Petrophysical and Geomechanical Properties of Late Jurassic Carbonates Outcropping in Central Saudi Arabia: Correlation with Depositional Sequences and Diagenetic Overprints*

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Abstract

Late Jurassic carbonates of the Jubaila Formation outcrop in an almost 800 km long escarpment in Central Saudi Arabia. Near Riyadh the formation is exposed along a 1.5 km road cut, which was previously scanned by Saudi Aramco using a high-resolution Lidar survey. Our group has drilled a 37 m long core at a location 20 m behind the road cut to investigate the expression of the depositional facies in core, establish diagenesis and the associated paragenetic sequence, document naturally existing fractures and measure petrophysical and geomechanical properties of the rock. Detailed investigations of the facies successions confirm a previously reported shallow water depositional origin and cyclicity similar to that of the prolific Arab reservoirs in eastern Saudi Arabia. Early marine and burial diagenesis to a depth likely exceeding 1 km are indicated by grain micritization, cements, partial dolomitization, and pressure solution. However, a reduced porosity and permeability compared to the equivalent oilfield sequences is attributed to a late phase meteoric diagenesis, which likely affected the rock during uplift and exposure. Dual energy CT scans have been found useful for selecting representative rock type samples for further petrophysical studies and in providing 3D models of depositional and diagenetic fabric. Rock mechanical and physical analyses using triaxial tests, continuous scratch testing as well as ultrasonic measurements along the entire core interval provide insight into mechanical stratigraphy and layering that are correlated with lithostratigraphy and diagenetic intervals and are used to further constrain rock types. After characterization of their petrophysical properties through routine and special core analysis the representative rock types are to be utilized for core flood experiments.

Selected References

Cantrell, D.L., and R.M. Hagerty, 2003, Reservoir Rock Classification, Arab-D Reservoir, Ghawar Field, Saudi Arabia: GeoArabia, v. 8/3, p. 435-462.

Kendall, C.G.St.C., V. Lakshmi, J. Althausen, and A.S. Alsharhan, 2003, Changes in Microclimate Tracked by the Evolving Vegetation Cover of the Holocene Beach Ridges of the United Arab Emirates, *in* A.S. Sharhan, W.W. Wood, A.S. Goudie, A. Fowler, and E.M. Abdellatif (eds.), The Desertification in the Third Millennium: Swets and Zeitlinger Publishers (Balkema), Lisse, The Netherlands, p. 91-98.

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Website Cited

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EXHIBITION: 6 – 8 March 2018
BAHRAIN INTERNATIONAL EXHIBITION & CONVENTION CENTRE

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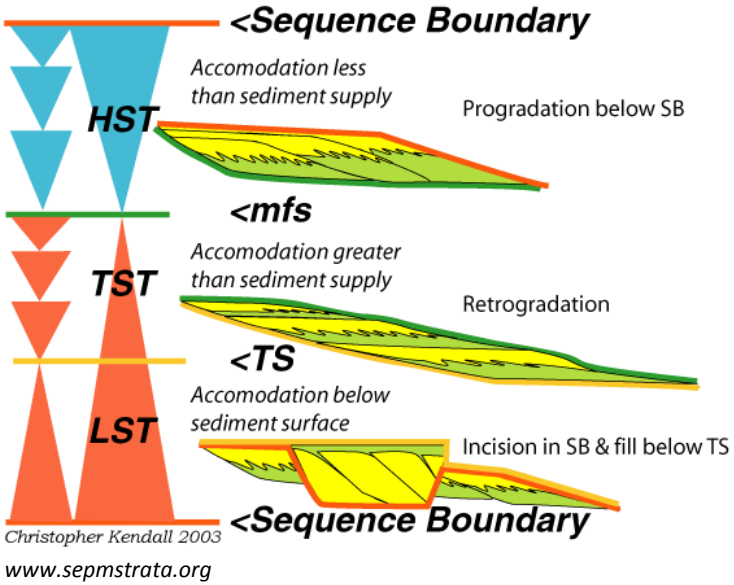
Introduction



Reservoir carbonate sequences are typically

- cyclic
- coarsening upward
- characterized by micro-pores

Development with water flooding from the flank

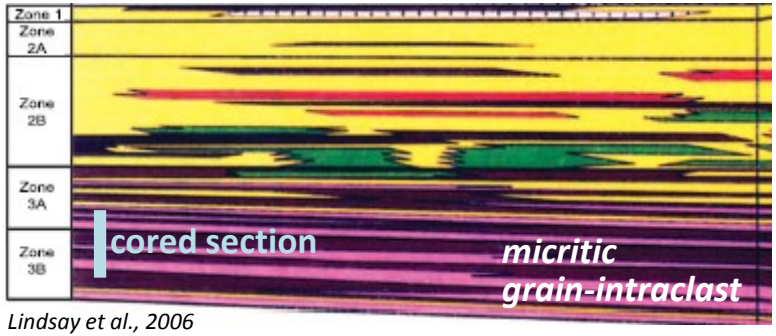
- tongue development
- water overrun at the top
- bypassed oil at the bottom

Outcrop analogue

How to access bypassed oil?

- Example: Arab-D reservoir analogue
  - Riyadh outcrop
  - Upper Jubailah Fm.
    → lower part of cycle
- Build reservoir model to find strategy for optimizing recovery

Outcrop analogue



Lindsay et al., 2006

Wackestones
Mudstones

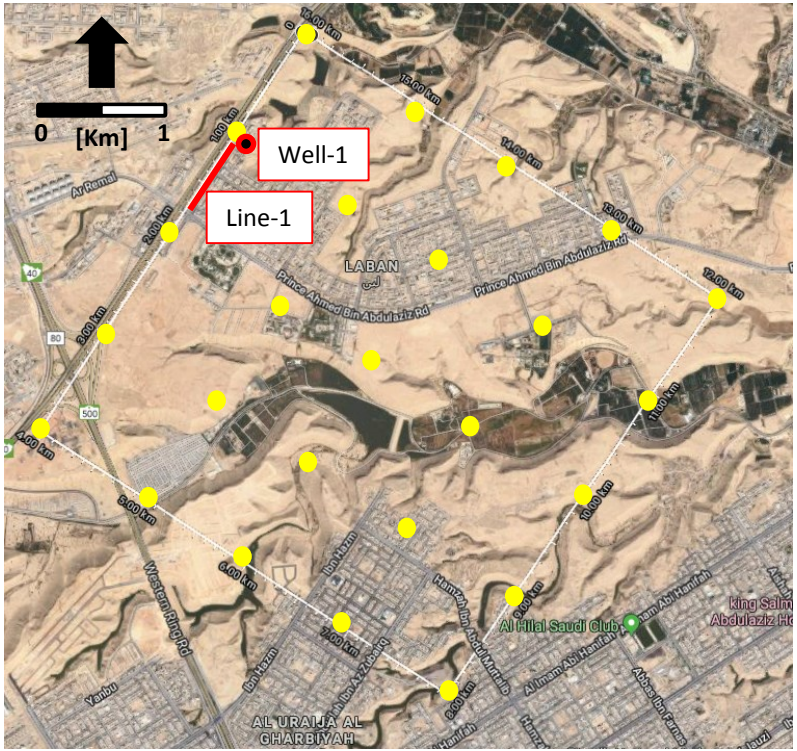
Goal

- develop workflow
- test procedures as if this would be a real development case

Analogue pitfalls / limitations:

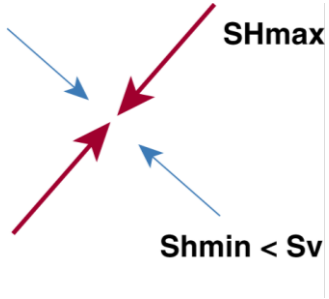
- similar depositional environment
- diagenetic overprint

