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Fracture behavior across interfaces in seal lithologies

Elizabeth S. Petrie
Utah State University

James P. Evans
Utah State University

Tamara Jeppson
Utah State University

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AGU-2011

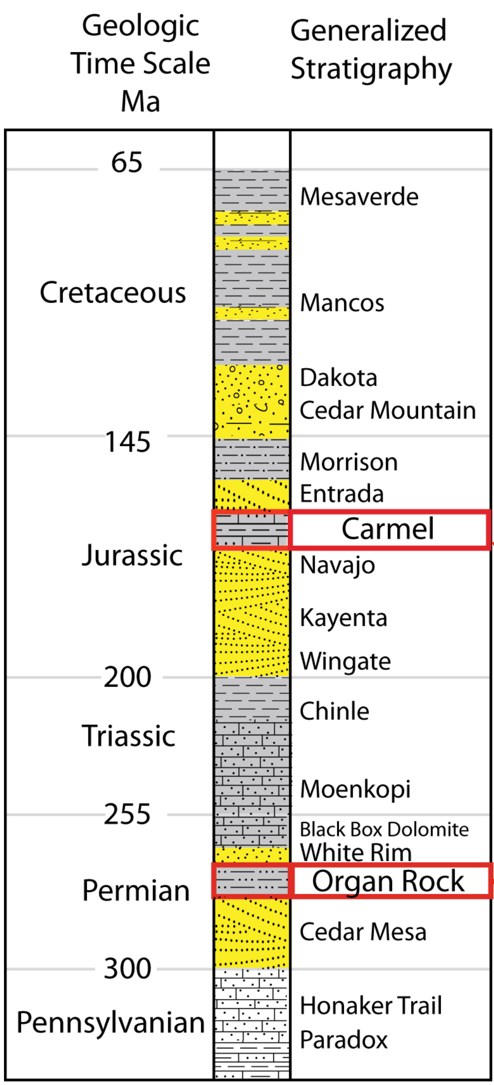
Elizabeth Petrie, James Evans, Tamara Jeppson

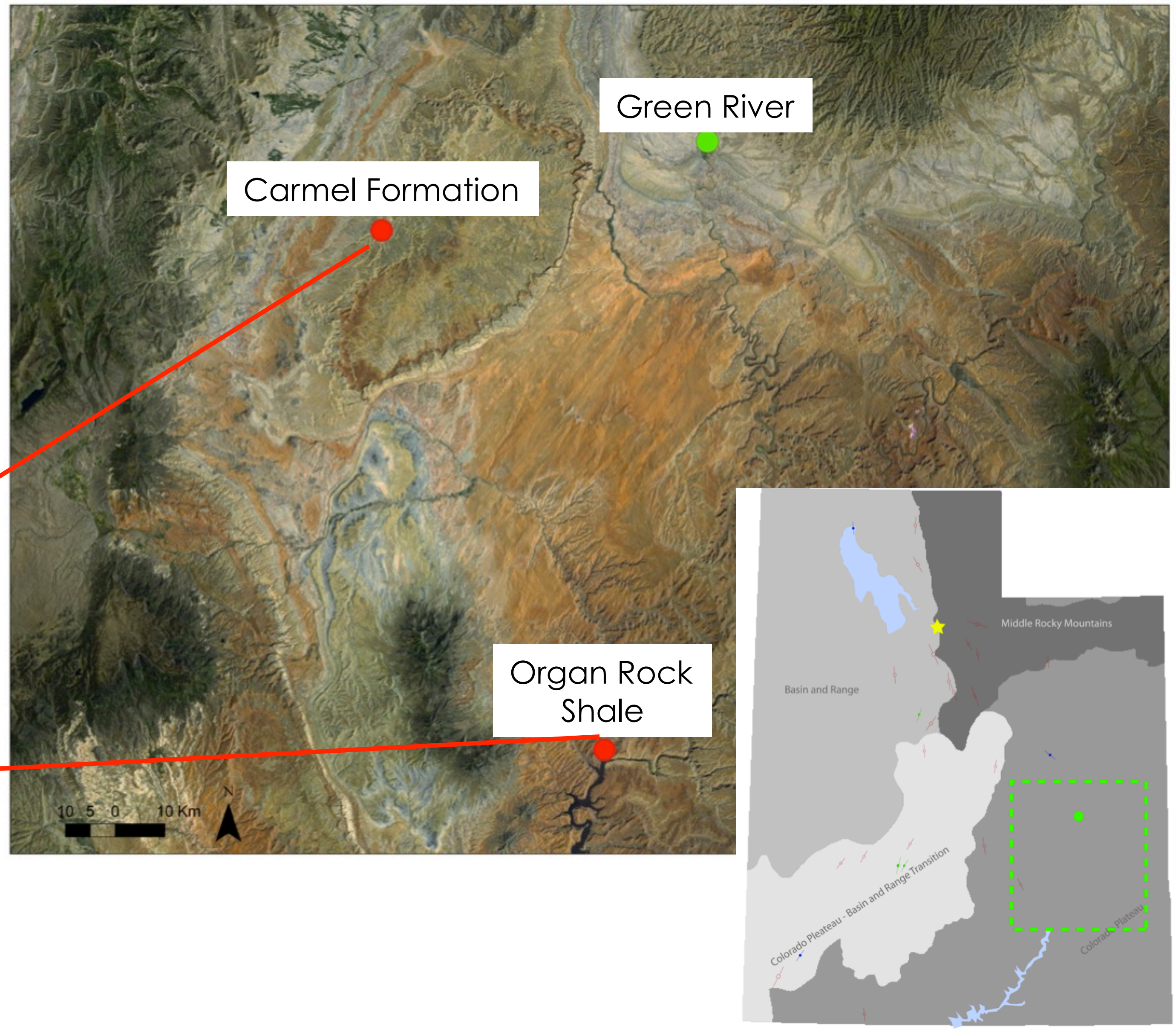
UtahState University

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





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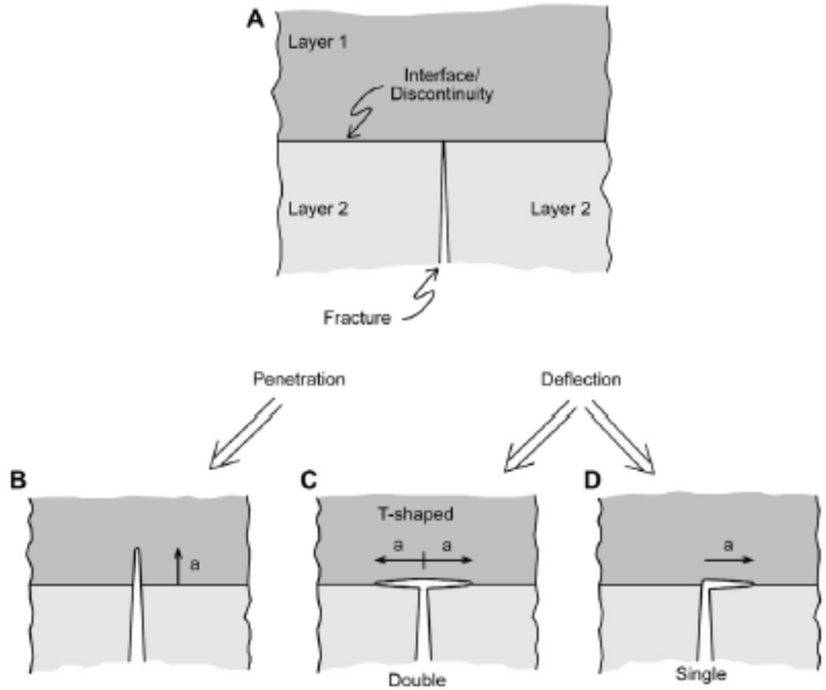
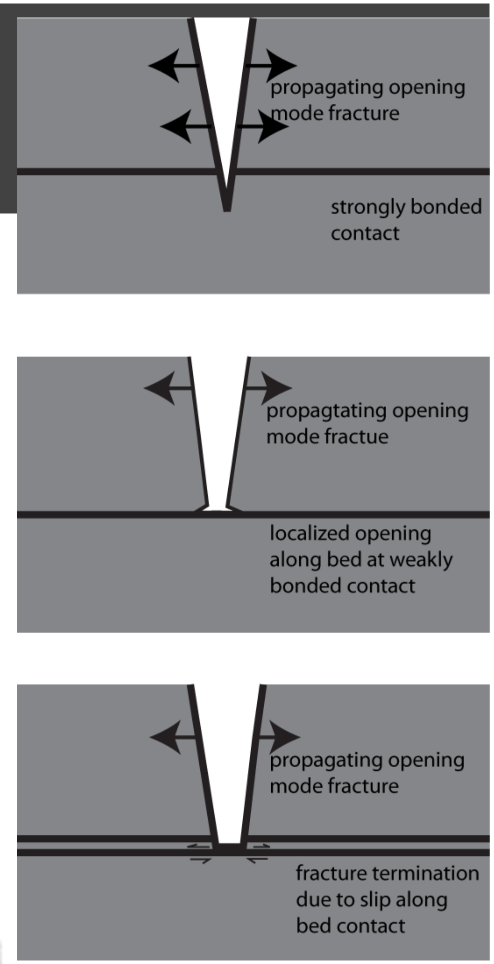
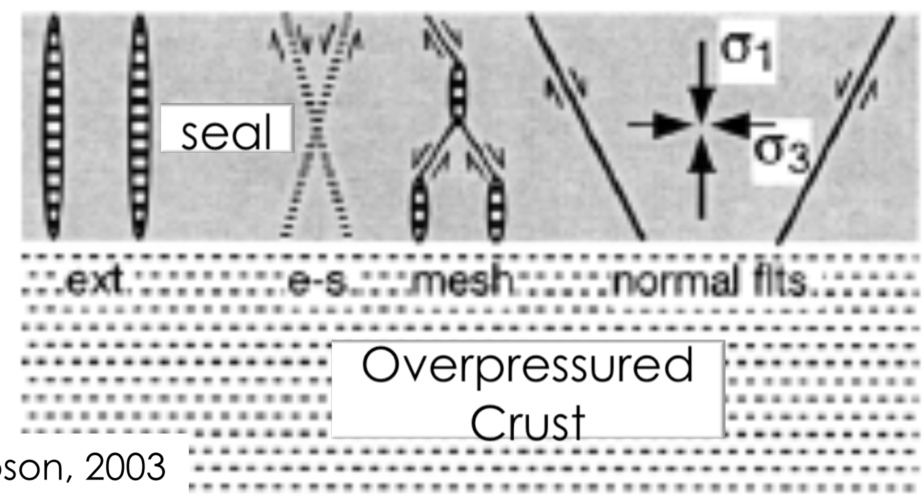
Fracture morphology



