CO_2 at the Interface: Nature and Dynamics of the Reservoir/Caprock Contact and Implications for Carbon Storage Performance

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Developing the Technologies and
Infrastructure for CCS
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Presentation Outline

- Introduction
- Organization
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Introduction

- Most storage modeling studies assume a discrete reservoir/caprock interface with simple (uniform) flow conditions.
- We address the question of whether or not heterogeneities at the interface influence transmission of CO_2 into the caprock

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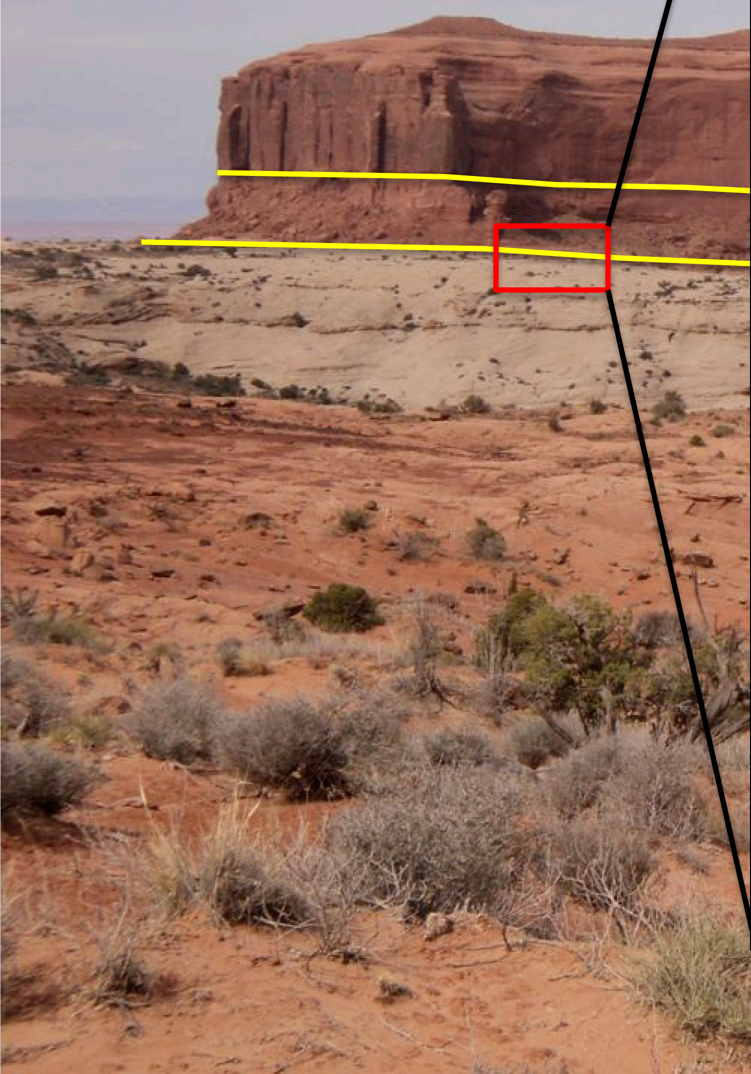
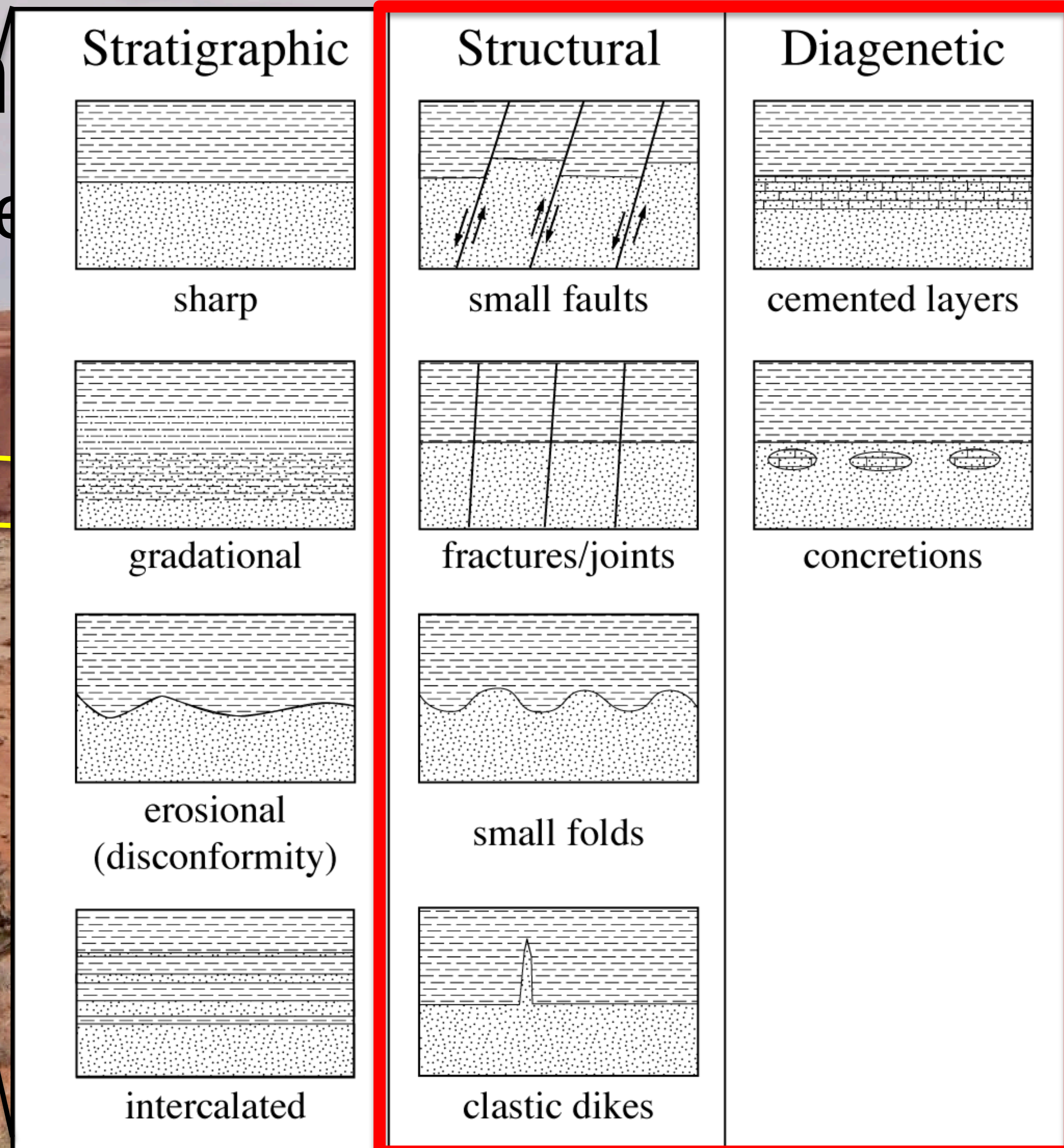
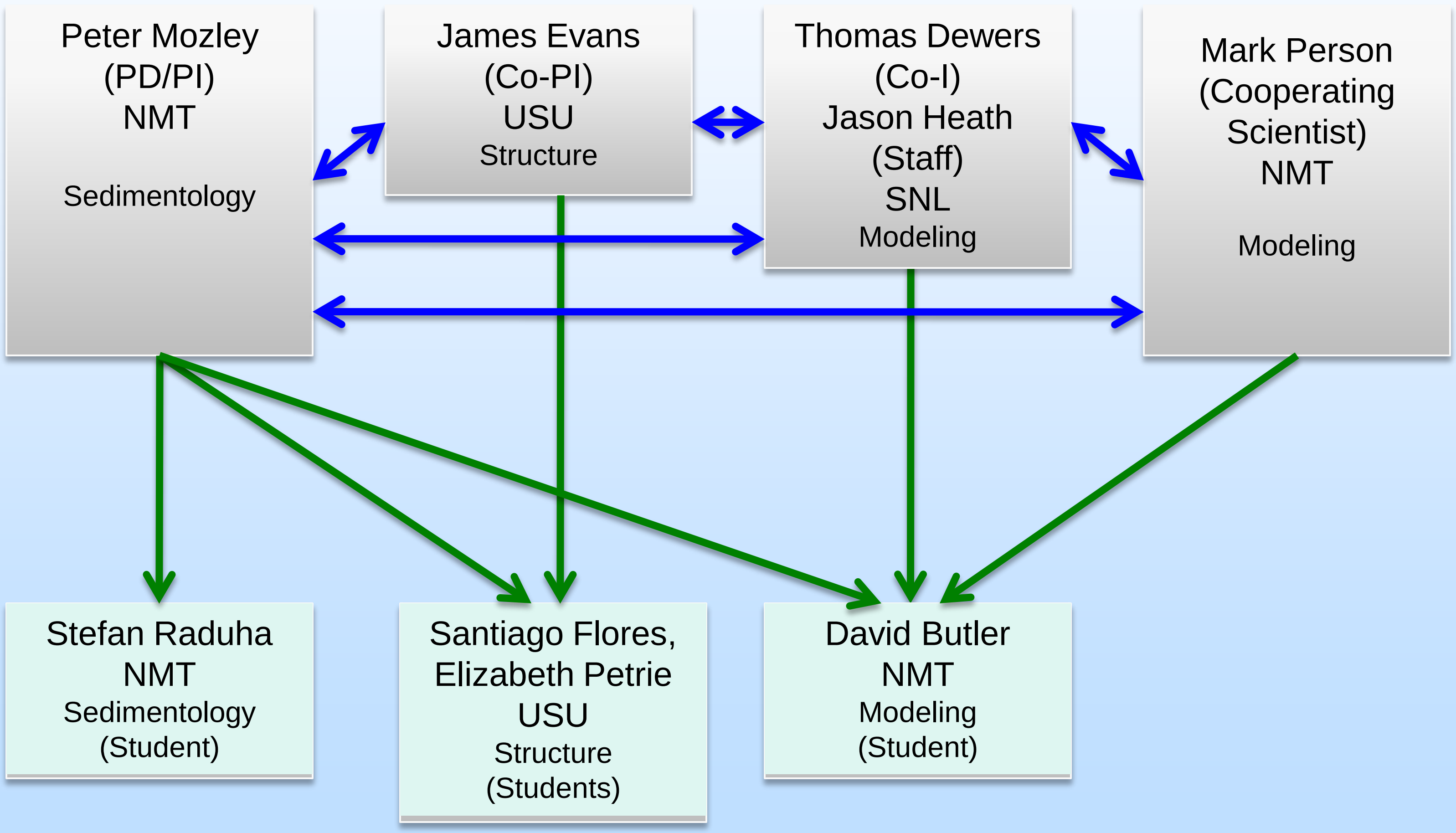