Field block analogue

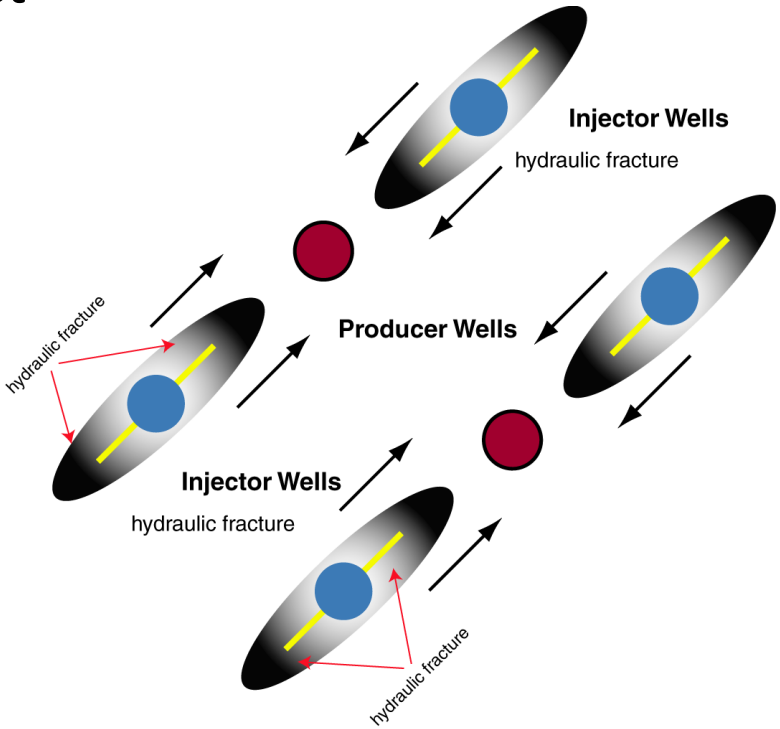


Water Flooding & Sweep Efficiency

Geomechanics impact



Poor sweep efficiency
Good sweep efficiency

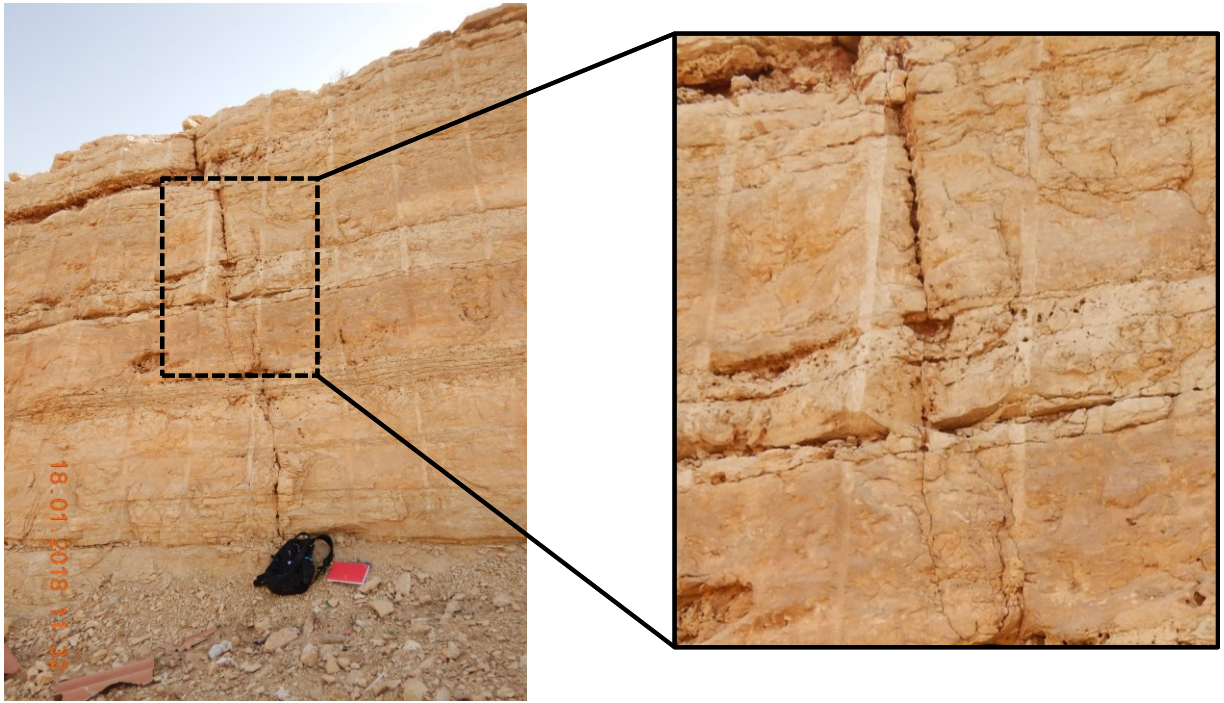


Zoback, 2006

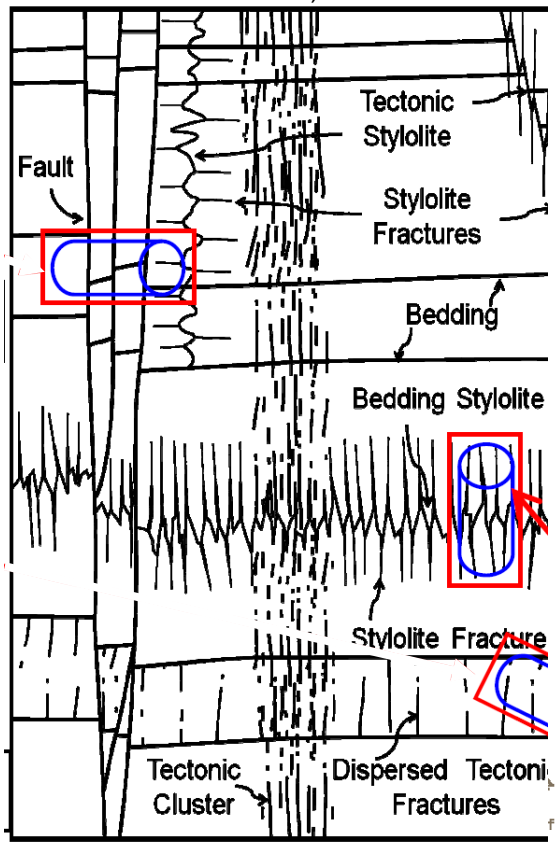
Data

- Outcrop
  - Pictures
  - Fractures
  - GR
- Seismic
- Core
  - Whole core CT scans
  - Scratch test
  - Rock mechanics
  - Acoustic
  - Plug poro-perm, MIP, SEM