From Larsen et al., 2010



From Cooke et al., 2006



From: Sibson, 2003

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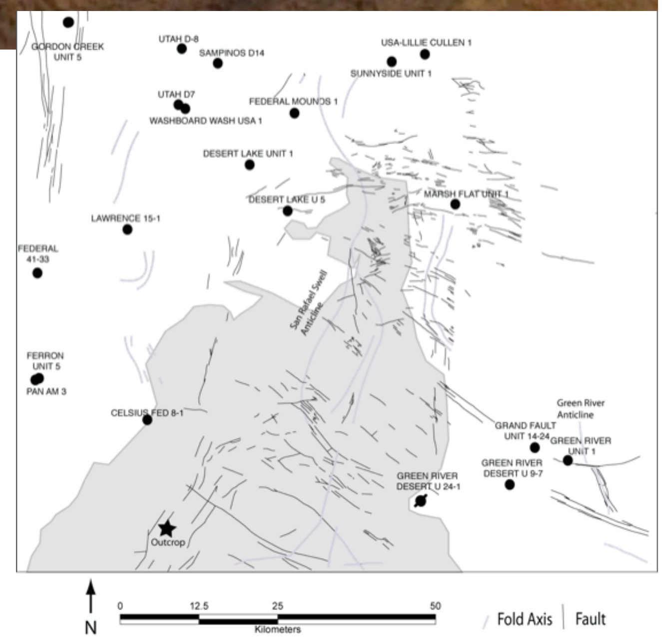
Jurassic Carmel Formation

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



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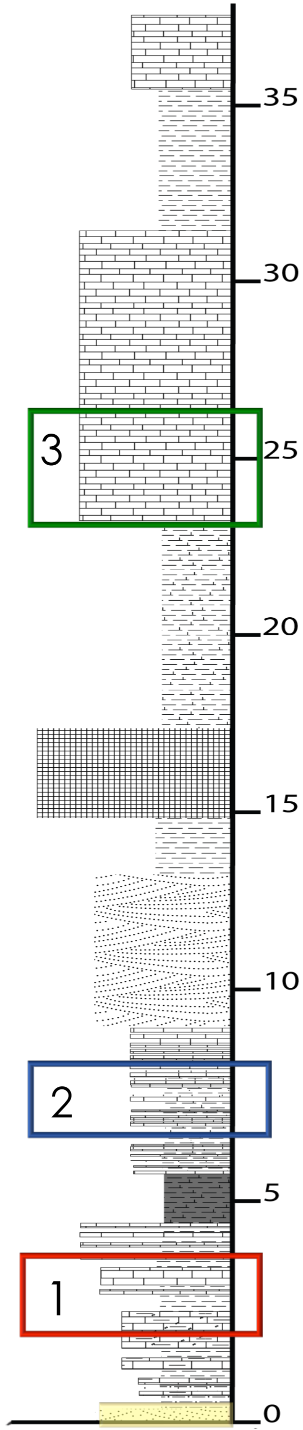
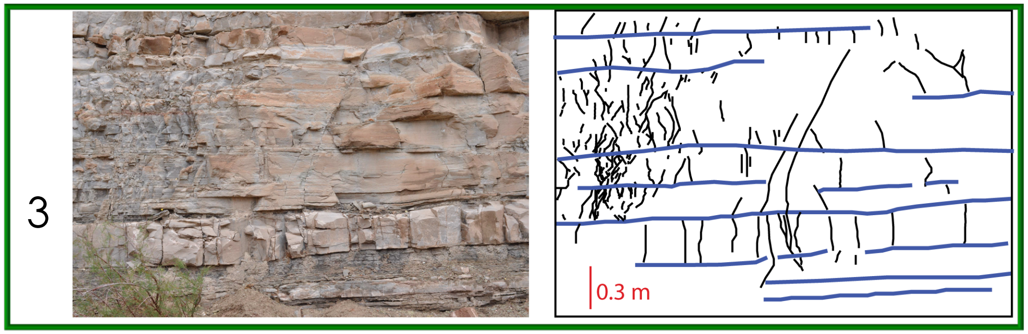
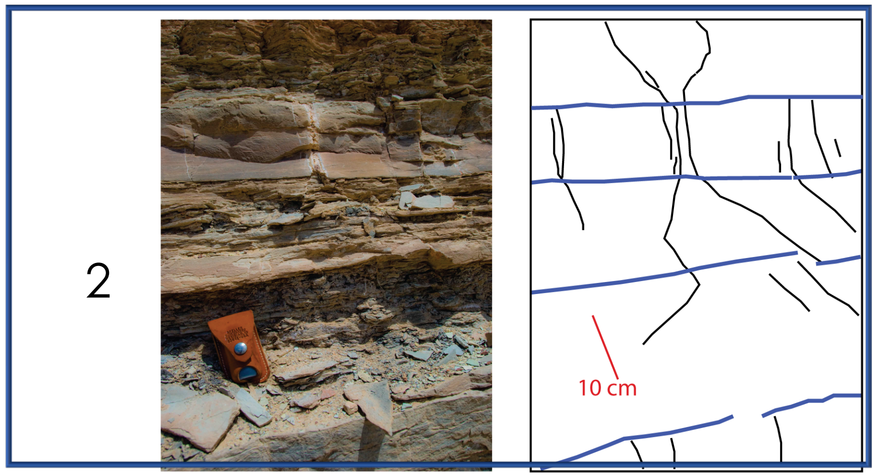
Outcrop analysis

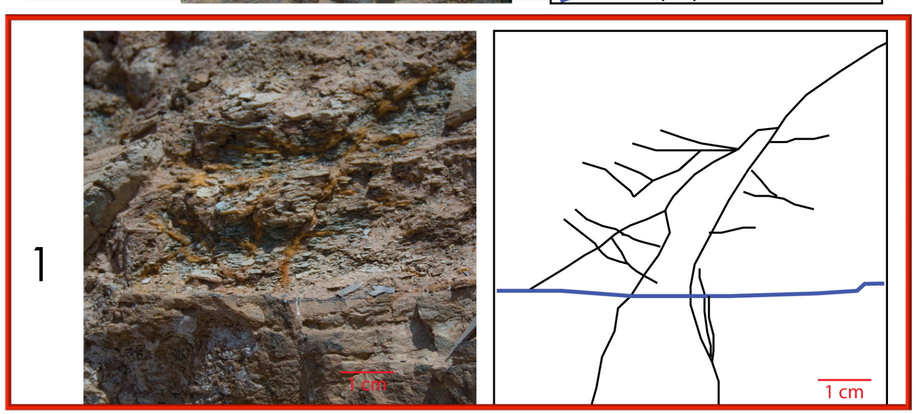




Fracture swarms associated with units lacking shale inter-beds and normal faults & spaced fractures



