Fracture behavior across interfaces in seal lithologies

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Fracture behavior across interfaces in seal lithologies

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Elizabeth Petrie, James Evans, Tamara Jeppson
Objectives

- Field observations used to characterize the variability in fracture patterns across lithologic boundaries
  - provide a comparison between two different seal lithologies, structural settings and interface types
  - natural analogs of failed seals and potential sequestration reservoir seal pairs

- Dynamic elastic moduli estimates from wire line logs
  - variability in dynamic elastic moduli within seal facies
  - tie subsurface to outcrop observations

- Provide data for modeling the mechanical response of seals and existing discontinuities to increased pressure
Comparison of two reservoir seal pairs

<table>
<thead>
<tr>
<th>Geologic Time Scale Ma</th>
<th>Generalized Stratigraphy</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>Mesaverde</td>
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<tr>
<td></td>
<td>Mancos</td>
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<tr>
<td></td>
<td>Dakota</td>
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<tr>
<td></td>
<td>Cedar Mountain</td>
</tr>
<tr>
<td>145</td>
<td>Morrison</td>
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<td></td>
<td>Entrada</td>
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<tr>
<td>Jurassic</td>
<td>Carmel</td>
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<tr>
<td></td>
<td>Navajo</td>
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<tr>
<td></td>
<td>Kayenta</td>
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<td></td>
<td>Wingate</td>
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<td>200</td>
<td>Chinle</td>
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<td>Triassic</td>
<td>Moenkopi</td>
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<td></td>
<td>Black Box Dolomite</td>
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<tr>
<td></td>
<td>White Rim</td>
</tr>
<tr>
<td>255</td>
<td>Organ Rock</td>
</tr>
<tr>
<td>Permian</td>
<td>Cedar Mesa</td>
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<tr>
<td></td>
<td>Honaker Trail</td>
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<tr>
<td></td>
<td>Paradox</td>
</tr>
</tbody>
</table>

Green River

Carmel Formation

Organ Rock Shale

Utah State University
Fracture morphology

From: Sibson, 2003

From Cooke et al., 2006

From Larsen et al., 2010
Jurassic Carmel Formation

- Seal to the underlying Navajo Sandstone
- Mixed siliciclastic carbonate system
- Deposition in near shore marine to sabkha setting
Outcrop analysis

Fracture swarms associated with units lacking shale inter-beds and normal faults & spaced fractures

Splitting of fractures across lithologic boundaries

Deflection or arrest of mineralized fractures at interface
Mechanical stratigraphy

- Bed thickness 0.25 – 3 m
- Higher fracture density in thin beds
- Compressive strength range 15-65
- Permeability range > 0.01 D to 0.1 D
Fracture Orientations

- Open fractures, veins & small offset normal faults in Carmel Fm. have dominant **NNE** orientation.
- Open joints in Navajo sst, have dominant **NNW** orientation. Fault deformation bands have **NNE** orientation.
Fracture formation at depth

xpl 4x
field of view 4 mm

xpl 10x
field of view 2.5 mm

13 cm
Elastic moduli from wire line logs

- Dipole sonic logs not available for all wells – must derive shear velocity from compressional velocity

- Empirical – based on relationships established by previous workers and verified using dipole sonic logs from two wells
Well-bore based estimates of dynamic Young’s Modulus show meter scale variability (15-34 Gpa)

Field-based fracture density and compressive strength also show meter scale variability

How important is this variability to seal failure and subsurface fluid flow?
Organ Rock Shale

- Seal to the underlying Cedar Mesa Sandstone
- Coarsening up-ward interbedded siltstones & mudstones
- Deposited in near shore marine lowlands, braided streams & tidal flats
Cedar Mesa Discontinuities

N: 342
Mean direction: 319°
Interval: 10°

From: nps.gov
Modified from: Willis et al, UGS; Glen Canyon NRA
Fracture character & distribution

1. Fracture trend parallels fault and joint trend in reservoir
2. Alteration halo and mineralization suggests fluid flow along fractures
3. Fracture density increases with proximity to faults and in coarse-grained lithology

N: 72
Mean direction: 309°
Interval: 10°
Outcrop observations

Alteration of Cedar Mesa Sandstone in fault damage zone includes oxide staining, calcite mineralization & calcite filled deformation bands.
Outcrop observations

Deformation bands in the fault damage zone often considered barriers to flow via reduced permeability.

Calcite mineralization indicates
- dilation bands
- reactivation of cataclastic bands & mineralization

Daylight

UV light
Outcrop observations

Termination of fractures and alteration halos at interface with high perm. aeolian bed
Outcrop observations

Fractures density increases in coarser-grained & thickly bedded units
<table>
<thead>
<tr>
<th>Carmel Formation</th>
<th>Organ Rock Shale</th>
</tr>
</thead>
<tbody>
<tr>
<td>o Highest fracture densities in thinly bedded units</td>
<td>o Higher fracture densities adjacent to fault</td>
</tr>
<tr>
<td>o Mineralized and altered fractures throughout</td>
<td>o Alteration halos and mineralized fractures adjacent to faults</td>
</tr>
<tr>
<td>o Permeability ranges 0.01 to 0.1D</td>
<td>o Permeability from 0.001 to 0.06D</td>
</tr>
<tr>
<td>o Schmidt hammer rebound values range 20-70</td>
<td>o Schmidt hammer rebound values range 10-40</td>
</tr>
</tbody>
</table>
Conclusions

- Stratigraphic variability and resulting changes in mechanical properties influence the variability in fracture morphology and density
  - Penetration, termination or deflection at interfaces
- Understanding variability in fracture morphology in different seal types, interface types, and structural settings is key to understanding hydraulic seal failure
Acknowledgements and Questions

Jim Evans, Tamara Jeppson and USU structural geology group
Field assistants: R. Wood, C. Barton, R. Petrie
DOE Grant # DE-FC26-0xNT4 FE0001786
GDL Foundation Fellowship
SMT Kingdom Software – University Grant
Sirovision Software – University Grant
Variability in bed thickness 0.25 – 10 m

Higher fracture density in thin beds

Altered fractures associated with faults

Higher fracture density adjacent to faults and in hanging wall

Fracture termination at high permeability aeolian marker bed

Variability in permeability from 0.02 D to 0.06 D
Shear Velocity Calculations

- Covert digitized sonic log travel times to velocity
- Vertical resolution limited by frequency and distance between transmitter and receiver ~ 2 ft or 61 cm

<table>
<thead>
<tr>
<th>GR</th>
<th>Vp</th>
<th>Vs</th>
</tr>
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<tbody>
<tr>
<td>0.00</td>
<td>125</td>
<td>8.00</td>
</tr>
</tbody>
</table>

Utah D-8

2.71 km

Utah D-7

Image of seismic data with GR, Vp, and Vs values and a map showing the locations of Utah D-7 and D-8.
Modified from Davatzes, 2003 and Pevear, 1997