Natural Fractures



MacPherson & M.S. Ameen, 2014



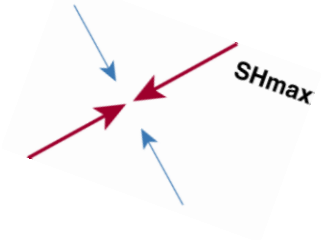
Natural Fractures

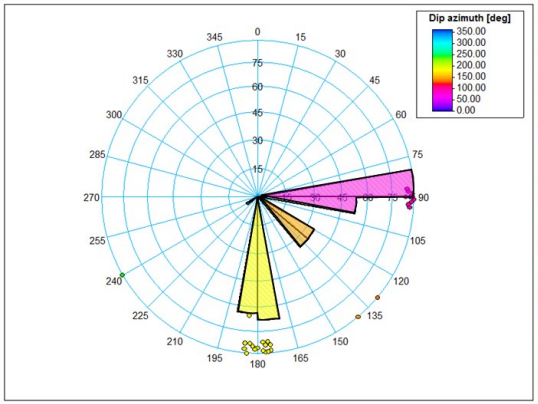
Fracture spacing: 8m – 10m

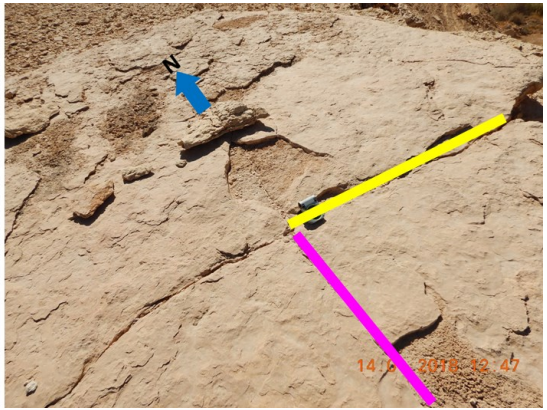
Natural Fractures

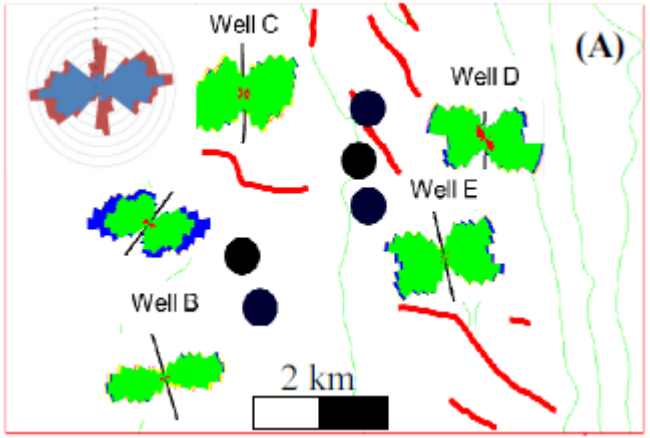
- orientations: E-W and N-S
- age of formation can be related to present day regional Arabian stress