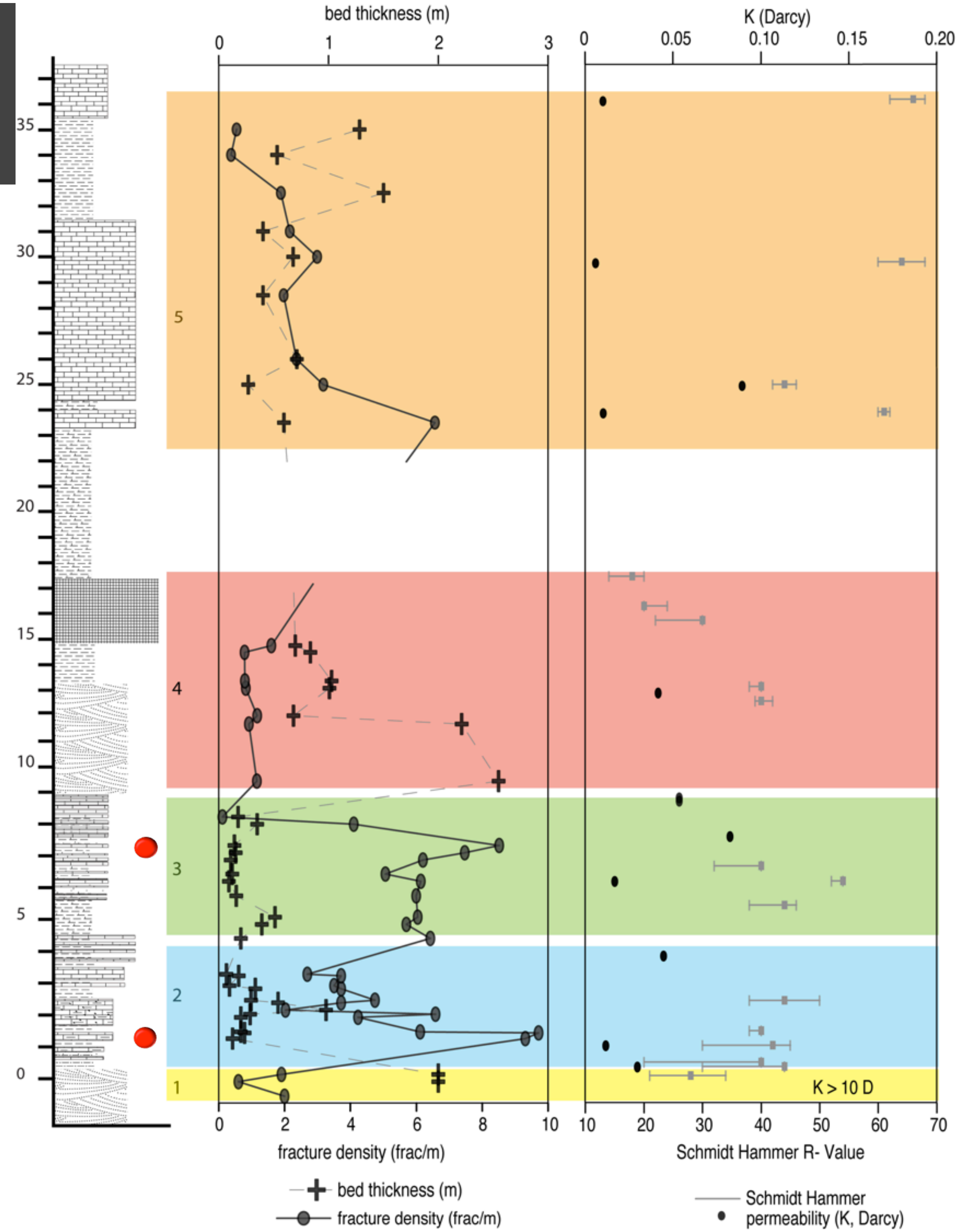
Splitting of fractures across lithologic boundaries



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**



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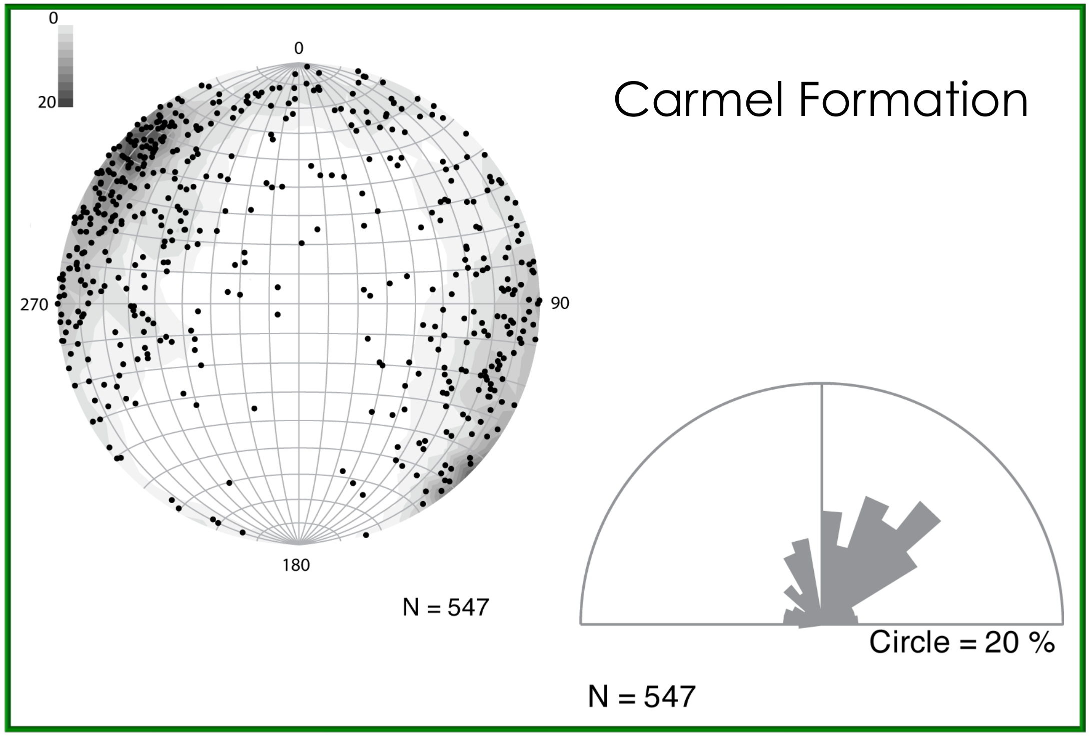
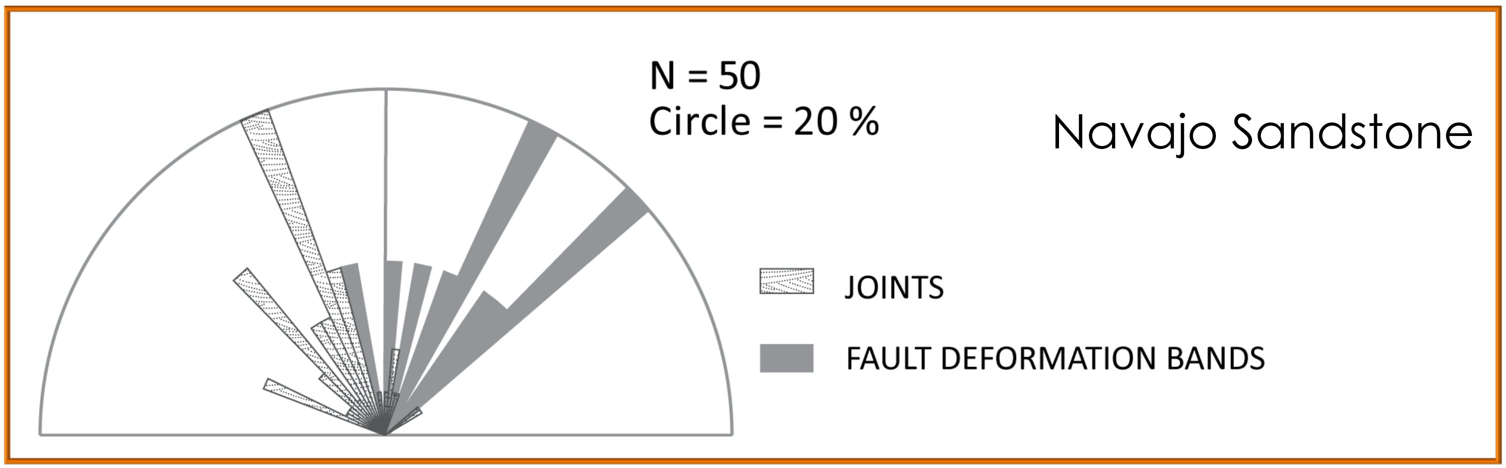
Fracture Orientations