Organization



Benefit to the Program

- Program goals being addressed.
  - Develop technologies that will support industries' ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
  - Develop technologies to demonstrate that 99 percent of injected CO_2 remains in the injection zones.
- Project benefits.
  - Our results have the potential to significantly improve prediction of containment system effectiveness.

Project Overview: Goals and Objectives

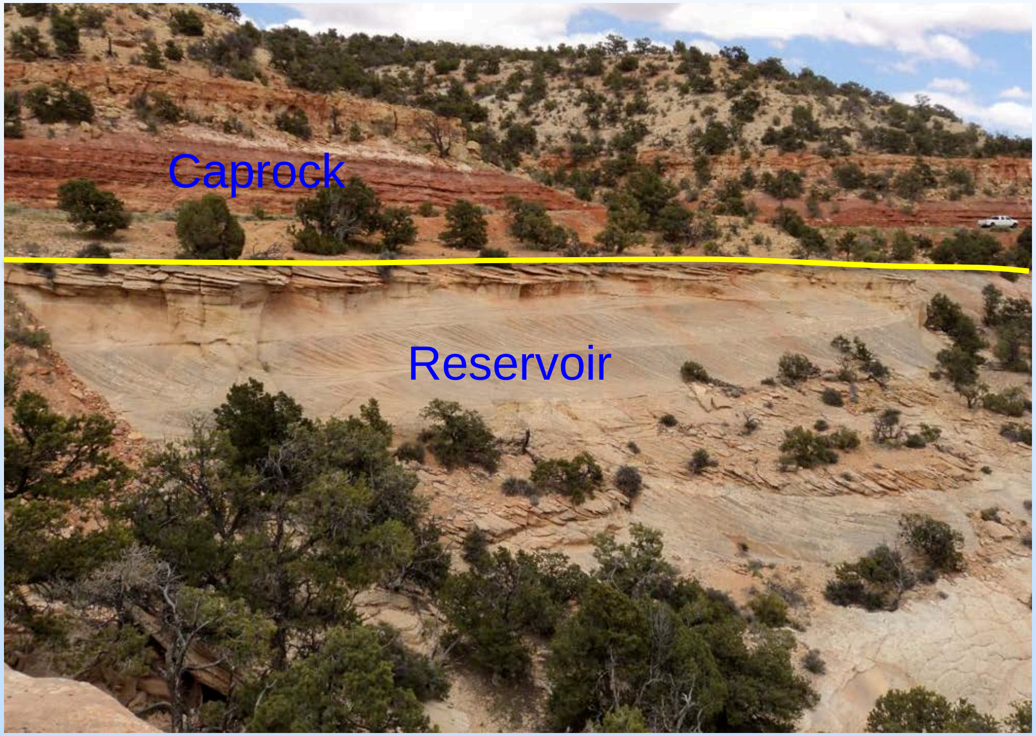
- To determine the influence of diagenetic and structural features of the reservoir/caprock interface on transmission of CO_2 into and through the caprock.

Technical Status

- Initial fieldwork to identify significant interface features and select study sites
- Collection of geological and petrophysical data from outcrop (Navajo/Carmel, Slickrock/Earthy) and core (Mt. Simon/Eau Claire)
- Use geological and petrophysical data to construct conceptual geologic and permeability models
- Modeling efforts
  - Single phase
  - Multiphase
- Structural framework to predict likelihood of encountering at sequestration sites

Common Interface Features Identified During Reconnaissance

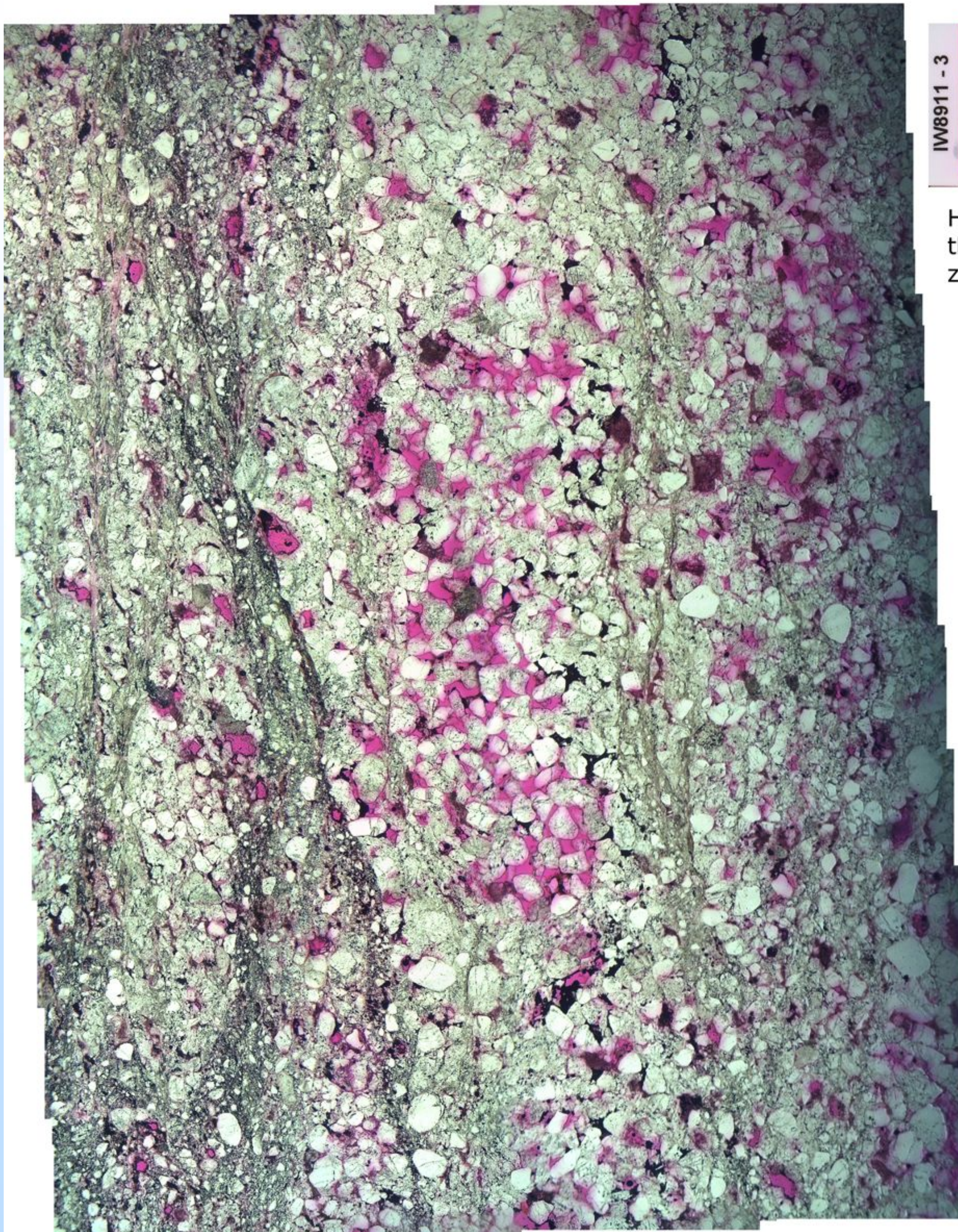
- Preferential cementation
- Deformation-band fault interfaces
  - Principal focus so far
  - Very common in porous sandstone reservoirs

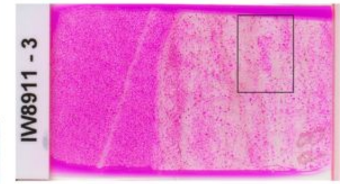


Deformation Bands

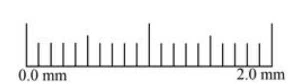
- The most common strain localization feature found in porous sandstones (e.g., Navajo, Entrada, Mt. Simon)
- Form by: grain reorganization and/or fracture
- Typically 2 – 5 orders of magnitude lower K than host sand
- Can form capillary seals to supercritical CO_2

ISS-1 Panormaic Photomicrographs of Deformation Band Faults from the Slickrock Member of the Entrada Sandstone