Richard et al., 2017





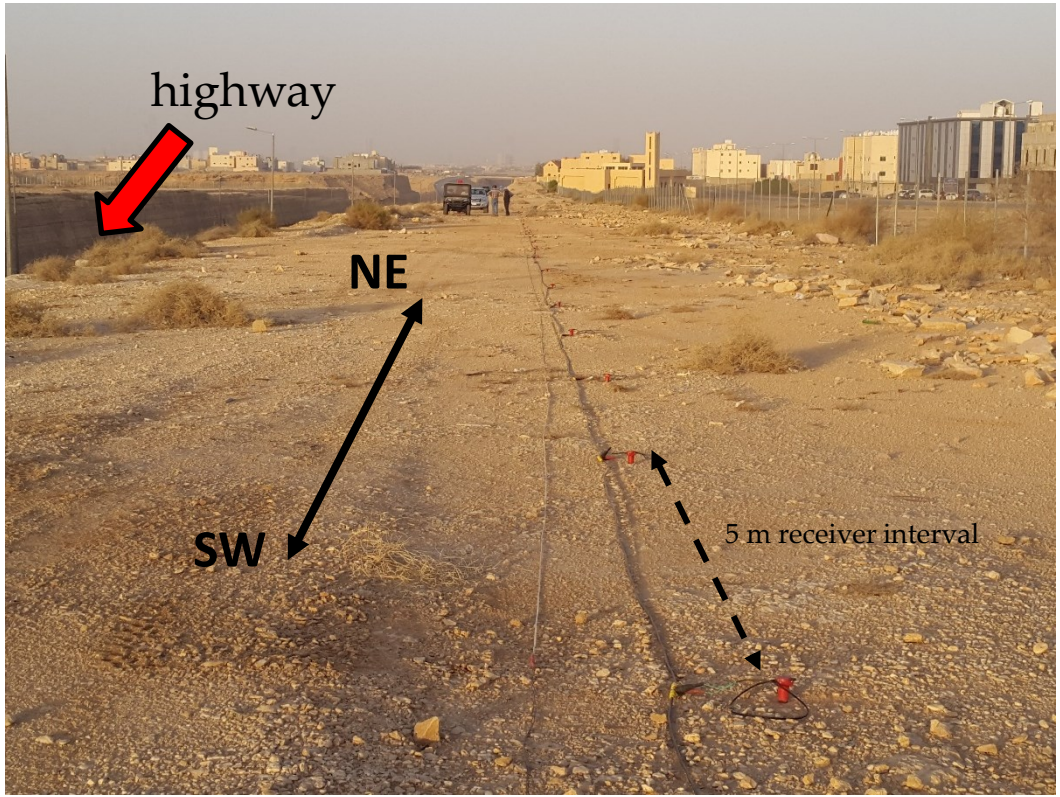




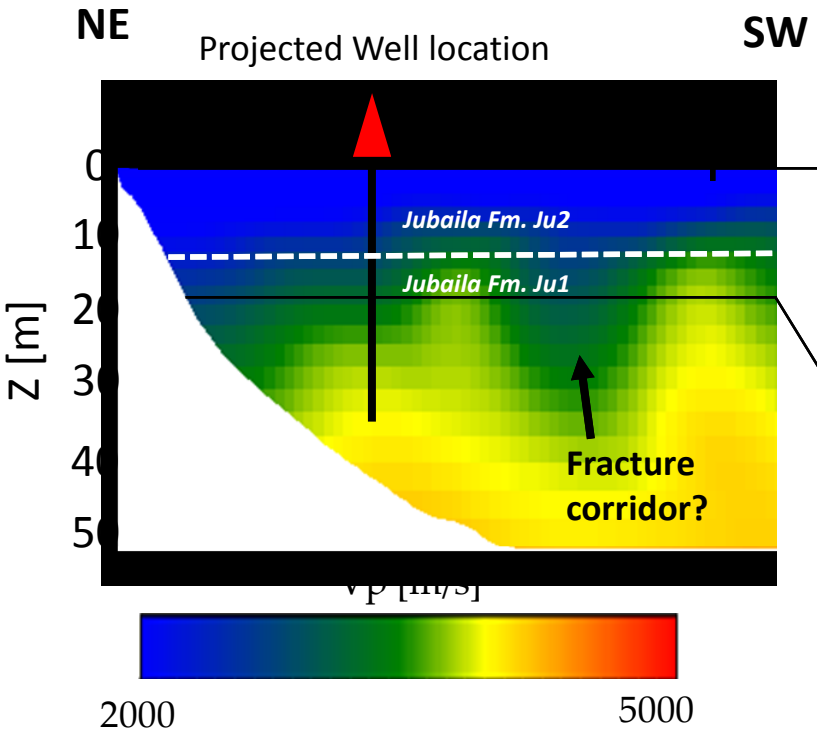
MacPherson & M.S. Ameen, 2014

Seismic Data

- Reflection seismic profile
- Refraction seismic profile

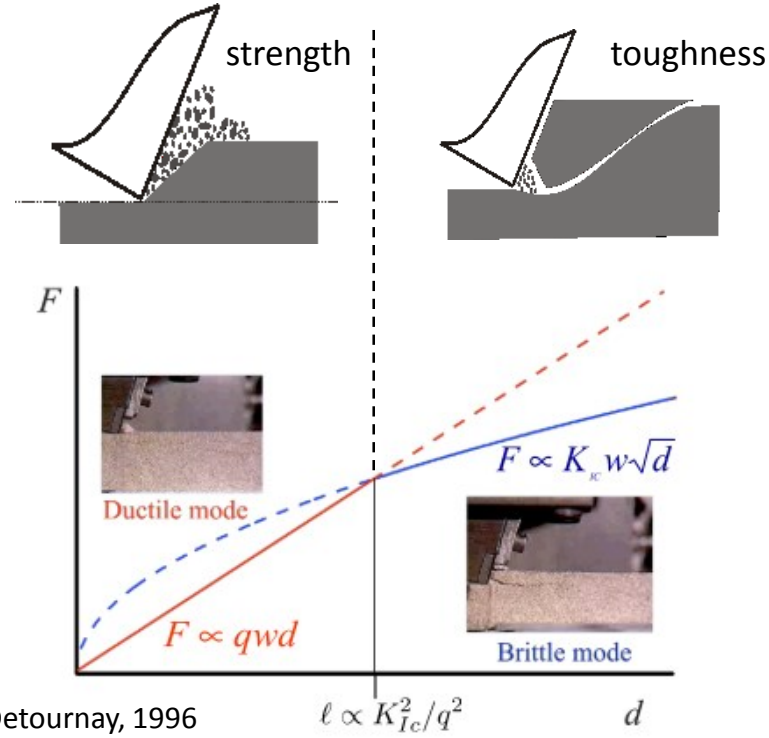


Seismic Refraction Data



Rock Strength

Scratch

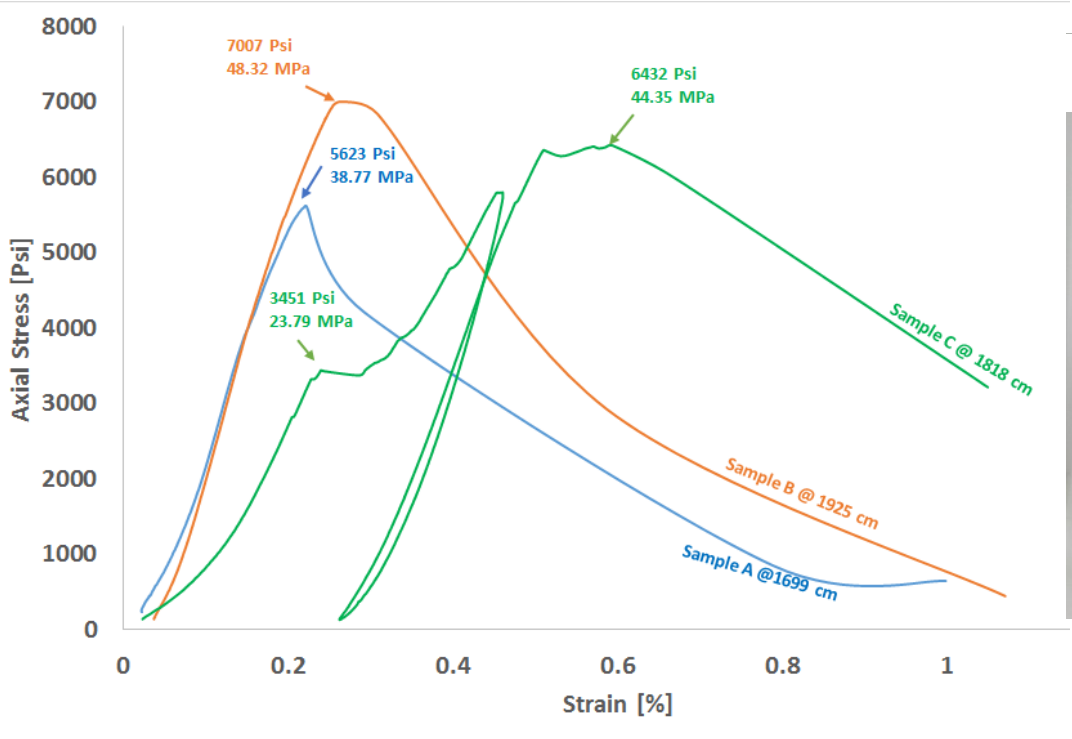


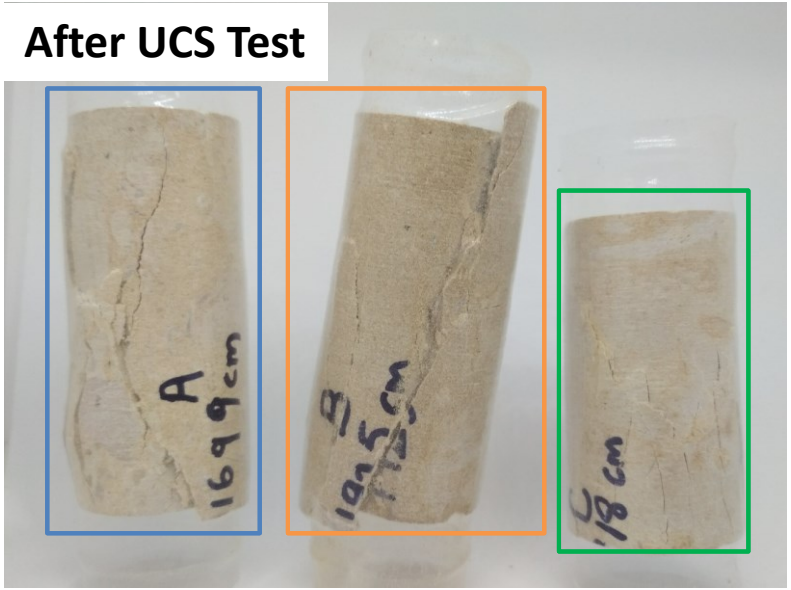
Detournay, 1996

- continuous compressive strength profile
- continuous ultrasonic acoustic profile
- optical image