- **Open fractures, veins & small offset normal faults in Carmel Fm. have dominant <u>NNE</u> orientation**
- **Open joints in Navajo sst, have dominant <u>NNW</u> orientation fault deformation bands have <u>NNE</u> orientation**





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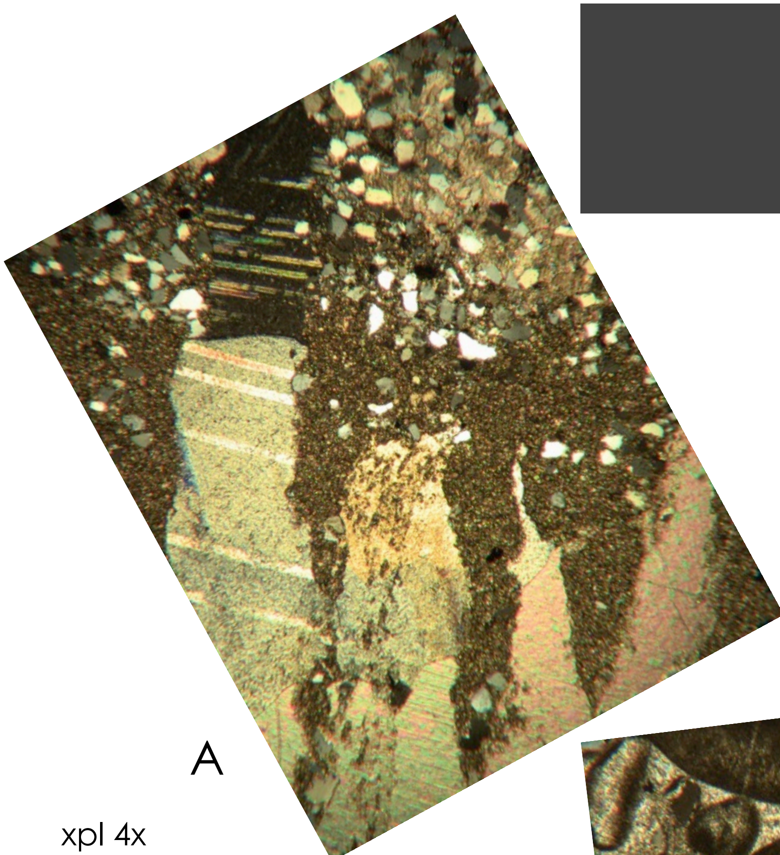
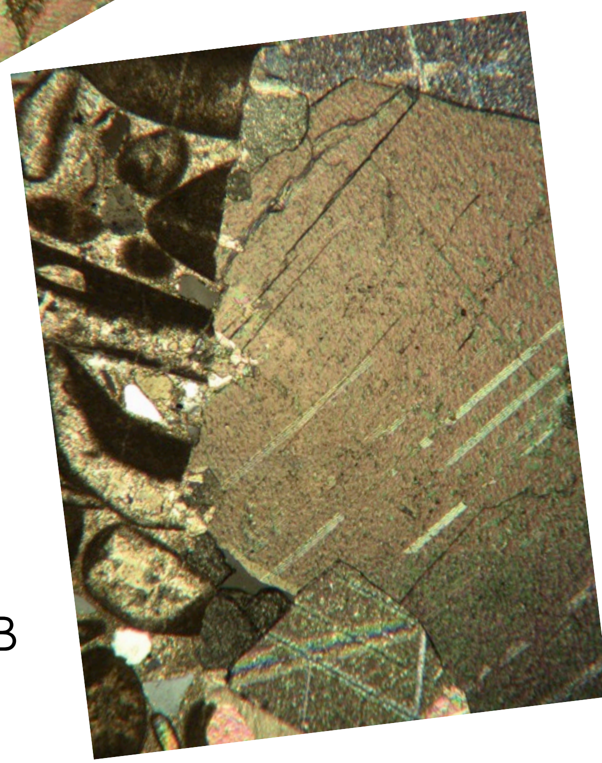
Fracture formation at depth



