Impact of Water Content and Saturation on Shale Strength & Stiffness

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Rationale

• Shale properties poorly understood and hard to measure
• Upsurge in interest recently
• Treat as conventional?
• Or worse.......

• Why saturation?:
  • Effect on strength
  • Affects elastic moduli/stiffness, static & dynamic
  • Changes microstructure & PSD

• Highlight Preservation
• Gas shales partially saturated
Impact of water content: full saturation

- Experimental data
- $y = 1.98 \times ^{-1.03}$
- $R^2 = 0.89$, $aR^2 = 0.89$
Impact of water content: full saturation

Redrawn from Dusseault et al., (1999)
Impact of water content: partial saturation

Redrawn from Nagra, 2002.
Objectives

- Whole project: Investigation of Interfacial Phenomena in Shales
- This Pilot Study: Impact of drying on rock properties.
- Test static rock strength, stiffness, wet and “dry”
- Calculate P and S-wave velocity and moduli, wet and “dry”
- Evaluate petrophysical properties, wet and “dry”
- Some initial implications
1a. Whole core x-ray CT
1b. x-ray CT of plugs
Plugs cut, preserved under oil

2a. Low field NMR: $T_1$, $T_2$ Diffusion
2b. High field NMR: solid state and surface interactions

5a. Ultrasonic Vp, Vs
5b. Acoustic emission

3. Electrical Impedance Spectroscopy
4. Dielectric Spectroscopy

6. X-ray microtomography

7. Electron Microscopy & FIB-SEM

8. Mercury injection porosimetry
9. Gas adsorption isotherms

Resination, polishing

Offcuts and end pieces divided

Selected cuttings powders and pastes

Intact pieces

10a. CEC, XRD, XRF
10b. Ethylene glycol surface area

11. Dielectric analysis of paste
The Shales: Officer Basin

- Laminated Proterozoic shales
- Dominated by quartz, orthoclase and illite
- CC ~ 30-35%; CF ~ 30%; φ ~ 5-6%; w = 2-3%
- Essentially hard, low porosity shales
The Drying

- Drying in vacuum oven at 70°C for 1 week plus

![Graph showing CPMG - T2 decay curves for Lancer-1 Preserved Shales and Vacuum dried Shales NMR Raw data.](image)
The Drying

- Drying in vacuum oven at 70°C for 1 week plus
Results: Strength testing

Strength similar but E larger when dry

- 4.9 GPa
- 5.8 GPa

Triaxial Compressive Strength (MPa)

Angle (degrees)

Redrawn from Vales et al., 2004
Results: Dynamic properties
Literature: Dynamic properties

Redrawn from Ghorbani et al., (2009)

![Graphs showing Normalised $V_p$ and Normalised $V_s$ vs Water saturation (%)](image-url)
Low Frequency Tests at ETH

• Bongabinni
  • Clay fraction (< 2 µm) = 25%
  • Clay content (clay minerals) = 40-45%
  • Water content = 4-5% (drying and NMR)
  • Porosity = 8-11% (5-6% by MICP)
  • Pore fluid salinity = ~600g/l

• Goldwyer
  • Clay fraction (< 2 µm) = 30-50%
  • Clay content (clay minerals) = 20-75%
  • Water content = 3-4% (drying and NMR)
  • Porosity = 7-11% (4-8% by MICP)
  • Pore fluid salinity = 350-500g/l
Results: Low Frequency

Water Loss
V: 2.1%
H: 3.7%
Results: Low Frequency

![Graph showing phase shift (rad) vs. frequency (Hz) for wet and dry conditions.](attachment:graph.png)
Implications: Preservation, Gas Shale and Clays

• Preserved water content important for rock properties

• Stiffness, strength can be affected significantly, e.g.:
  • Stress dependent permeability on dry samples
  • Increasing strength/velocity with inc clay content in dry samples
  • Comparing dry shale to in situ logs/conditions
  • Estimation of stiffness assuming constant saturation

• For preservation: think human impact before geological interpretation

• For gas shale, saturation variable, impact on strength/stiffness predictions??
Preservation of Carbonates!!!
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