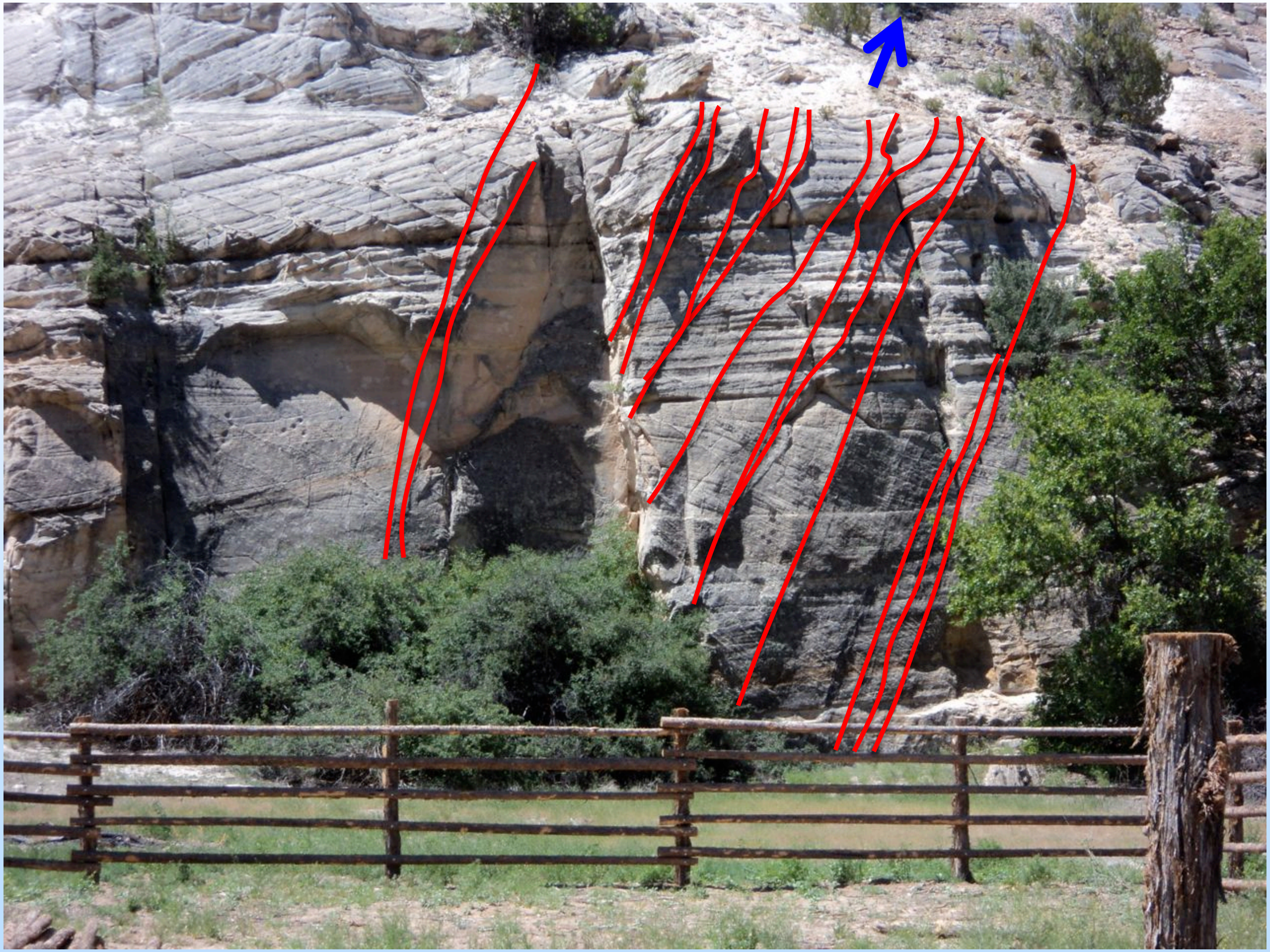




Host thin section with the photomicrographed zone labeled in black

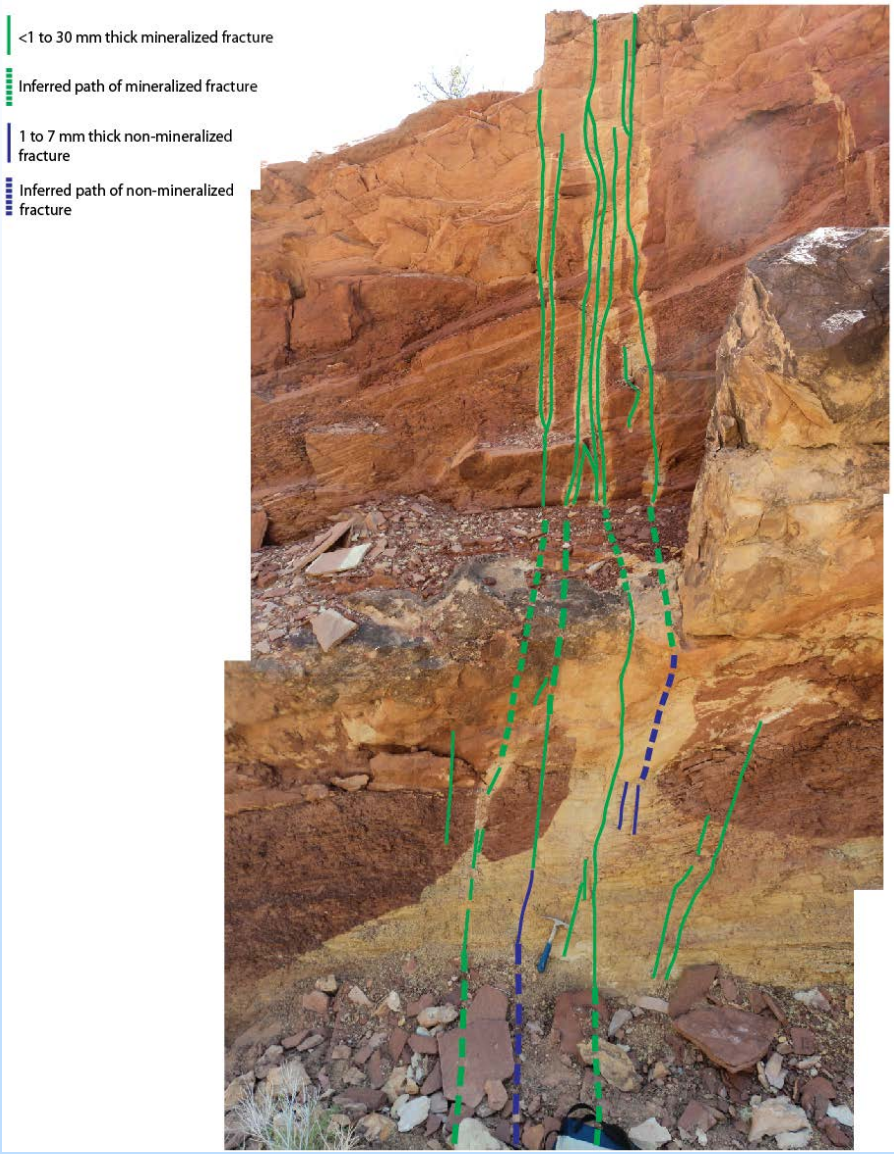


What happens when deformation band faults hit the interface?