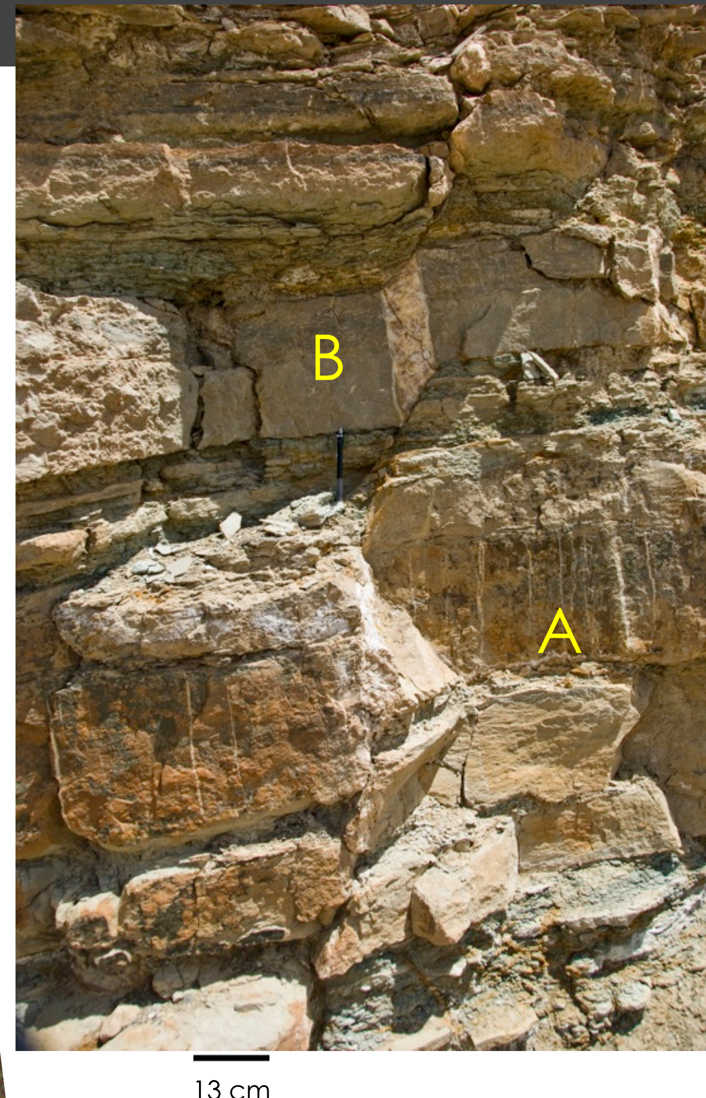
A

xpl 4x
field of view 4 mm



B

xpl 10x
field of view 2.5 mm



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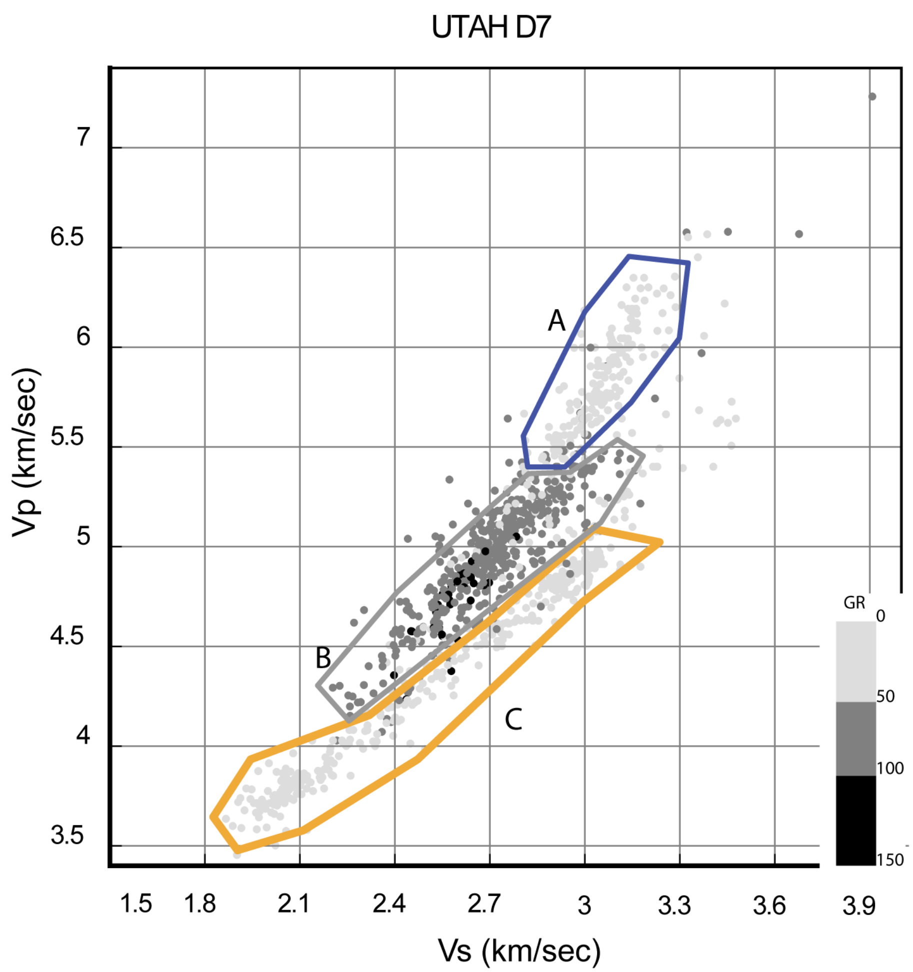
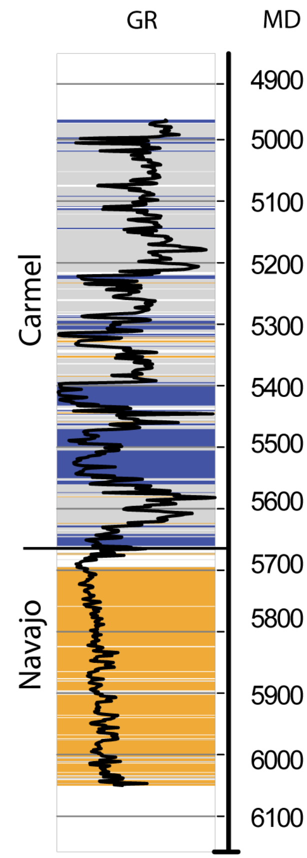
Elastic moduli from wire line logs





Gamma Ray	V_p/V_s	Cross plot
GR<50, Carmel	1.9	A
150>GR>50	1.8	B
GR<50, Navajo	1.6	C
GR>150	1.5	

- **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**

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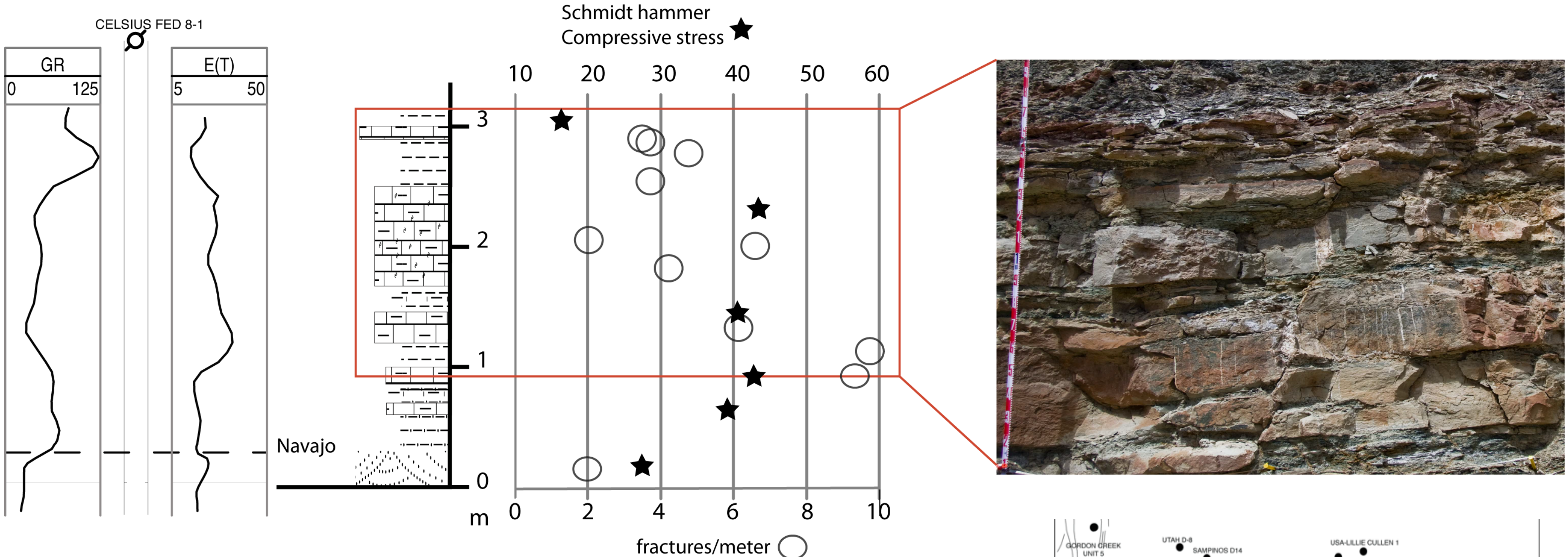
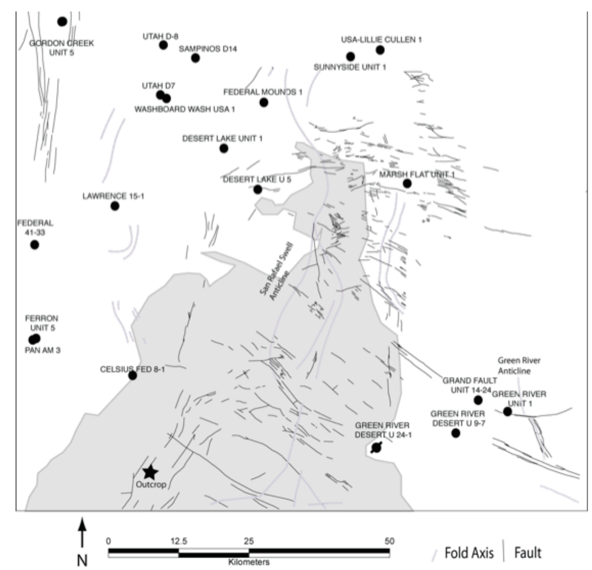
Subsurface to outcrop correlation



- **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?**



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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

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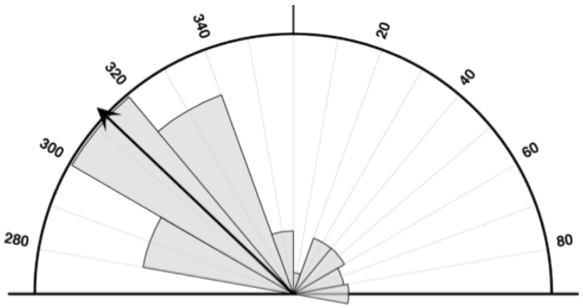
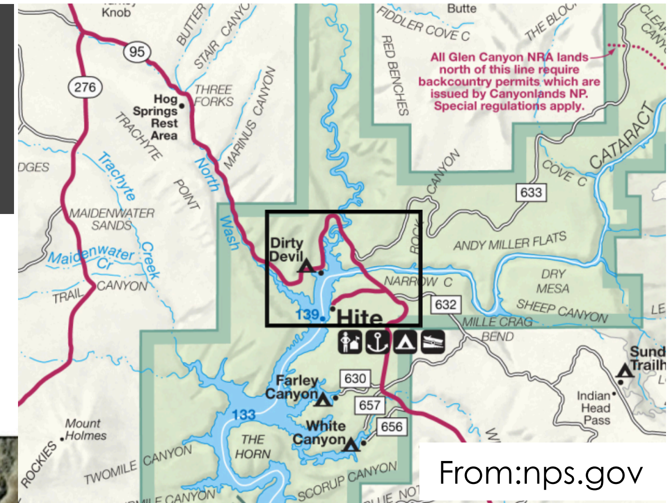
Cedar Mesa Discontinuities