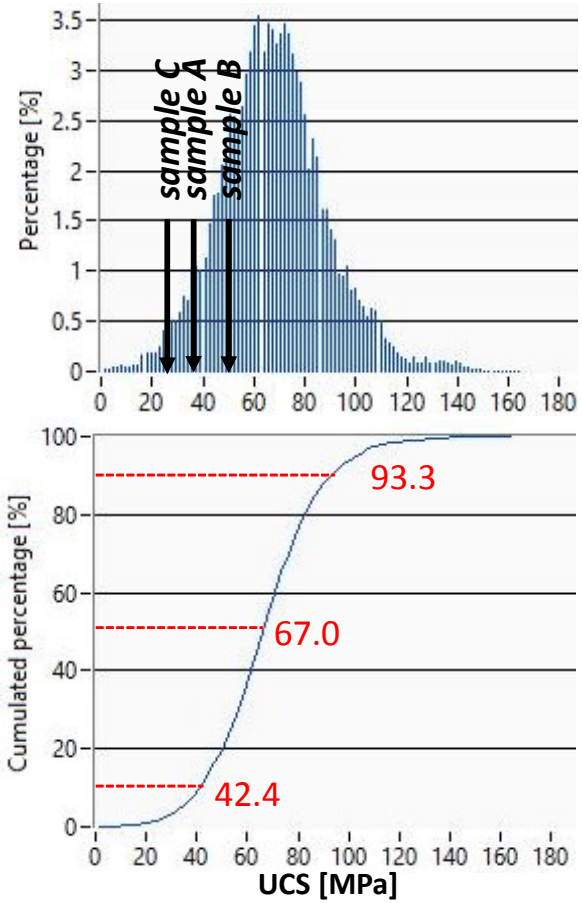
Rock Strength

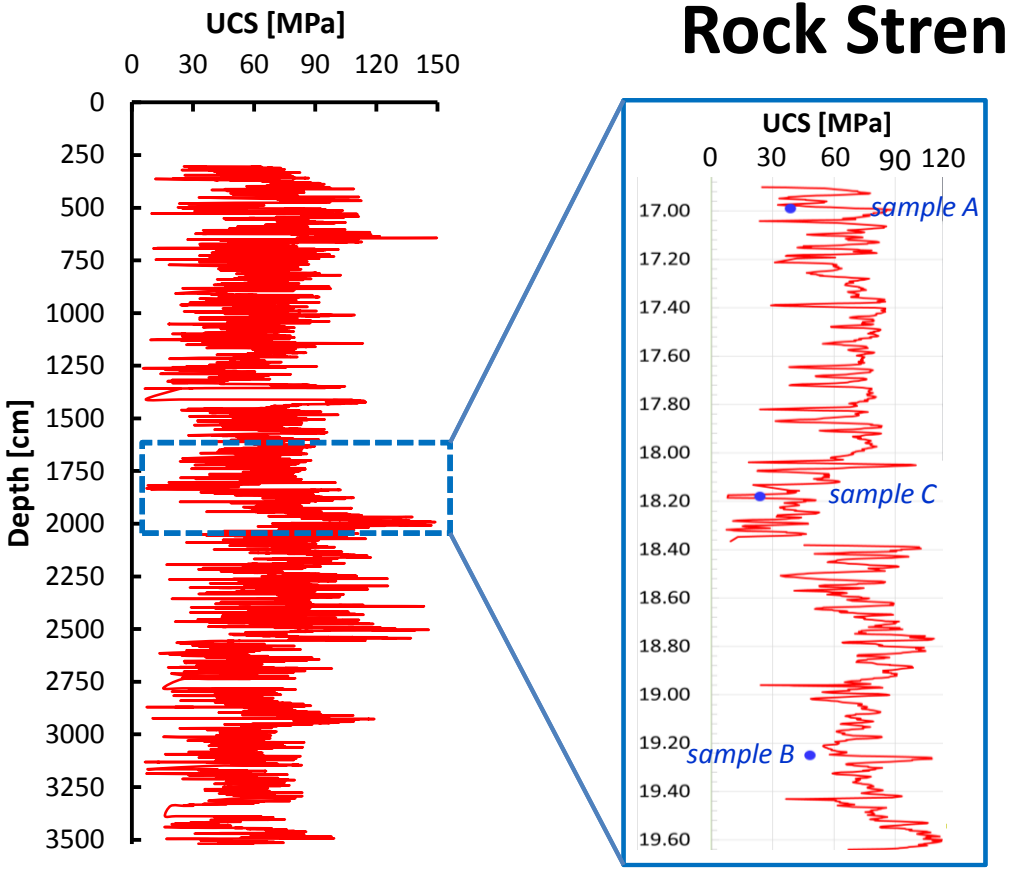
Triaxial

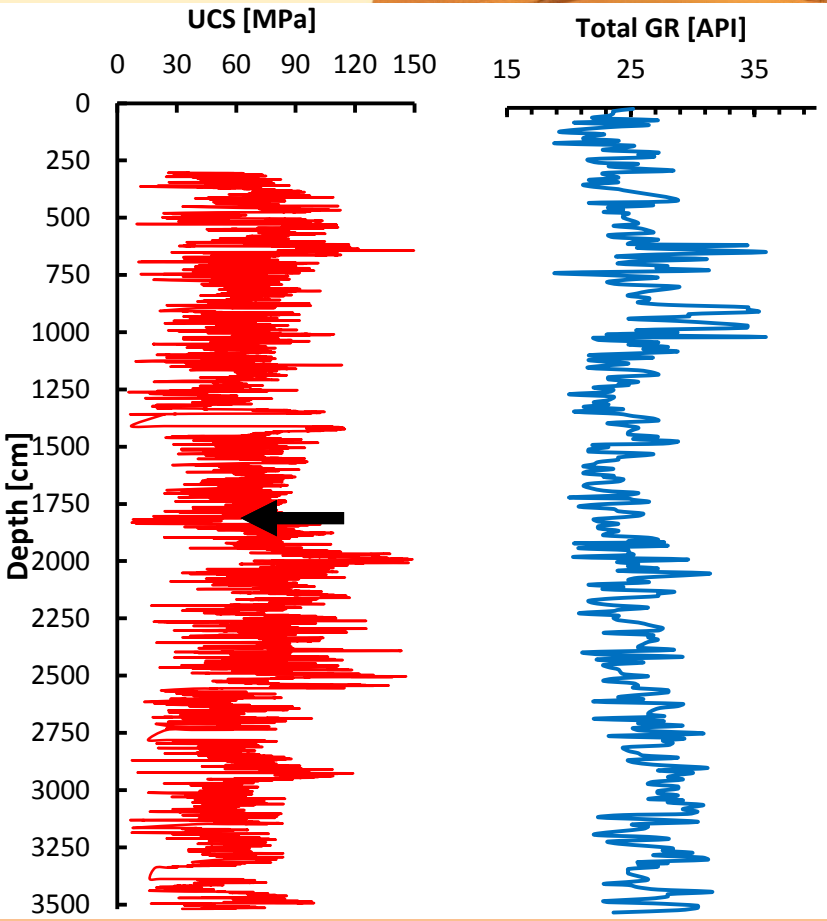


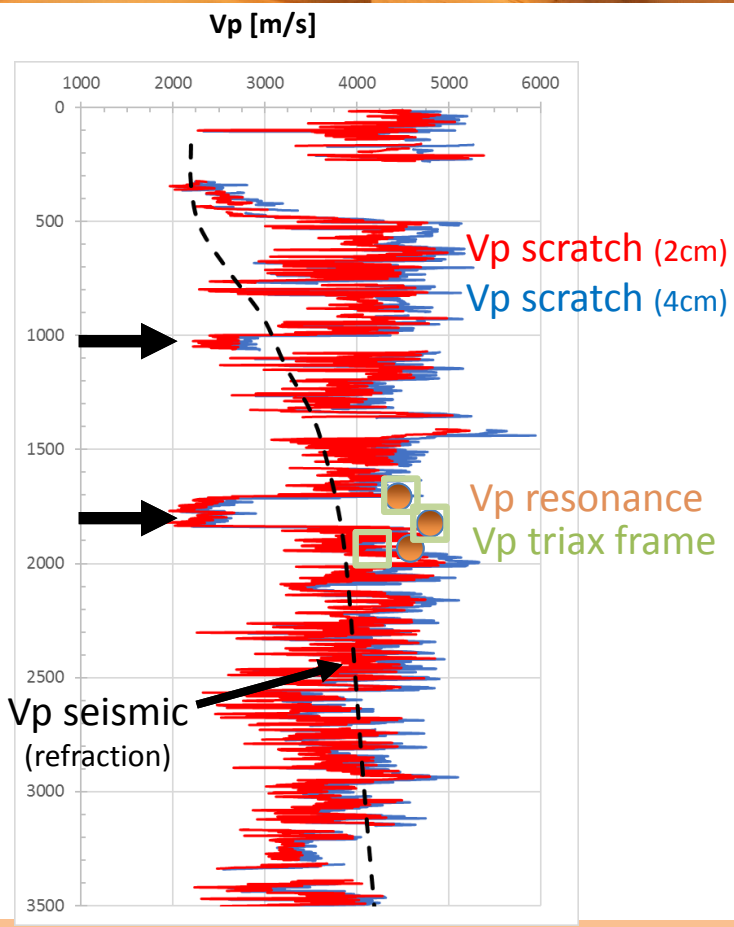


Rock Strength

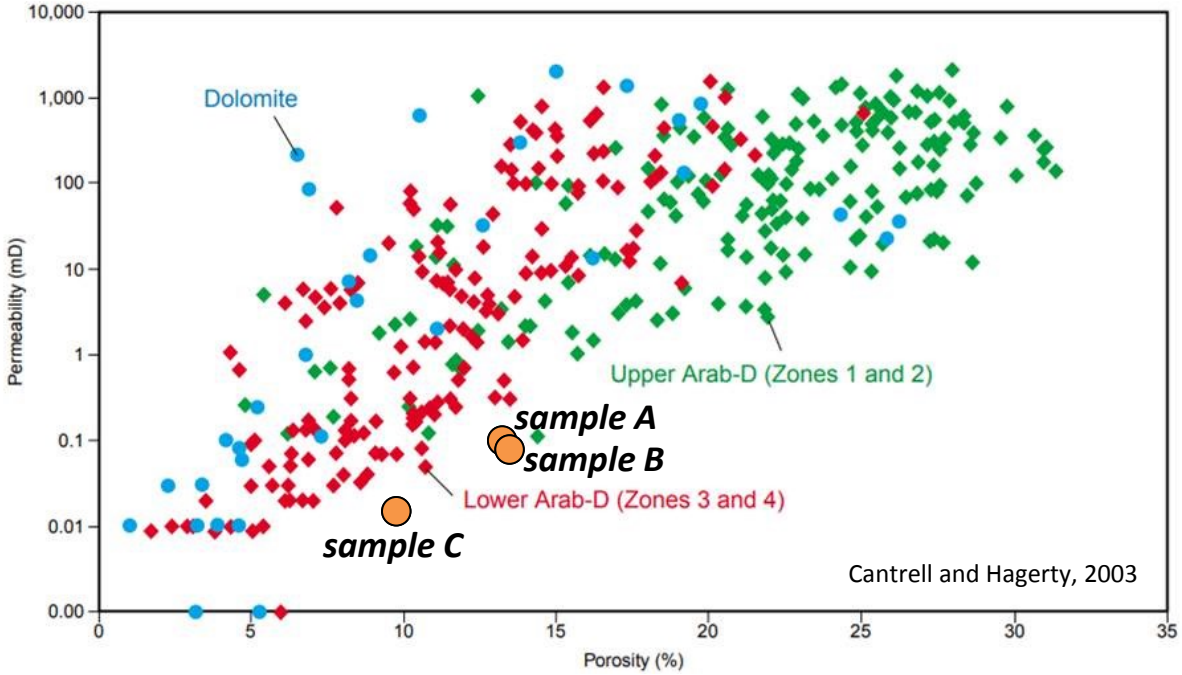




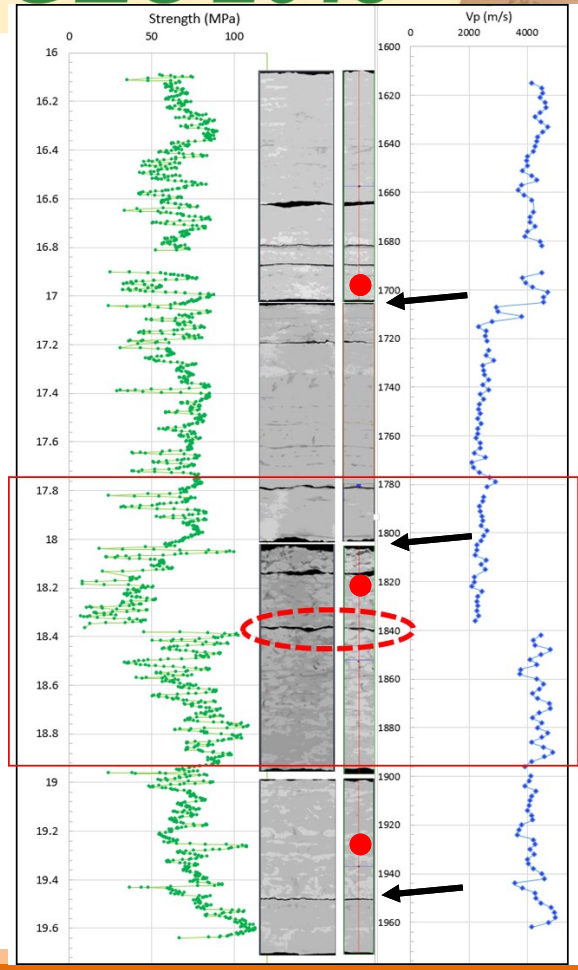

UCS [MPa]
0 30 60 90 120 150
Total GR [API]
15 25 35
Depth [cm]
0 250 500 750 1000 1250 1500 1750 2000 2250 2500 2750 3000 3250 3500


Vp [m/s]
1000 2000 3000 4000 5000 6000
0 500 1000 1500 2000 2500 3000 3500
Vp scratch (2cm)
Vp scratch (4cm)
Vp resonance
Vp triax frame
Vp seismic