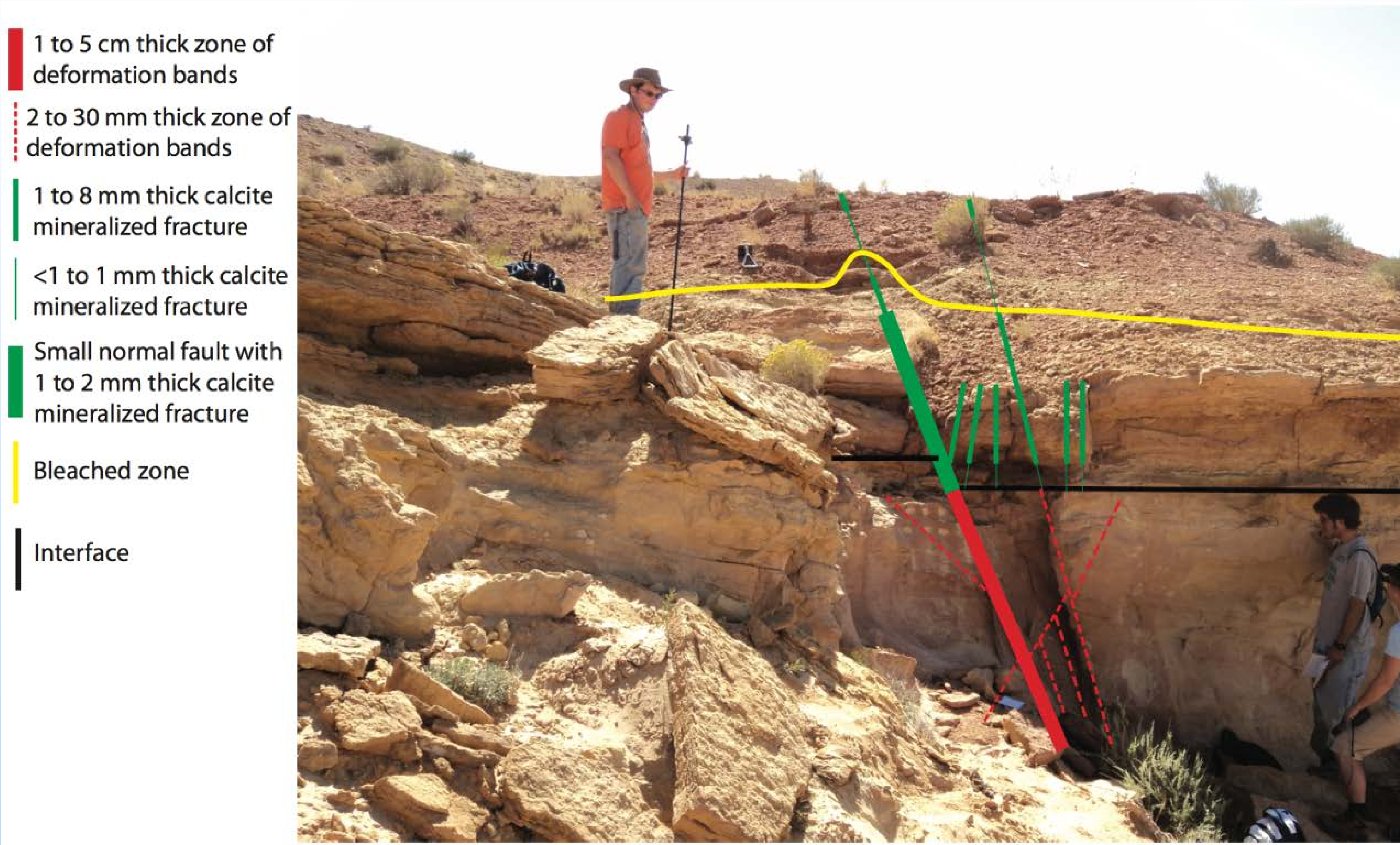


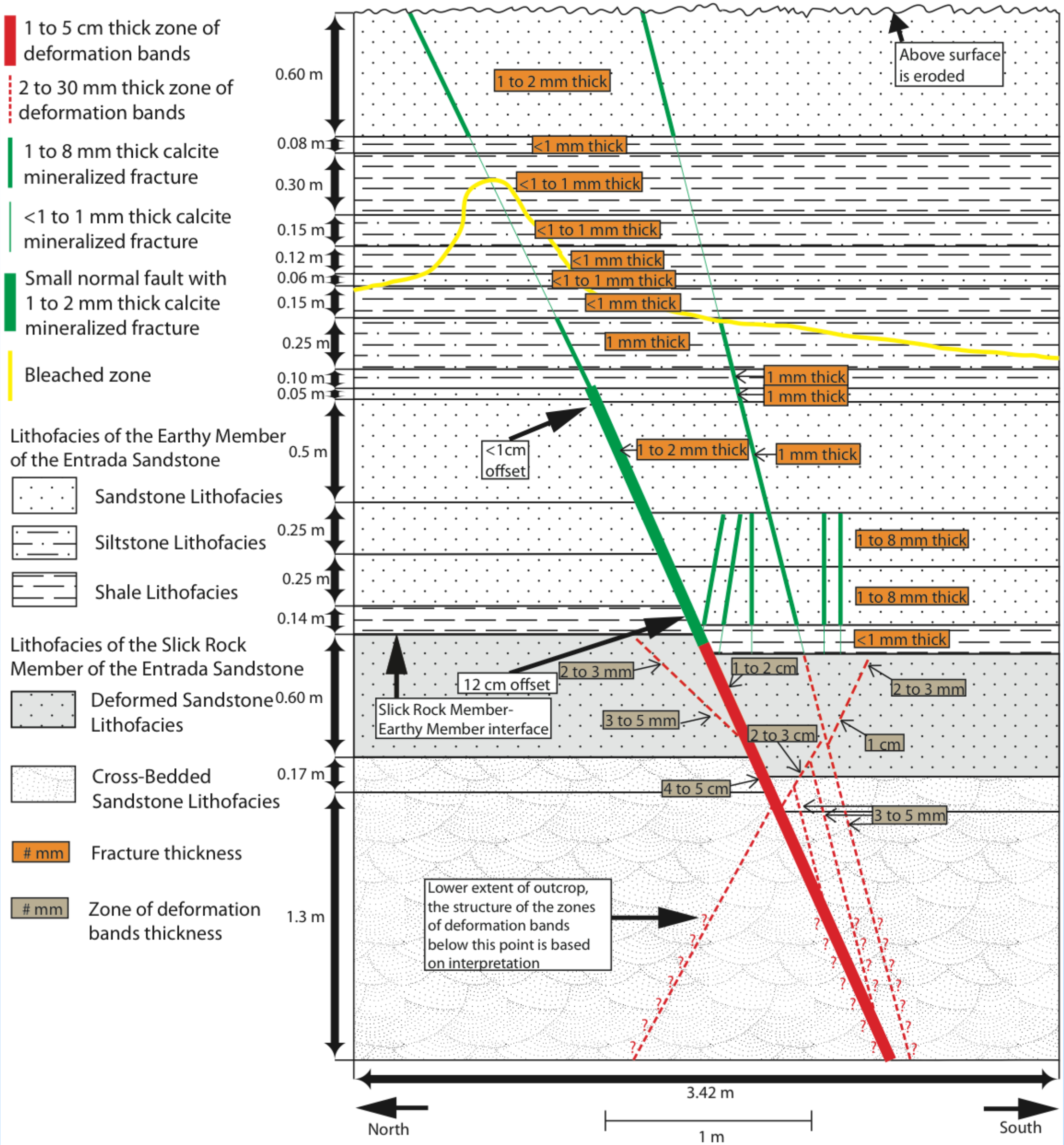
Transition to Fractures

- How do we know they are “real” fractures?
- Used diagenetic alterations
  - Bleaching
  - Mineralization
    - Carbonate cementation
    - Fe-oxide pseudomorphs of pyrite
    - Hydrocarbon inclusions
    - Can infer aperture history through petrography



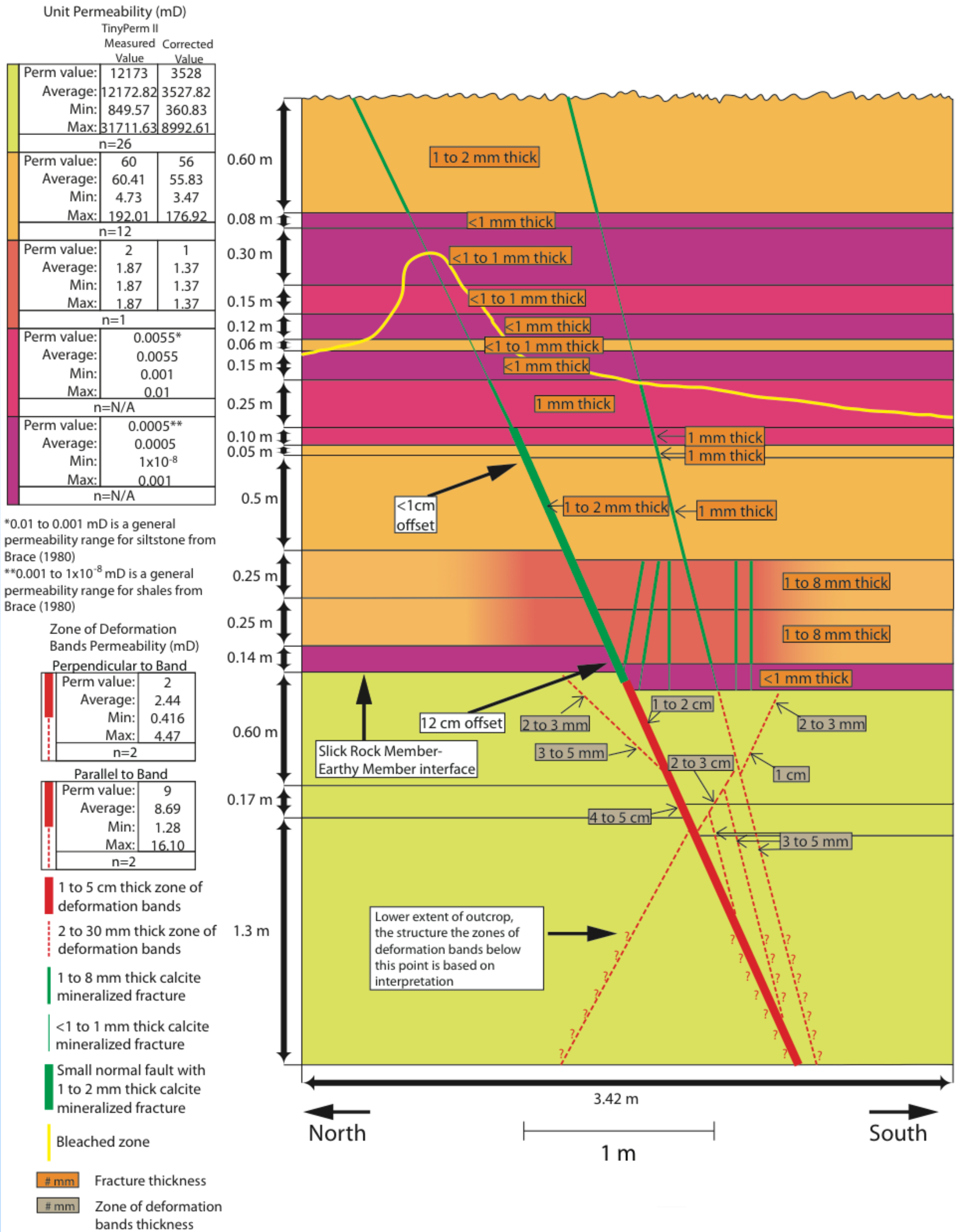
Deformation Band/Fracture Transition, Slickrock/Earthy