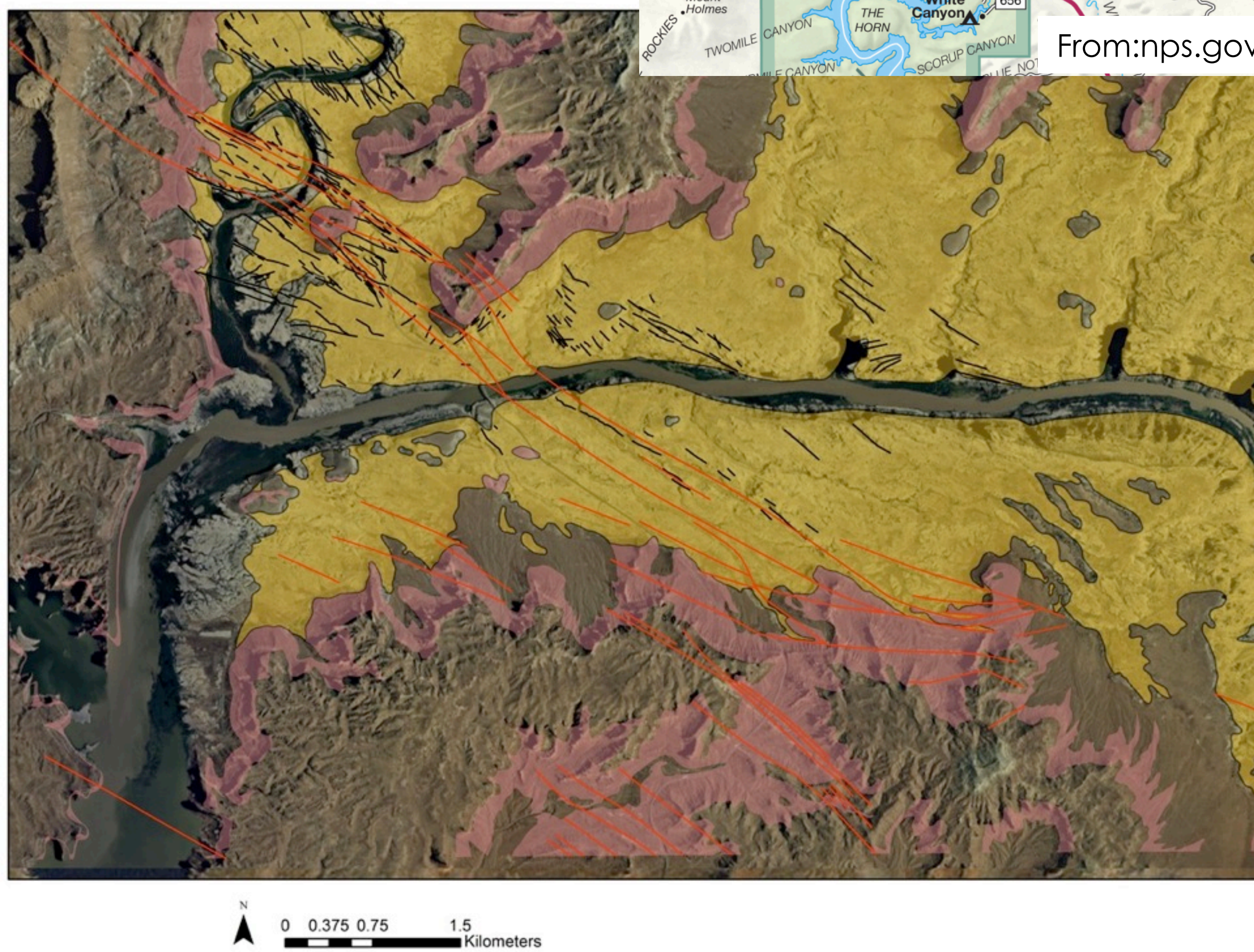
N: 342

Mean direction: 319°

Interval: 10°



From:nps.gov



Cedar Mesa Sst

Organ Rock Shale

Normal faults

Cedar Mesa joints

Modified from: Willis et al, UGS; Glen Canyon NRA

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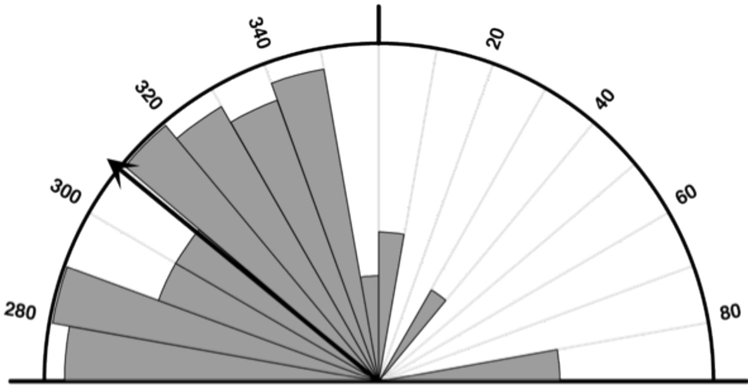
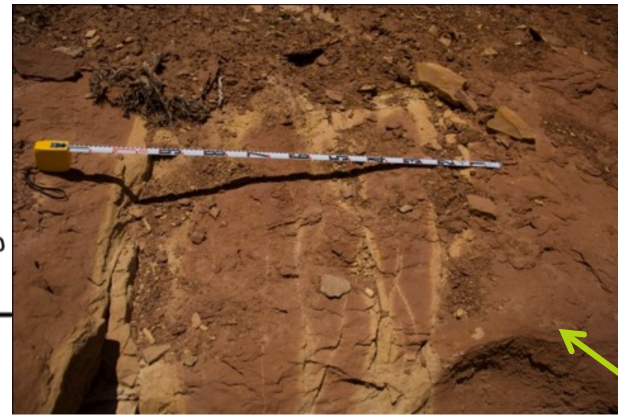
Fracture character & distribution

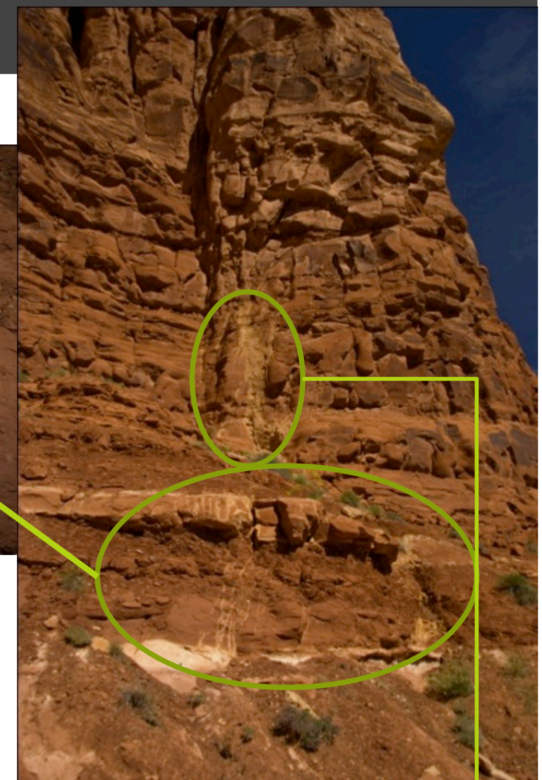


N: 72

Mean direction: 309°

Interval: 10°





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

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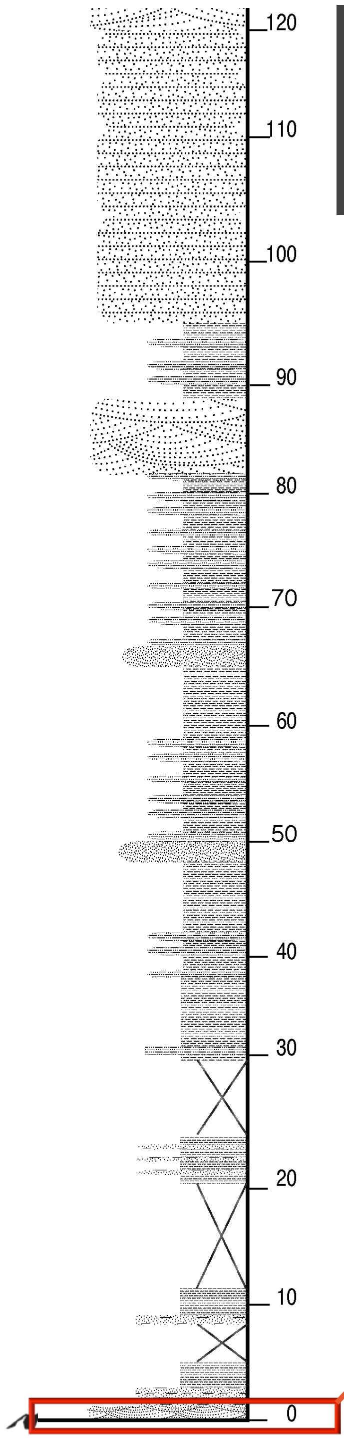
Outcrop observations



