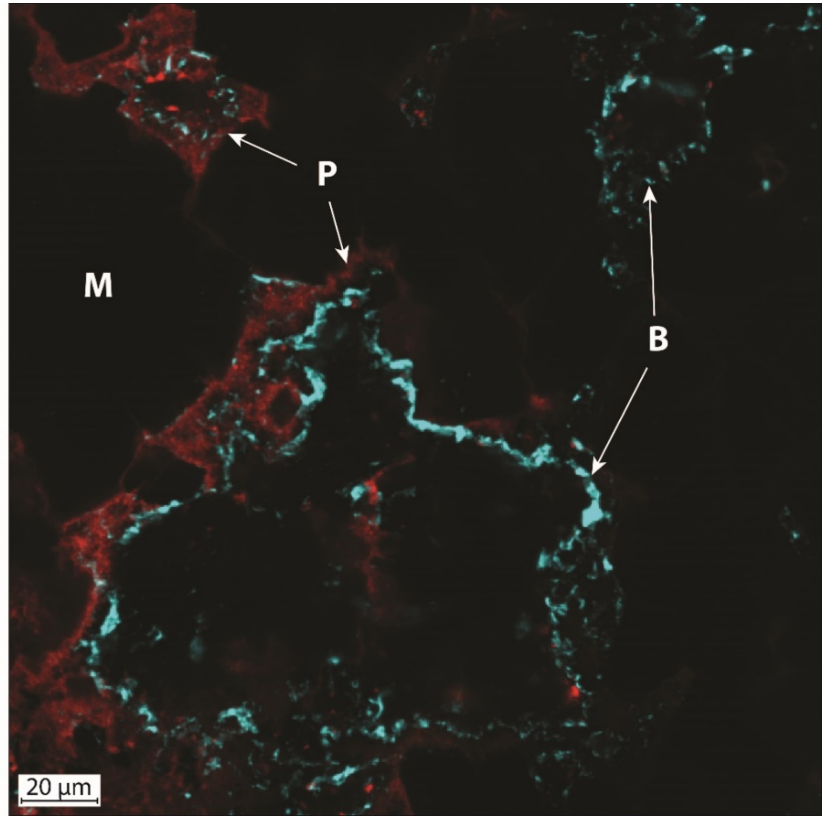


Self-charging petroleum system:

- Hydrocarbon charge and Bitumen formation in first 50 my of burial
- Early charge arrests dolomite recrystallization and contributes to further overpressure generation

Micro-/Nanoporosity and Hydrocarbons





P Pores (red)
B Bitumen (blue)
M Mineral phases (black)

Smodej et al., in prep.

Confocal Laser Scanning Microscopy:

- Imaging of Microporosity and hydrocarbon distribution on a scale from several centimetres to micrometres
- Microbial laminites show alternations of finer and coarser crystalline laminae
- Bitumen lines dolomite crystals in fine crystalline laminae ⟶ inhibiting dolomite recrystallization

Summary

Main messages:

1. Reservoir quality in Ara Microbialites determined by Nano-/Micropores:
Nanopores control permeability, Micropores provide pore volume

2. Micron-sized carbonate crystals, formed in microbial-dolomite environments, were preserved from near-surface to deep burial diagenesis in a diagenetically closed system – since 550 my & > 4 km depth.

Main controls on Micro- and Nanopores:

- Intercrystal micropores are hosted by micron-sized carbonate crystals formed in microbial-dominated Late Neoproterozoic environments.
- Early halite sealing caused a diagenetically closed system with fluid overpressures.
- Overpressures and oil charge in self-sourcing Ara carbonates minimized recrystallization of dolomite and preserved Nano-/Microporosity.

Technical Workflow:

Combination of BIB-SEM with Confocal Laser Scanning Microscopy (CLSM) enables the imaging of Nano-/Microporosity and its relationship to hydrocarbon phases.

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Shell International

Olympus

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