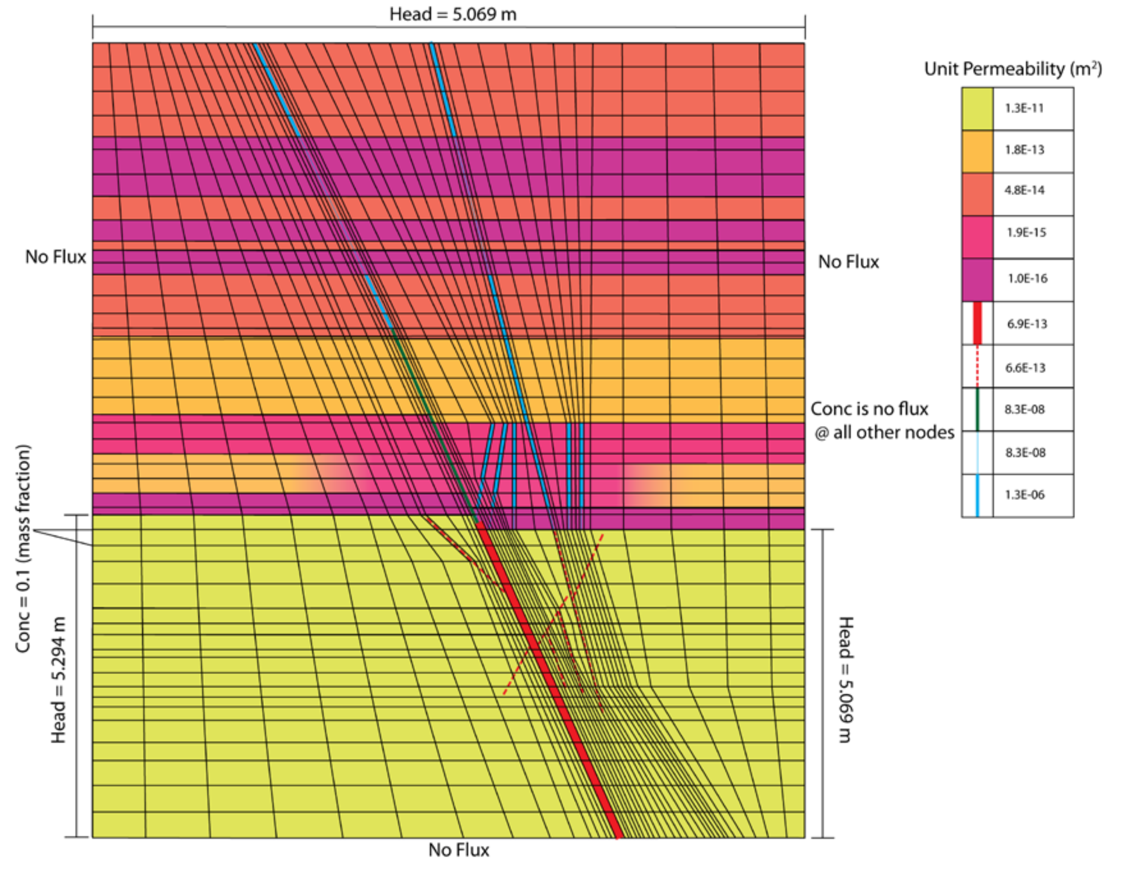
1 to 5 cm thick zone of deformation bands
2 to 30 mm thick zone of deformation bands
1 to 8 mm thick calcite mineralized fracture
<1 to 1 mm thick calcite mineralized fracture
Small normal fault with 1 to 2 mm thick calcite mineralized fracture
Bleached zone
Lithofacies of the Earthy Member of the Entrada Sandstone
Sandstone Lithofacies
Siltstone Lithofacies
Shale Lithofacies
Lithofacies of the Slick Rock Member of the Entrada Sandstone
Deformed Sandstone Lithofacies
Cross-Bedded Sandstone Lithofacies
mm
Fracture thickness
mm
Zone of deformation bands thickness
0.60 m
0.08 m
0.30 m
0.15 m
0.12 m
0.06 m
0.15 m
0.25 m
0.10 m
0.05 m
0.5 m
0.25 m
0.25 m
0.14 m
0.60 m
0.17 m
1.3 m
Above surface is eroded
1 to 2 mm thick
<1 mm thick
<1 to 1 mm thick
<1 to 1 mm thick
<1 mm thick
<1 to 1 mm thick
<1 mm thick
1 mm thick
1 mm thick
1 mm thick
<1cm offset
1 to 2 mm thick
1 mm thick
1 to 8 mm thick
1 to 8 mm thick
<1 mm thick
12 cm offset
2 to 3 mm
1 to 2 cm
2 to 3 mm
Slick Rock Member-Earthy Member interface
3 to 5 mm
2 to 3 cm
1 cm
4 to 5 cm
3 to 5 mm
Lower extent of outcrop, the structure of the zones of deformation bands below this point is based on interpretation
3.42 m
North
1 m
South