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

Outcrop observations

Daylight

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**

UV light

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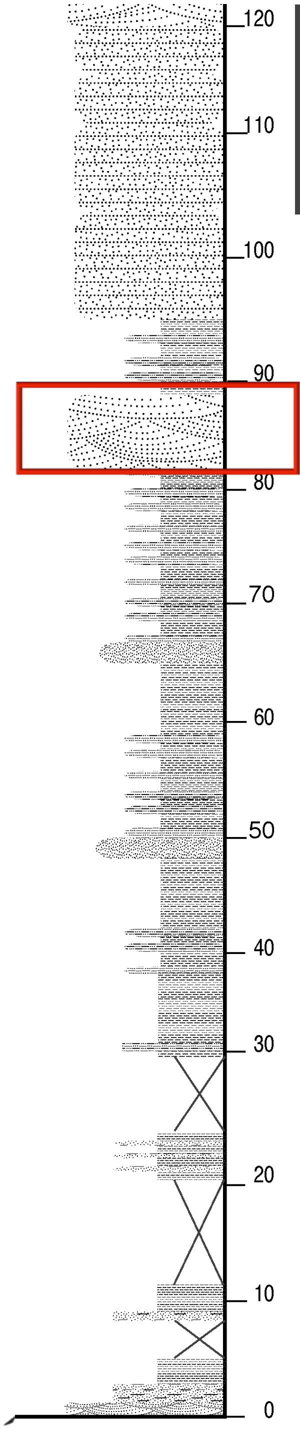
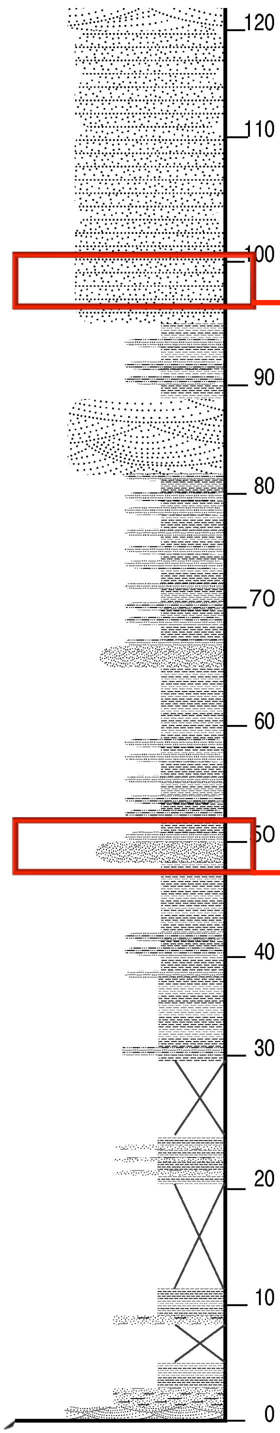


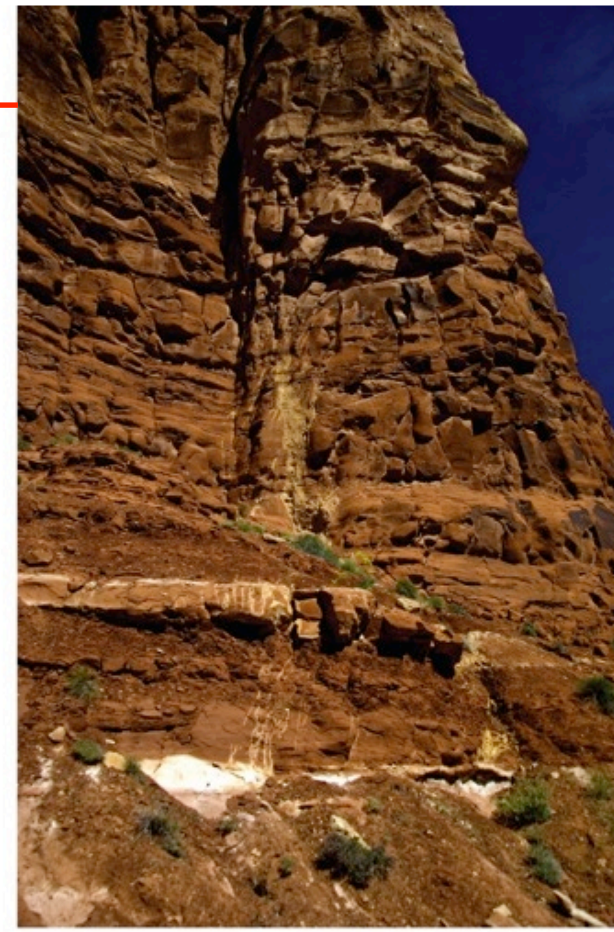
Outcrop observations

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

Outcrop observations



Fractures density increases in coarser-grained & thickly bedded units



- Variability in lithologies and bed thickness
- Continuation, deflection and termination of fractures at lithologic interfaces
- Lower fracture density in fine grained lithologies

Carmel Formation

- Highest fracture densities in thinly bedded units
- Mineralized and altered fractures throughout
- Permeability ranges 0.01 to 0.1D
- Schmidt hammer rebound values range 20-70

Organ Rock Shale

- Higher fracture densities adjacent to fault
- Alteration halos and mineralized fractures adjacent to faults
- Permeability from 0.001 to 0.06D
- Schmidt hammer rebound values range 10-40

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**

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Acknowledgements and Questions

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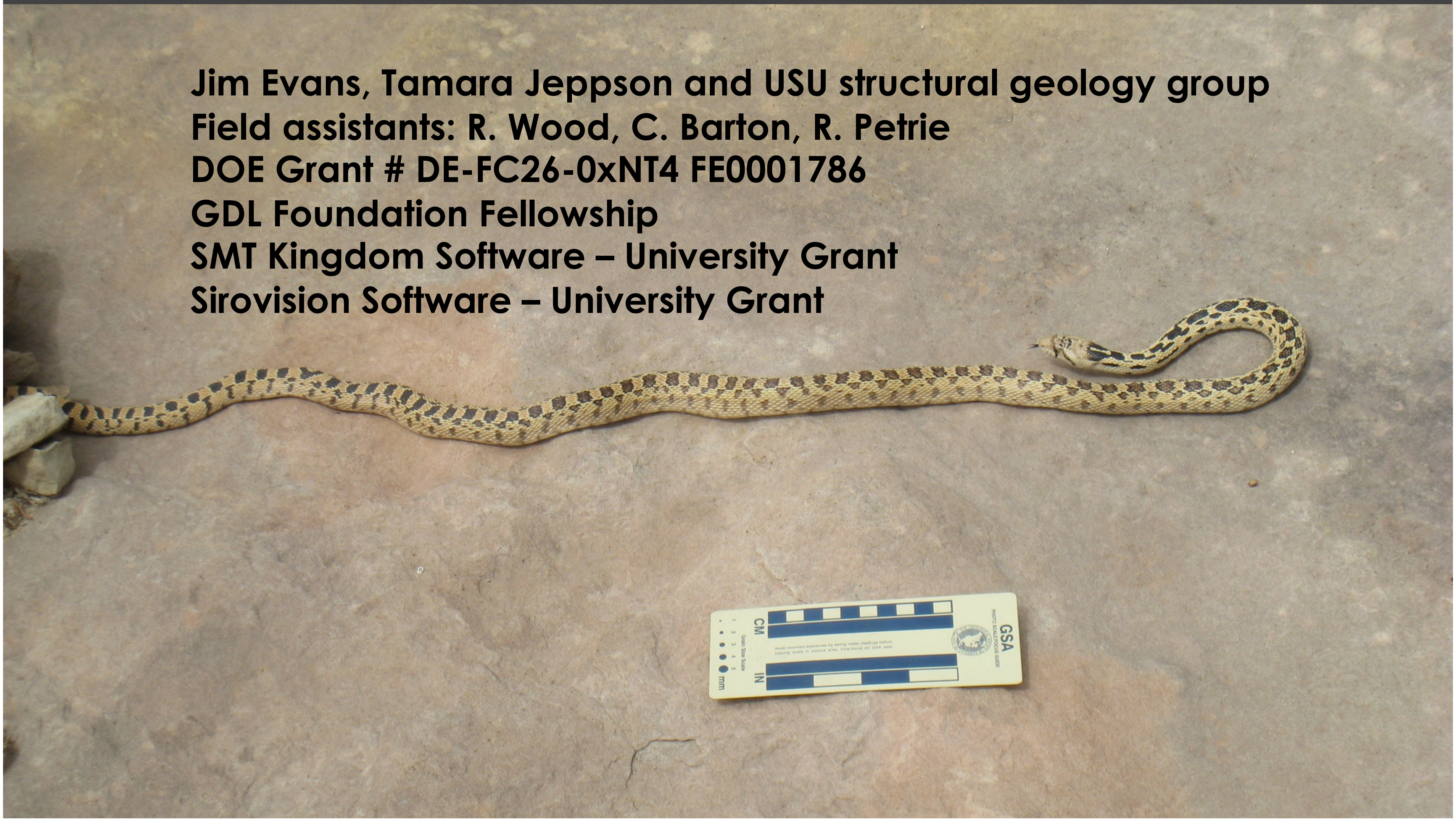