(refraction)

Porosity & Permeability

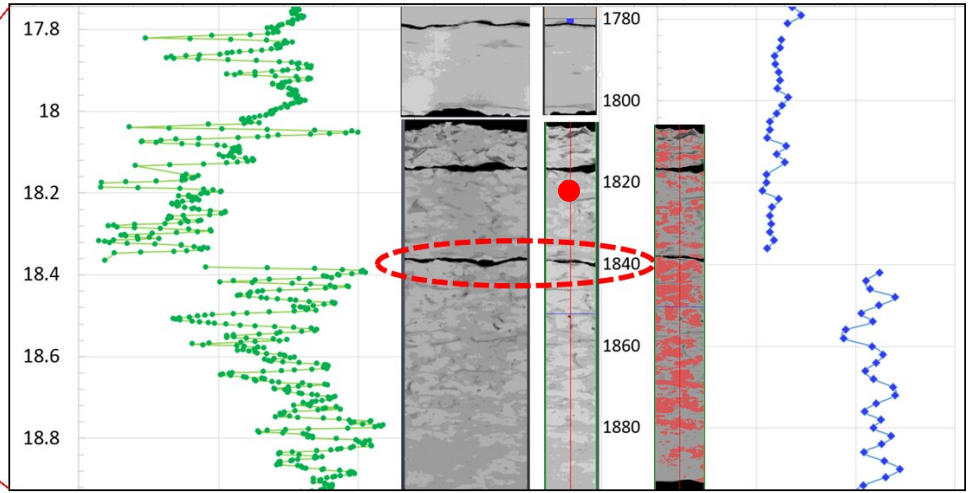


- reduction of porosity and permeability by uplift / exhumation
- for modeling a correction factor is required to bring properties in line with lower Arab-D reservoir field data (detailed petrographic evaluations such as thin sections, SEM, ...)



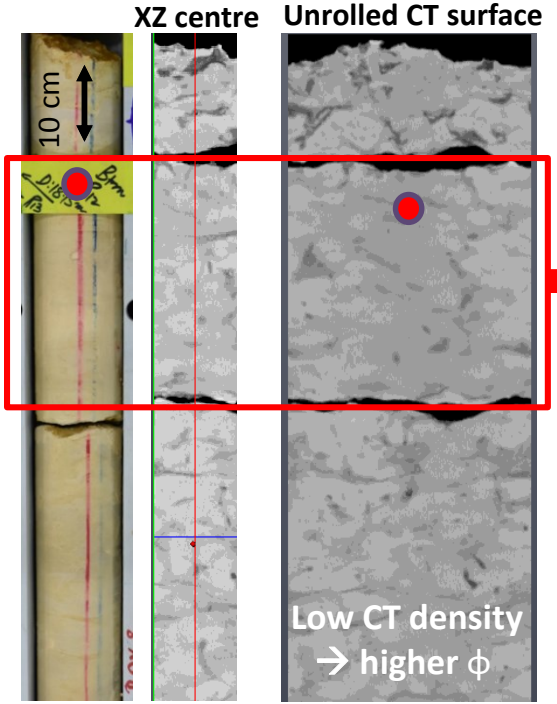
Rock physics and CT density

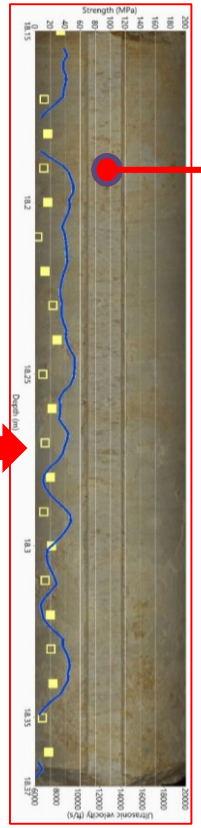
Change in rock velocity and UCS above/below stylolites
→ change in CT density
→ mechanical stratigraphy



Sample C (18.18 m)