Slickrock/Earthy Permeability Model

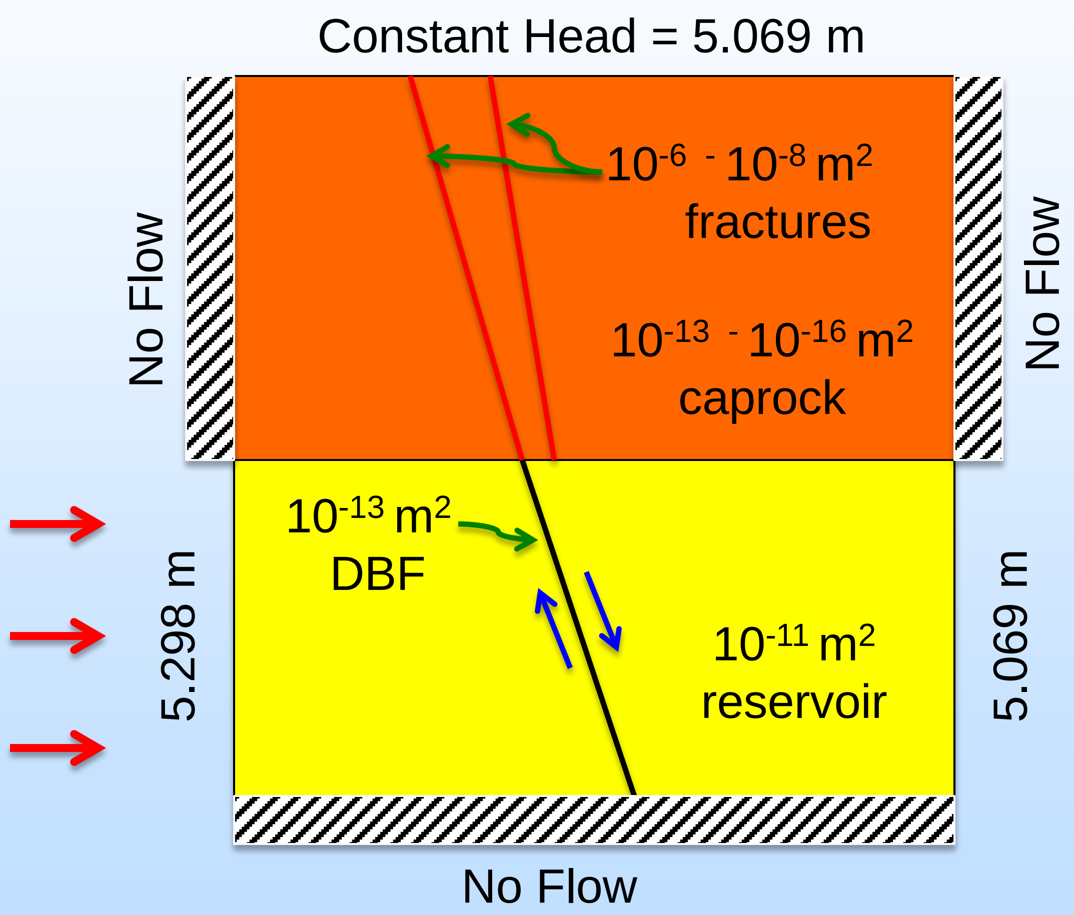


Single-Phase Modeling

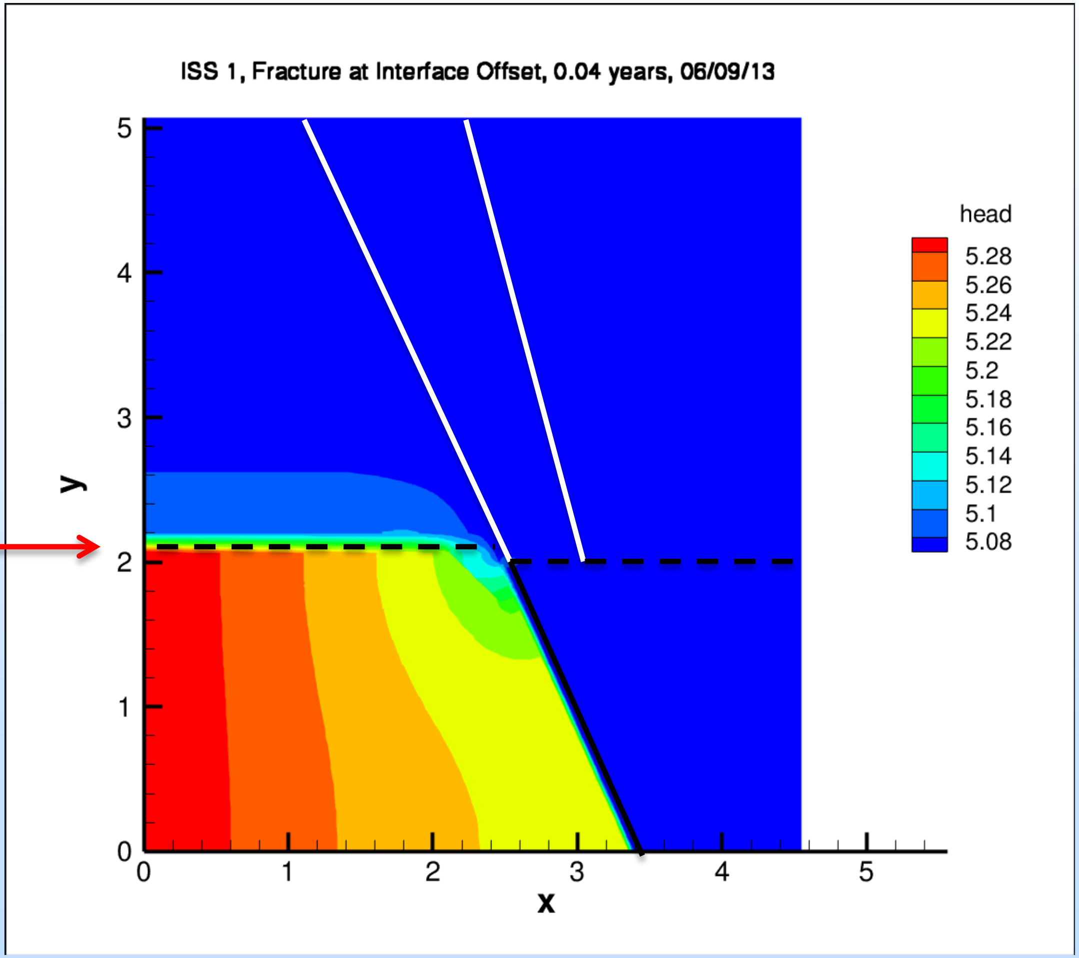
- FEMOC (finite element method of characteristics) code



Simplified Boundary Conditions and Permeabilities



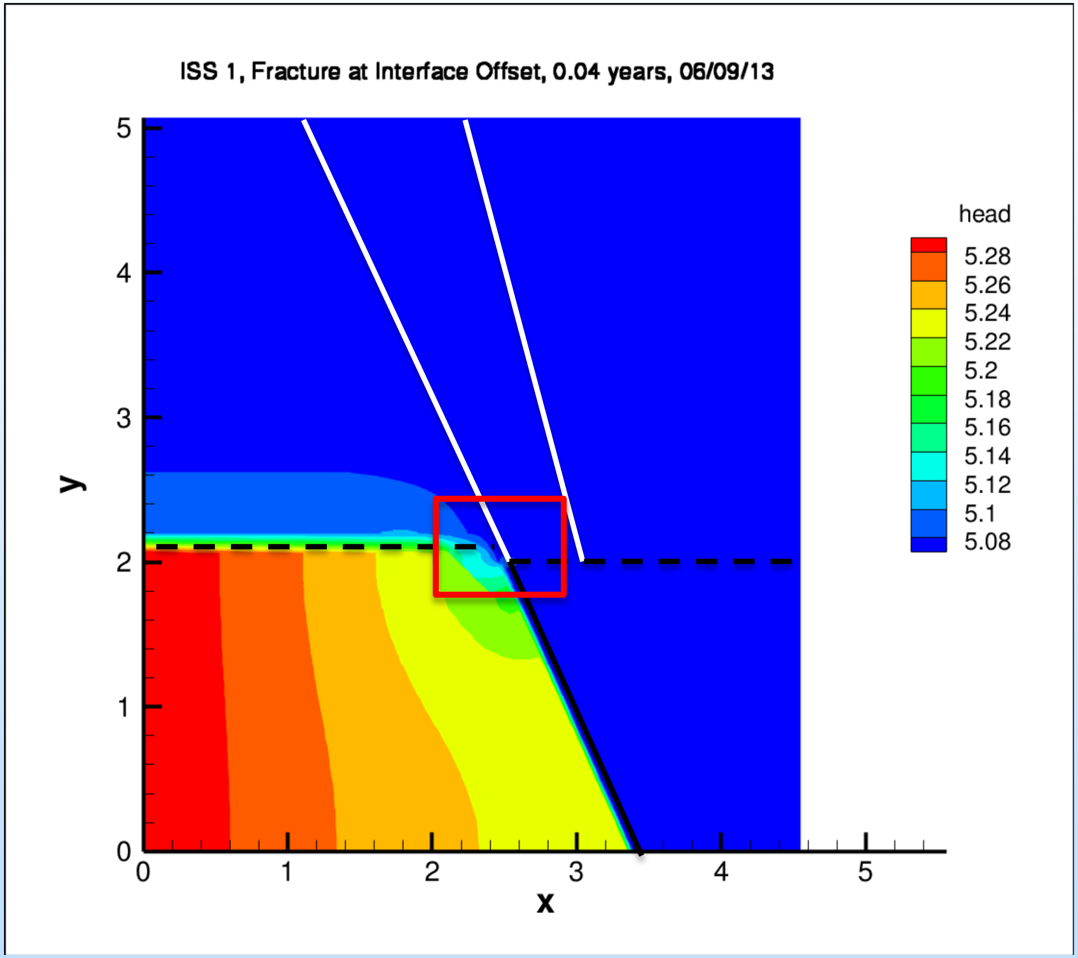
Hydraulic Head



Interface

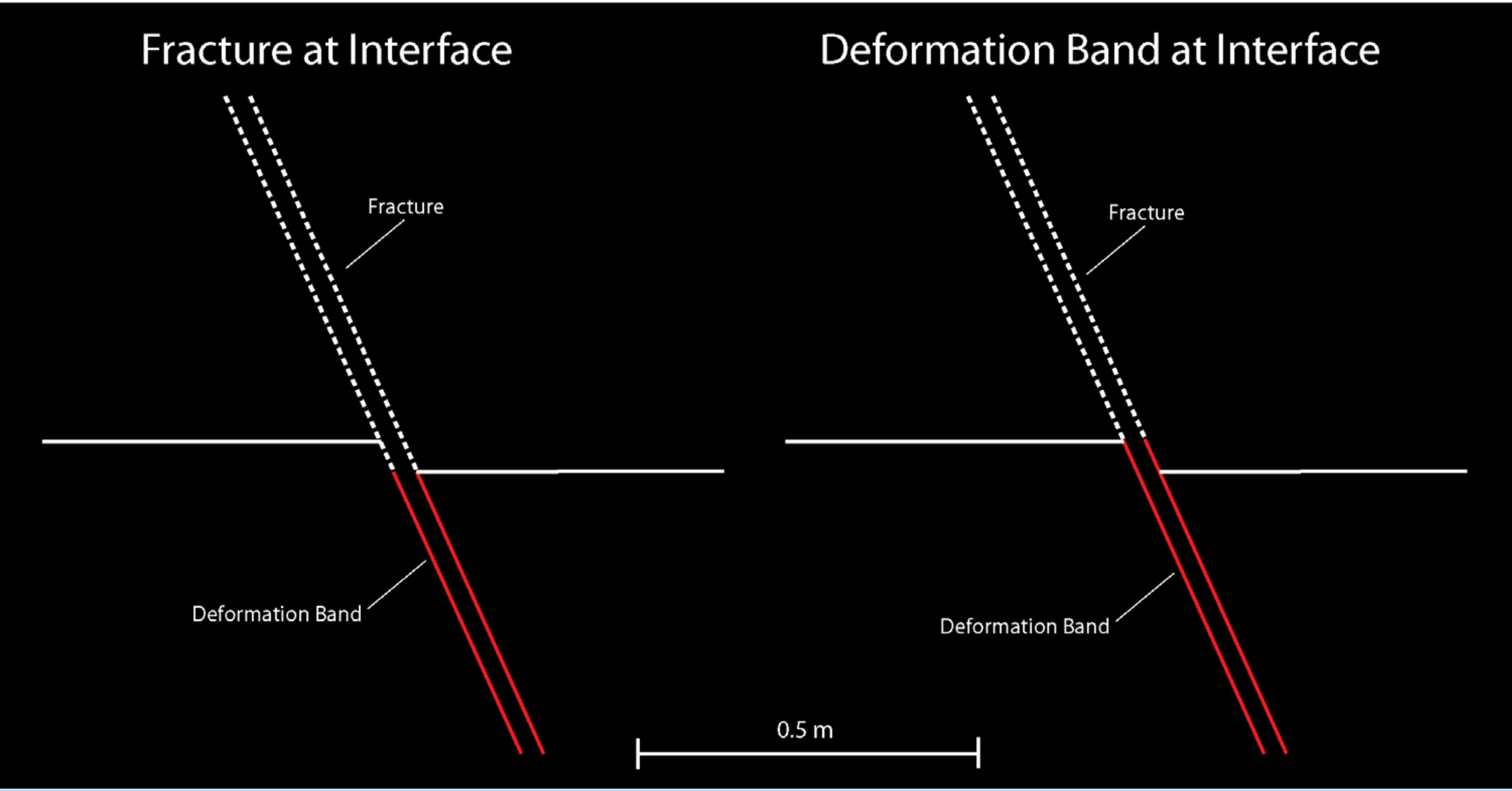
- Head compart-mentalization
- Low head at fracture tip
- Greater compart-mentalizaiton if fracture has lower K
- High risk site for seal failure