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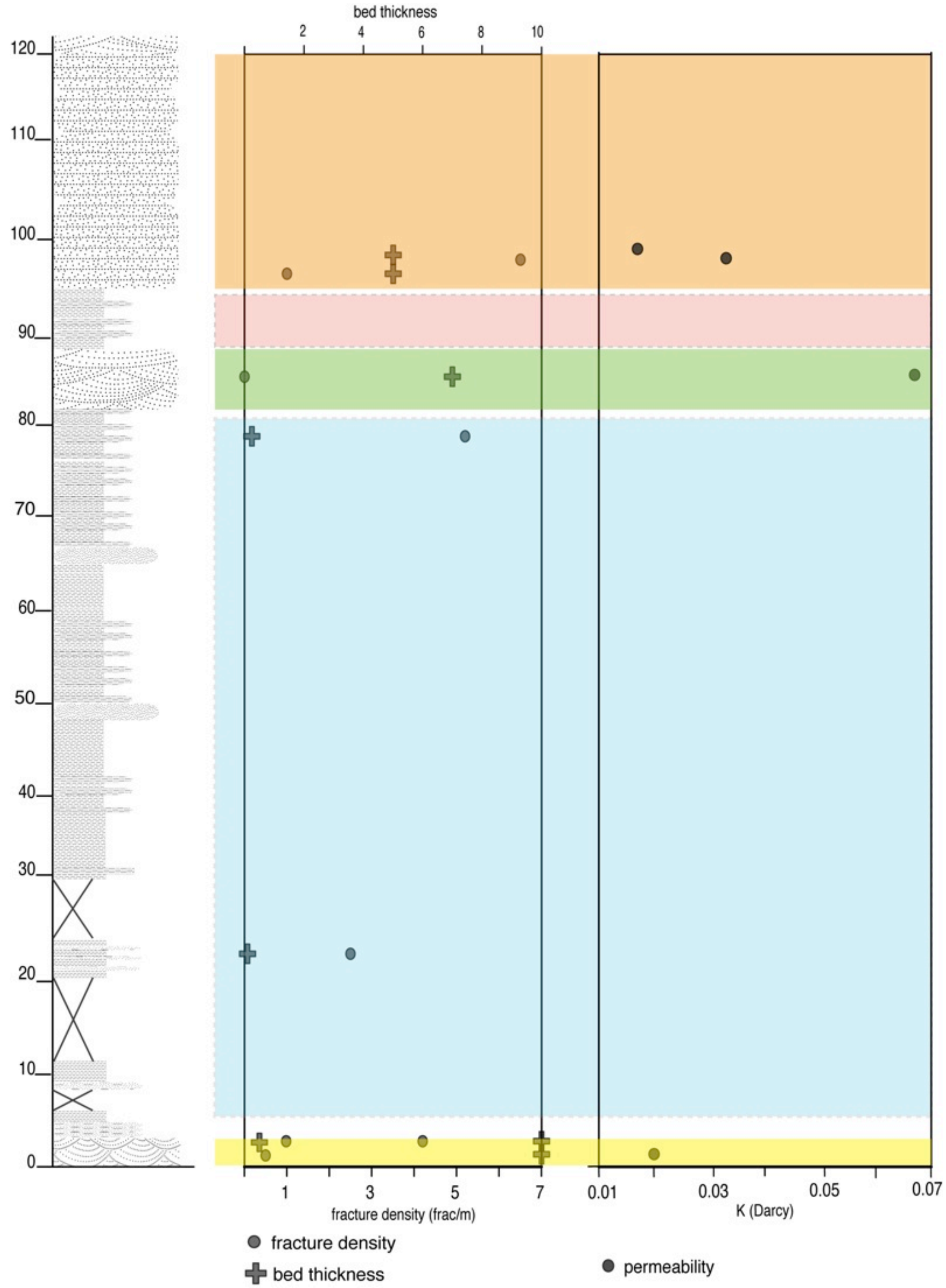
REFORAMT TO compare constrast

- 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



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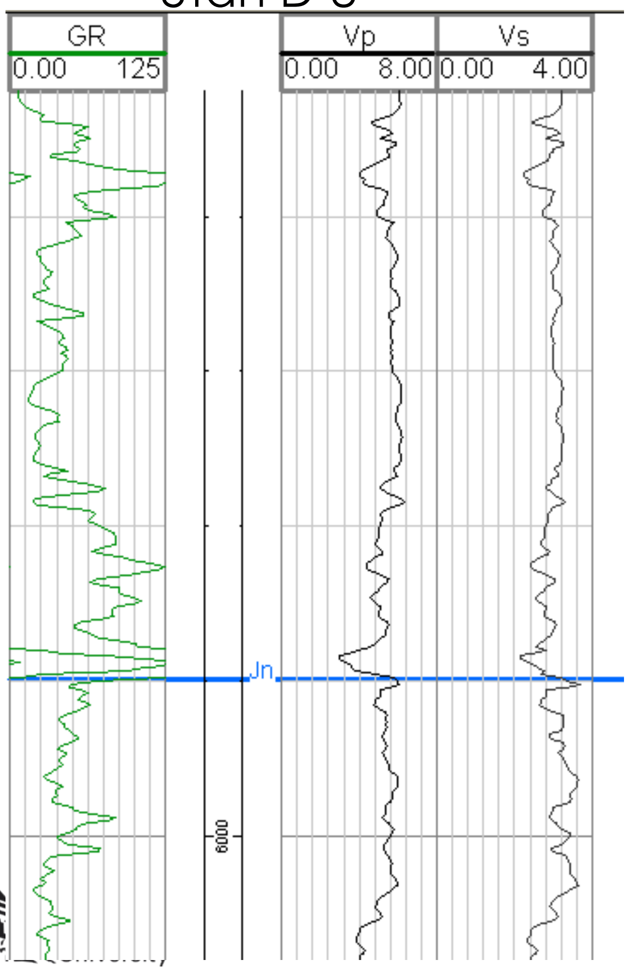
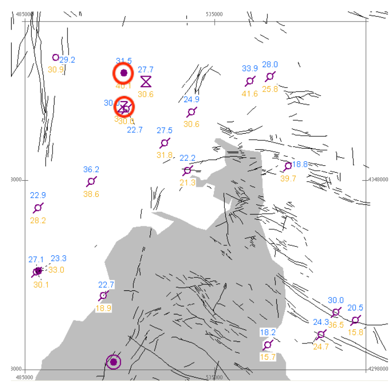
Shear Velocity Calculations

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

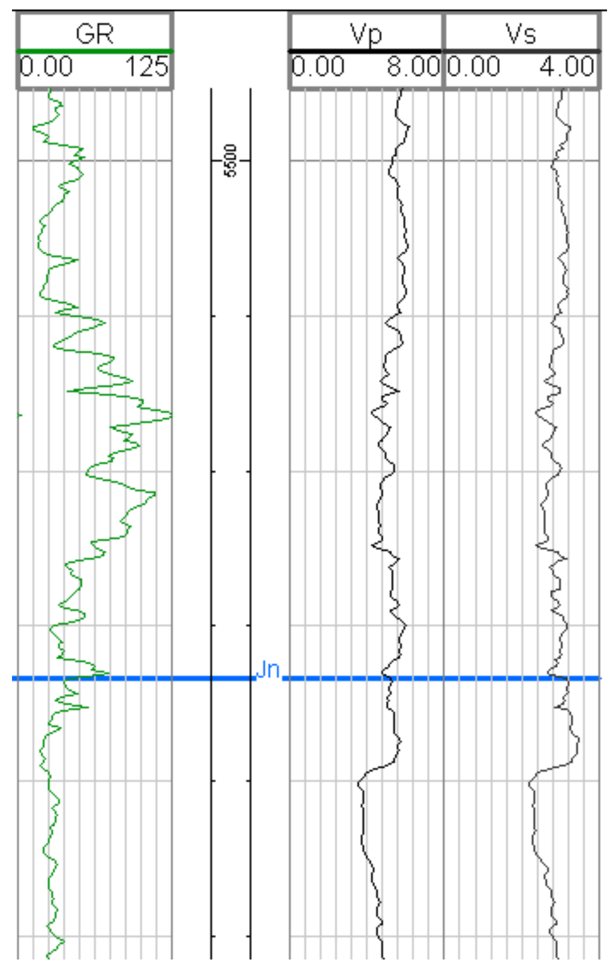
Utah D-8



2.71 km



Utah D-7



Modified from Davatzes, 2003 and Pevear, 1997