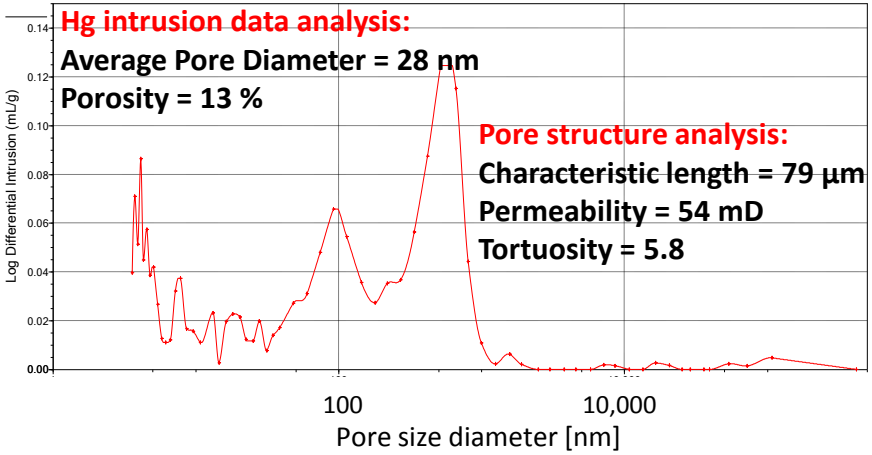
scratch UCS ~ 7MPa



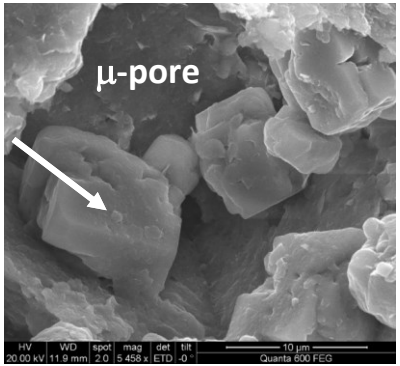


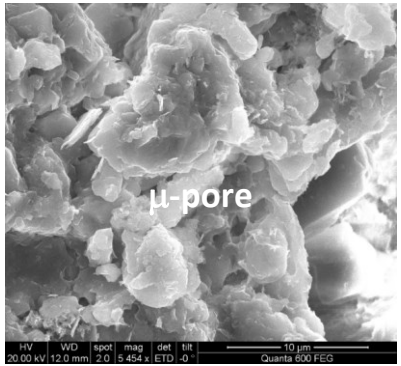
Plug:
ϕ : 10 %
k : 0.02 mD

Low tortuosity & higher perm and pore connectivity



Angular micritic grains

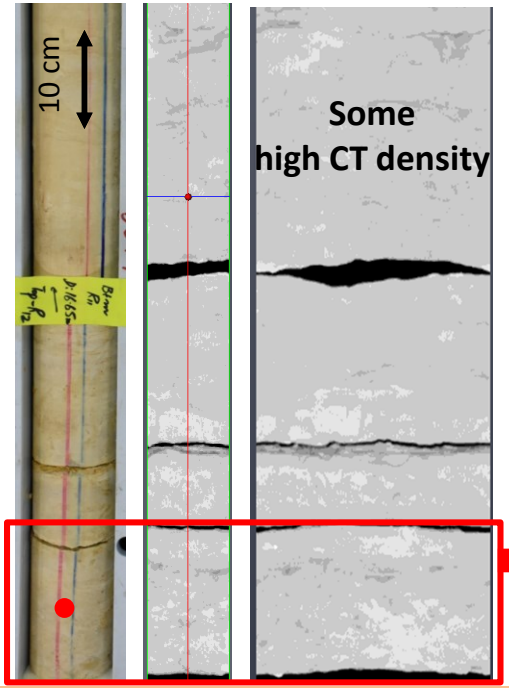


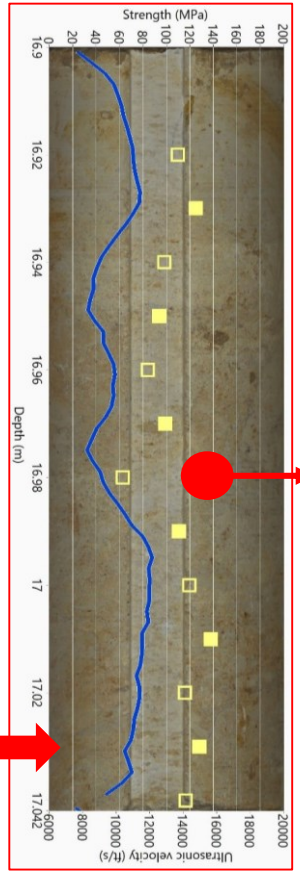


Sample B (16.99 m)

scratch UCS ~ 70MPa

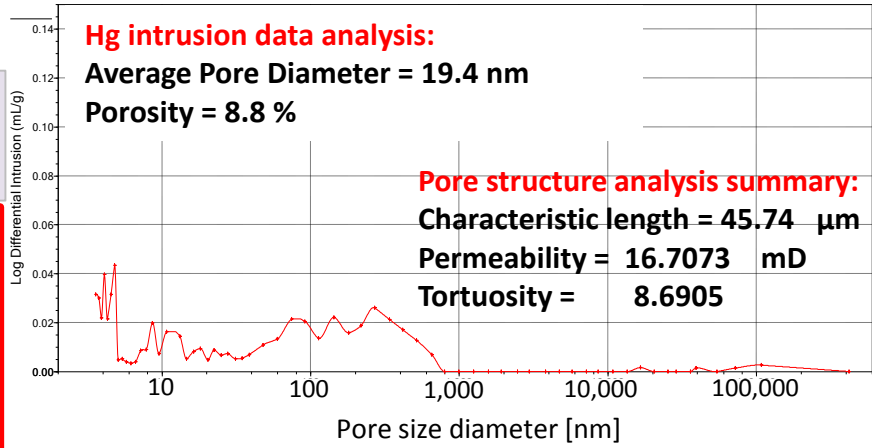
XZ centre Unrolled CT surface





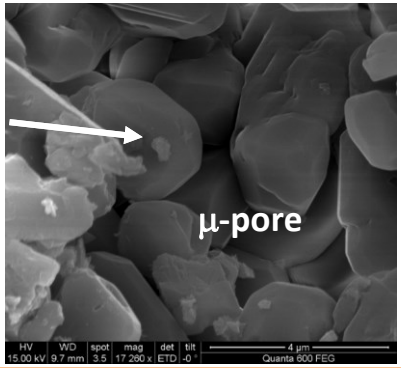
Plug:
ϕ : 13 %
k : 0.09 mD

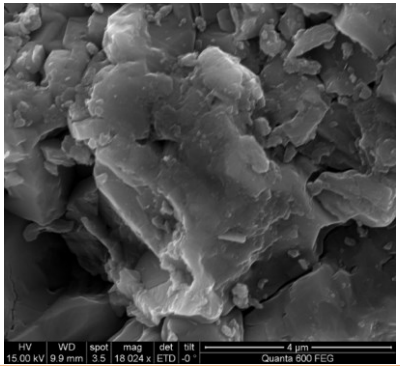
Intermediate tortuosity & perm



rounded micritic grains

tighter fabric

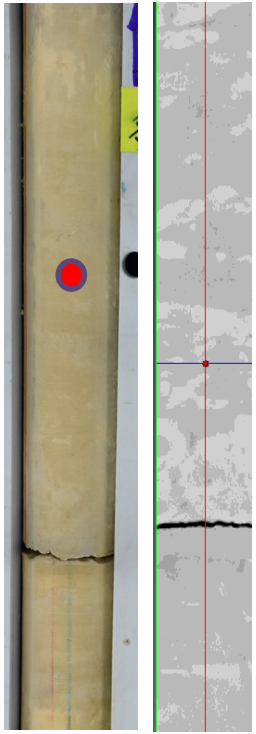


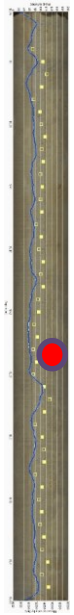


Sample C (19.25 m)