Importance of small-scale architecture



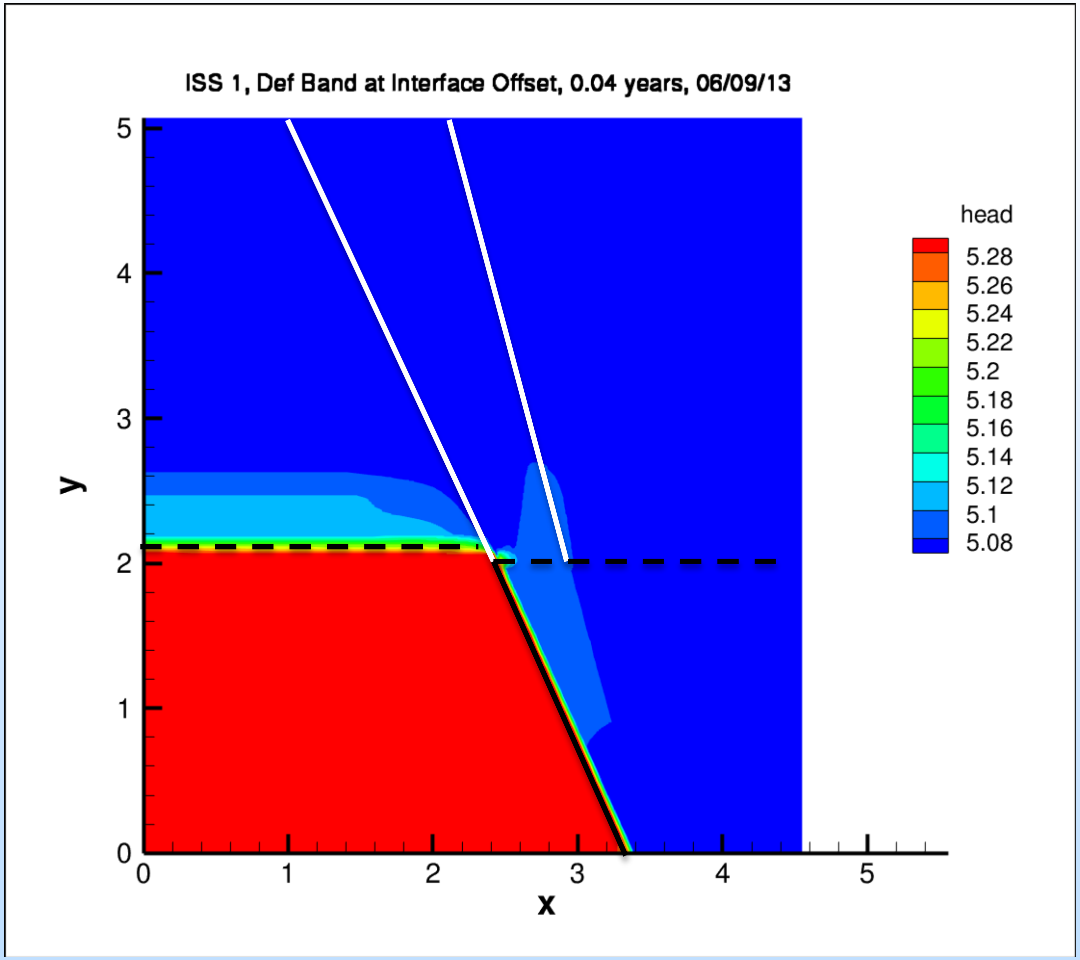
- Deformation band to fracture transition zone
- Have assumed fracture in direct contact with reservoir for this model

