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

Thomas Finkbeiner¹, Viswasanthi Chandra², Volker Vahrenkamp², Bora Yalcin², Ahmad Ramdani², and Andika Perbawa²

Search and Discovery Article #51479 (2018)**
Posted May 28, 2018

*Adapted from oral presentation given at GEO 2018 13th Middle East Geosciences Conference and Exhibition, Manama, Bahrain, March 5-8, 2018
**Datapages © 2018 Serial rights given by author. For all other rights contact author directly.

1King Abdullah University of Science and Technology, Thuwal, Saudi Arabia (thomas.finkbeiner@kaust.edu.sa)
2King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

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


Website Cited

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

Thomas Finkbeiner, Viswasanthe Chandra, Volker Vahrenkamp, Bora Yalcin, Ahmad Ramdani, and Andika Perbawa
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

Goal

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

Analogue pitfalls / limitations:

- similar depositional environment
- diagenetic overprint

Lindsay et al., 2006
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
Seismic Data

- Reflection seismic profile
- Refraction seismic profile
Seismic Refraction Data

Projected Well location

Fracture corridor?

Jubaila Fm. Ju2
Jubaila Fm. Ju1

Core (35m)
Rock Strength

- Scratch
- Continuous compressive strength profile
- Continuous ultrasonic acoustic profile
- Optical image

Detournay, 1996
Rock Strength
Triaxial

After UCS Test

Axial Stress [Psi]

Strain [%]

7007 Psi
48.32 MPa

6432 Psi
44.35 MPa

5623 Psi
38.77 MPa

1451 Psi
23.79 MPa

Sample A @ 1699 cm

Sample B @ 1925 cm

Sample C @ 1518 cm

A
1699 cm

B
1025 cm

1/8 cm
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, ...)

Cantrell and Hagerty, 2003
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

Hg intrusion data analysis:
- Average Pore Diameter = 28 nm
- Porosity = 13%

Pore structure analysis:
- Characteristic length = 79 µm
- Permeability = 54 mD
- Tortuosity = 5.8

Low tortuosity & higher perm and pore connectivity

Plug:
- $\phi$: 10%
- $k$: 0.02 mD

XZ centre Unrolled CT surface

Low CT density $\rightarrow$ higher $\phi$

Angular micritic grains

$\mu$-pore
Sample B (16.99 m)

scratch UCS ~ 70MPa

XZ centre Unrolled CT surface

Some high CT density

Intermediate tortuosity & perm

Hg intrusion data analysis:
Average Pore Diameter = 19.4 nm
Porosity = 8.8 %

Pore structure analysis summary:
Characteristic length = 45.74 µm
Permeability = 16.7073 mD
Tortuosity = 8.6905

10 cm rounded micritic grains
tighter fabric

Plug:
φ : 13 %
k : 0.09 mD

μ-pore
Sample C (19.25 m) scratch UCS ~ 140MPa

Abundance of high CT density

Plug:
\[ \phi : 13 \% \]
\[ k : 0.09 \text{ mD} \]

Hg intrusion analysis:
Average Pore Diameter = 51.2 nm
Porosity = 12.3 %

Pore structure analysis:
Characteristic length = 1.1 µm
Permeability = 0.09 mD
Tortuosity = 144.35
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
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