scratch UCS ~ 140MPa

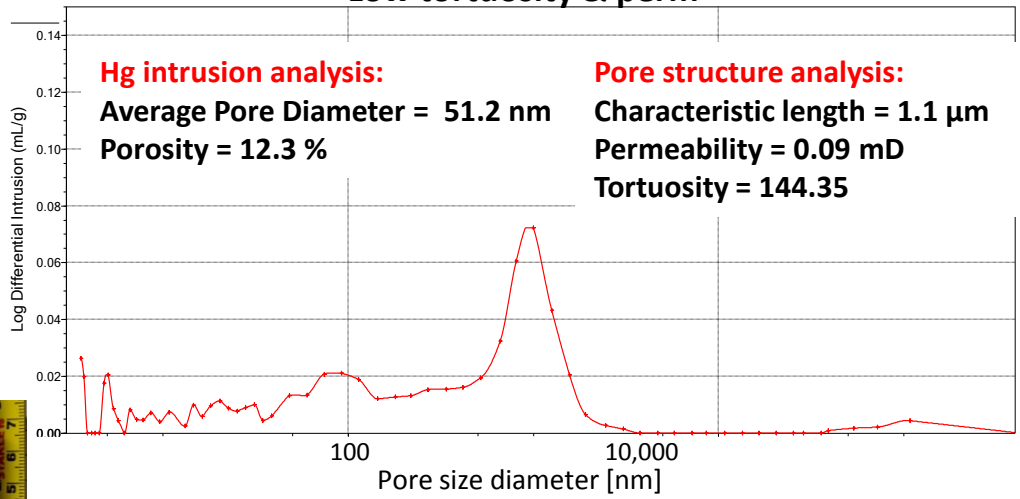
10 cm

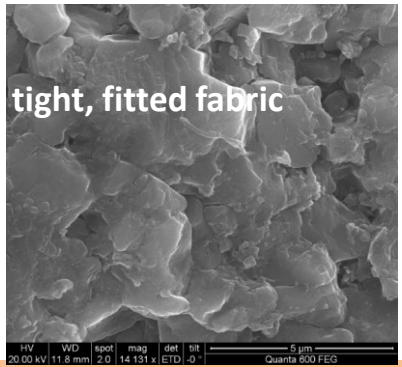


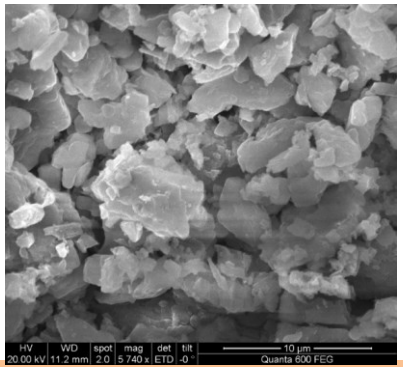


Plug:
ϕ : 13 %
k : 0.09 mD

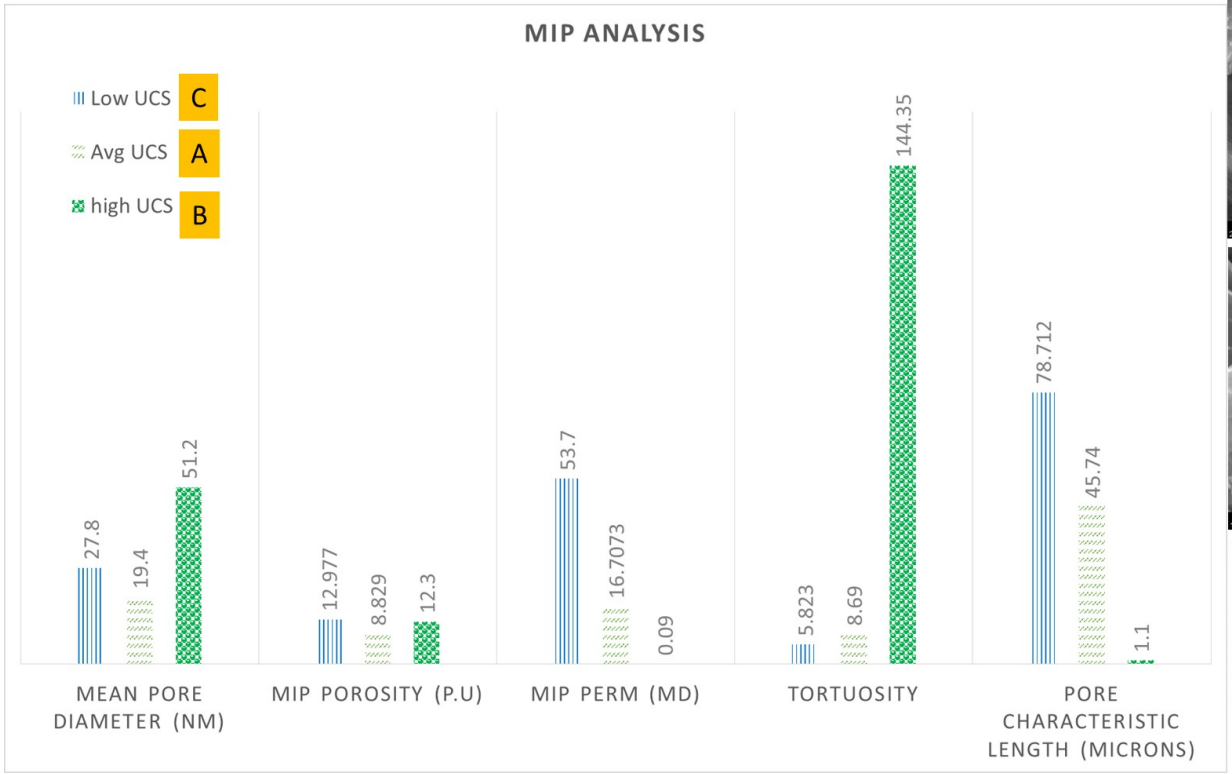
Low tortuosity & perm

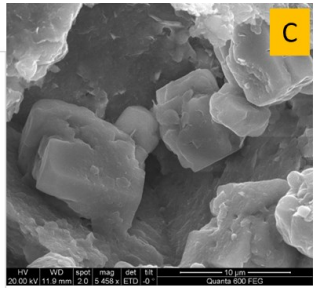




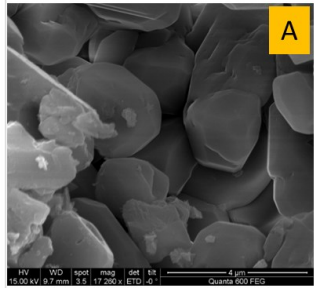


Micro pore structure and rock strength

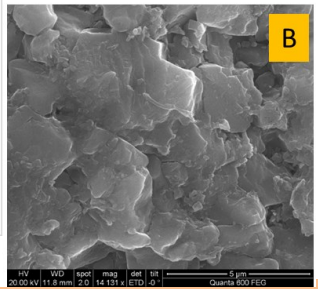




UCS= 7 MPa
Vp= 22 m/s



UCS= 80 MPa
Vp= 42 m/s



UCS= 108 MPa
Vp= 42 m/s

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Conclusions

- Mapped natural fracture corridors correlate with field observation in the eastern province suggesting they have the same origin
- Positive correlation between micro pore structure, acoustic velocity and compressive rock strength (at similar porosity values)
- CT density corroborates with the above conclusion
- Strong correlation between the occurrence of stylolites and mechanical stratigraphy
- Reduction of porosity and permeability by uplift / exposure diagenesis; modeling requires a correction factor to bring properties in line with lower Arab-D reservoir data

Next Steps

- Detailed depositional description and characterization
  - petrography
  - rock typing incl. rock physics and geomechanics
  - further refine natural fracture network and build DFN

- Analyses serve as calibration points for scenario-based reservoir analogue modeling & simulation in support of field development optimization