Importance of small-scale architecture



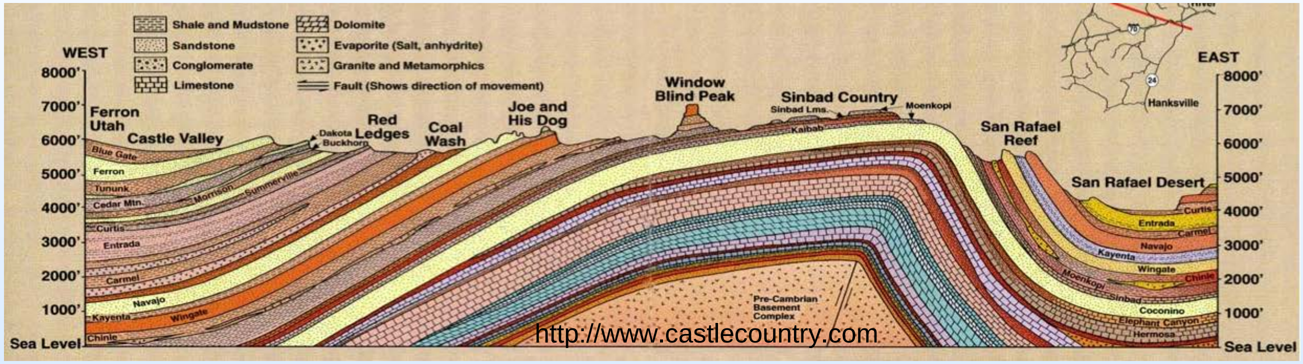
Importance of small-scale architecture

Deformation band at interface

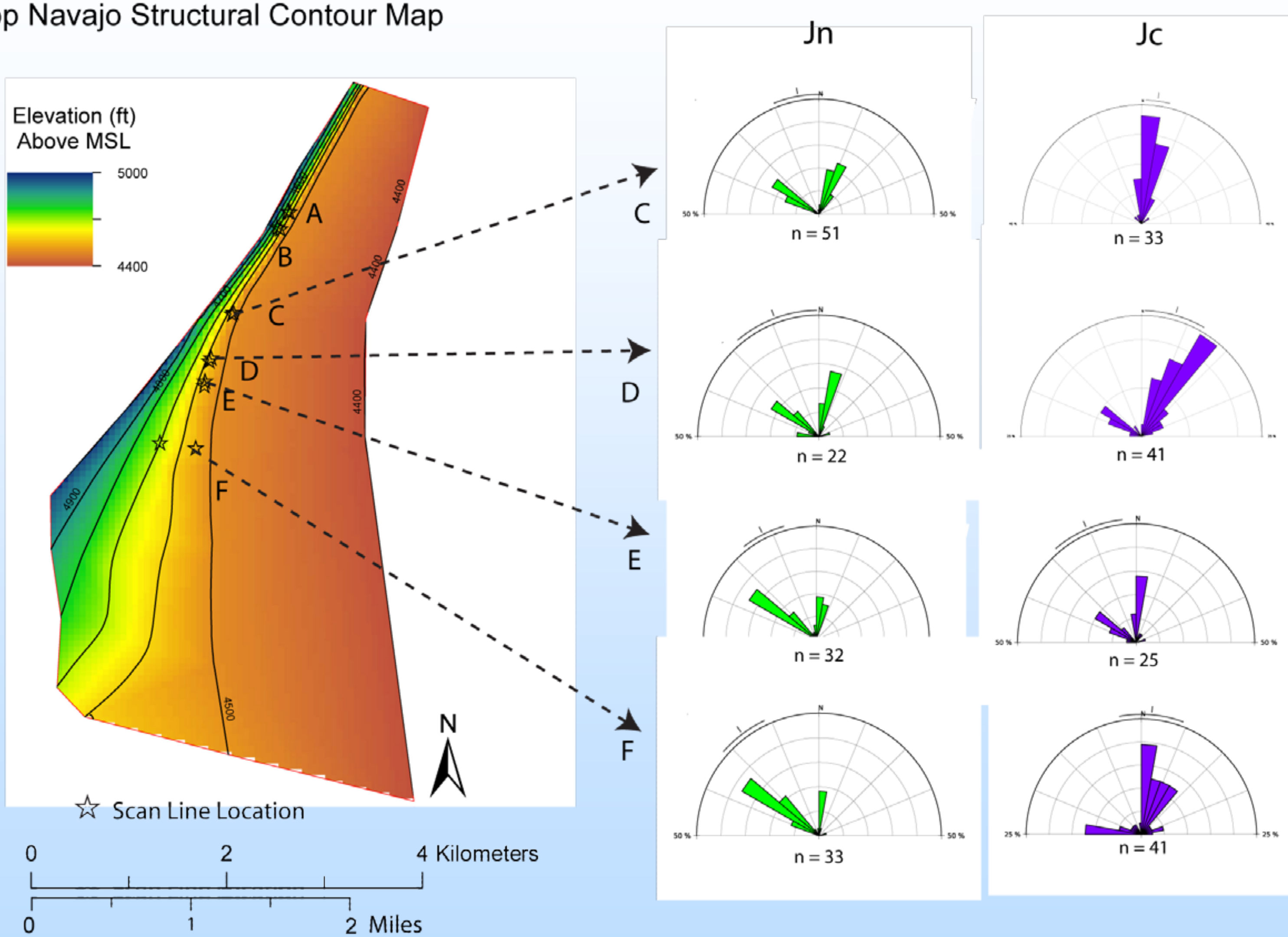


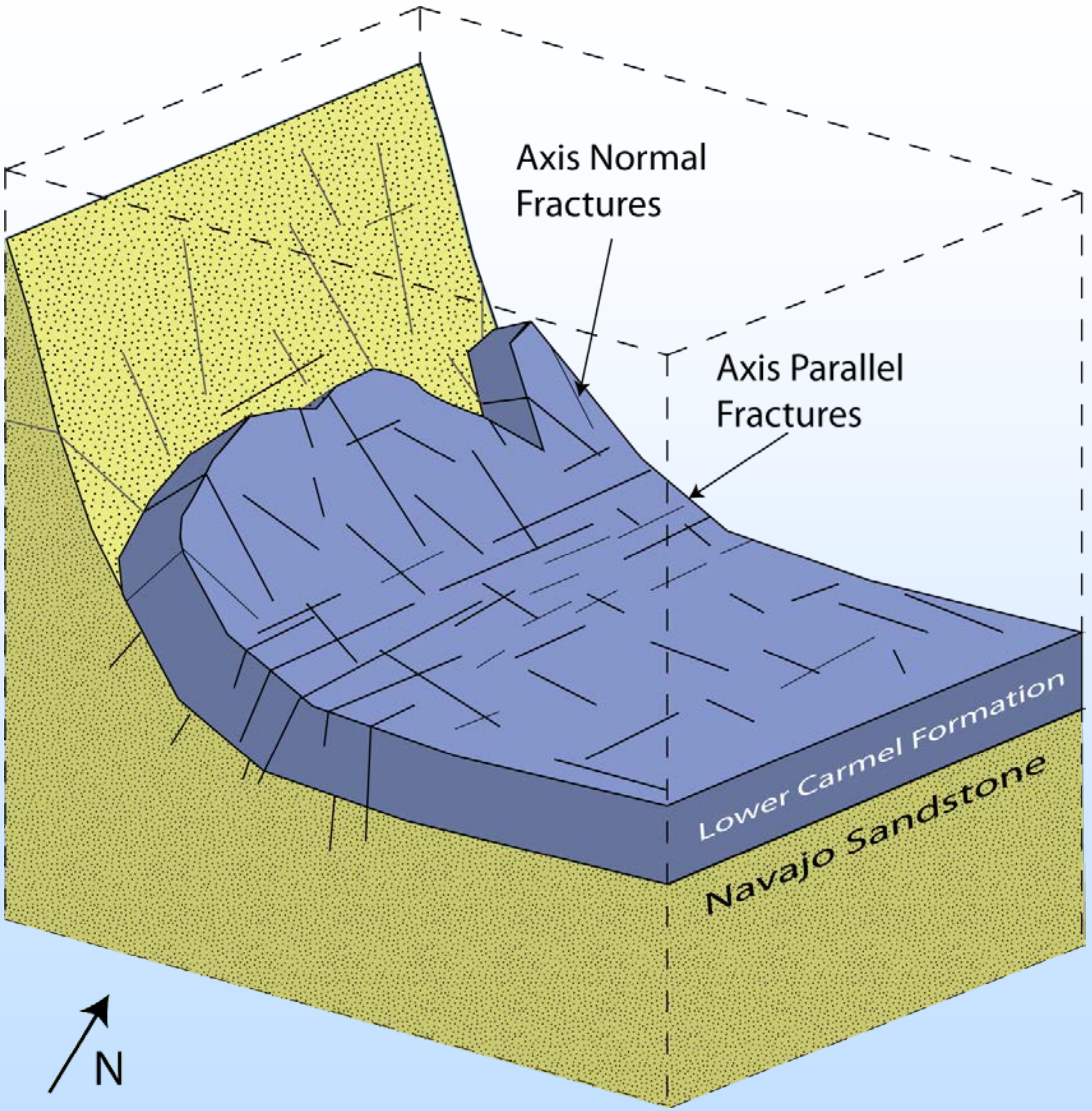
- Greater compart-mentalization
- 2 orders of magnitude lower flux through fracture

Relating Fractures to Structural Position on the SR Swell



Top Navajo Structural Contour Map





- Curvature changes across fold limbs that creates changes in fracture patterns
- Transverse fracture swarms 100's m long
- Concentrations of fractures near faults create pathways up to a km long

Accomplishments to Date

- Navajo/Carmel, Earthy/Slickrock
  - Geologic description and conceptual permeability models of interfaces for 6 Utah sites
  - 10s of km fracture density and orientation data
  - Single-phase modeling results
  - Progress on multiphase modeling
- Mt. Simon/Eau Claire
  - Core description, petrographic analysis and mercury porosimetry competed for 180 ft of Mt. Simon/Eau Claire (Dallas Center Structure, central Iowa)

Summary

- Key Findings
  - Deformation-band faults often link to transmissive fracture networks in the caprock
  - Deformation bands can form capillary seals to CO_2
  - Can compartmentalize the reservoir adjacent to the interface
  - Small-scale interface features can have a huge impact on fluid transmission
  - Distribution of such features a function of structural position at analog storage sites
  - If deformation bands are in your reservoir, they should be considered when risking the caprock

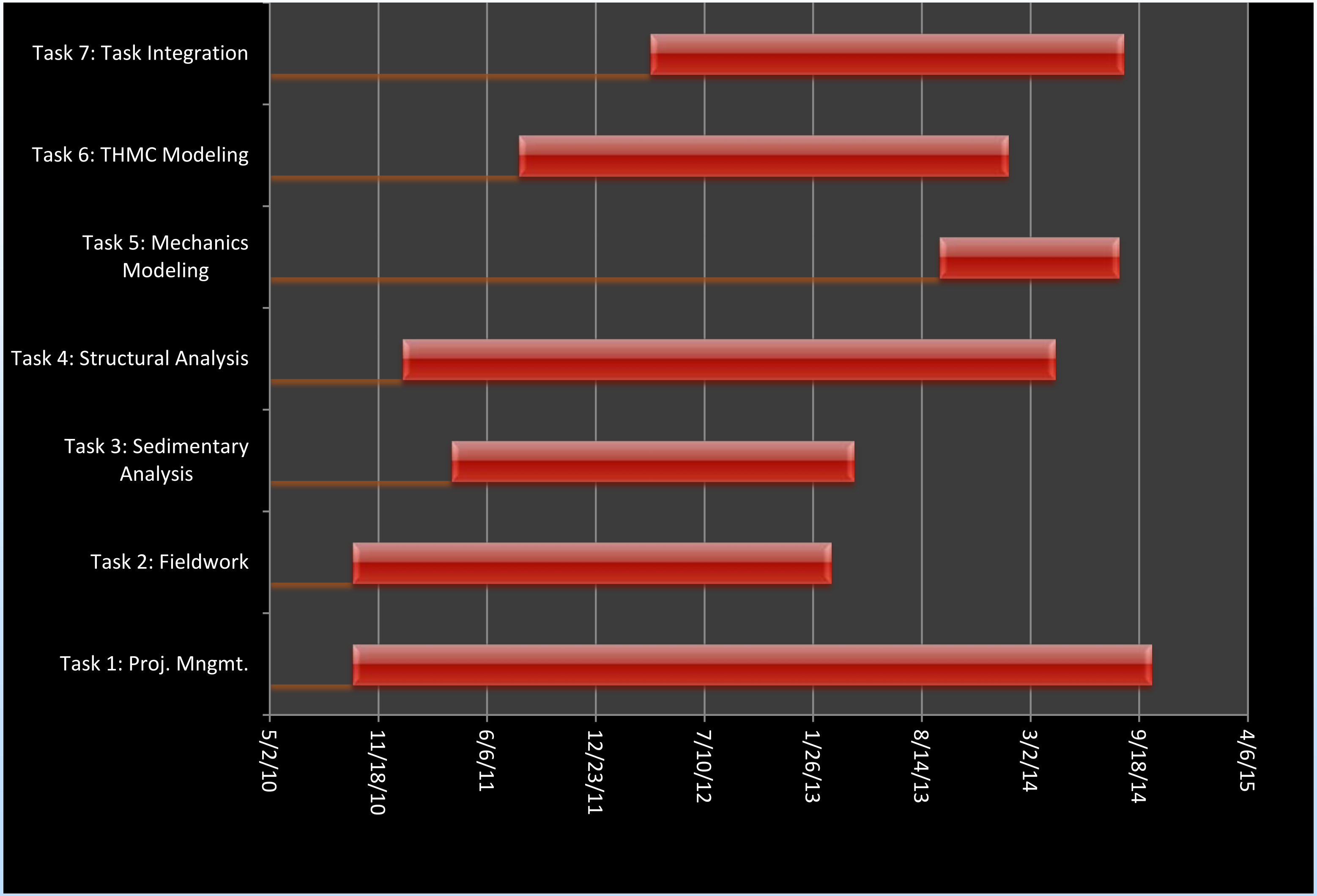
  - Deformation bands and fractures are present in the Mt. Simon, but have not observed fractures in the Eau Claire.

Summary

- Lessons Learned
  - Bring your modelers to the field site
- Future Plans
  - Multiphase flow modeling using FEHM
  - Additional larger-scale modeling
  - Calculating reservoir-scale fluxes

Appendix

Gantt Chart



Task 7: Task Integration
Task 6: THMC Modeling
Task 5: Mechanics Modeling
Task 4: Structural Analysis
Task 3: Sedimentary Analysis
Task 2: Fieldwork
Task 1: Proj. Mngmt.
5/2/10
11/18/10
6/6/11
12/23/11
7/10/12
1/26/13
8/14/13
3/2/14
9/18/14
4/6/15

Bibliography

No peer reviewed publications generated from project yet.

Raduha, S., 2013, Influence of mesoscale features at the reservoir-caprock interface on fluid transmission into and through caprock: New Mexico Tech MS Thesis. (Available at ees.nmt.edu)

Raduha, S, Butler, D., Mozley, P., Person, M., Evans, J., Flores, S., Heath, J., Dewers, T., 2013, Potential seal bypass features produced by deformation-band fault to opening-mode fracture transition at the reservoir-caprock interface: GSA Annual Meeting, Denver. (Submitted)

Mozley, P., Heath, J., Dewers, T., 2014, Origin and size distribution of porosity in the Mt. Simon Sandstone and Eau Claire Formation: Implications for multiphase fluid flow: AAPG Annual Meeting, Houston. (To be submitted)