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 Building the Infrastructure for CO_2 Storage
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Presentation Outline

- Introduction
- Organization
- Benefit to Program
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- Technical Status
- Accomplishments to Date
- Summary
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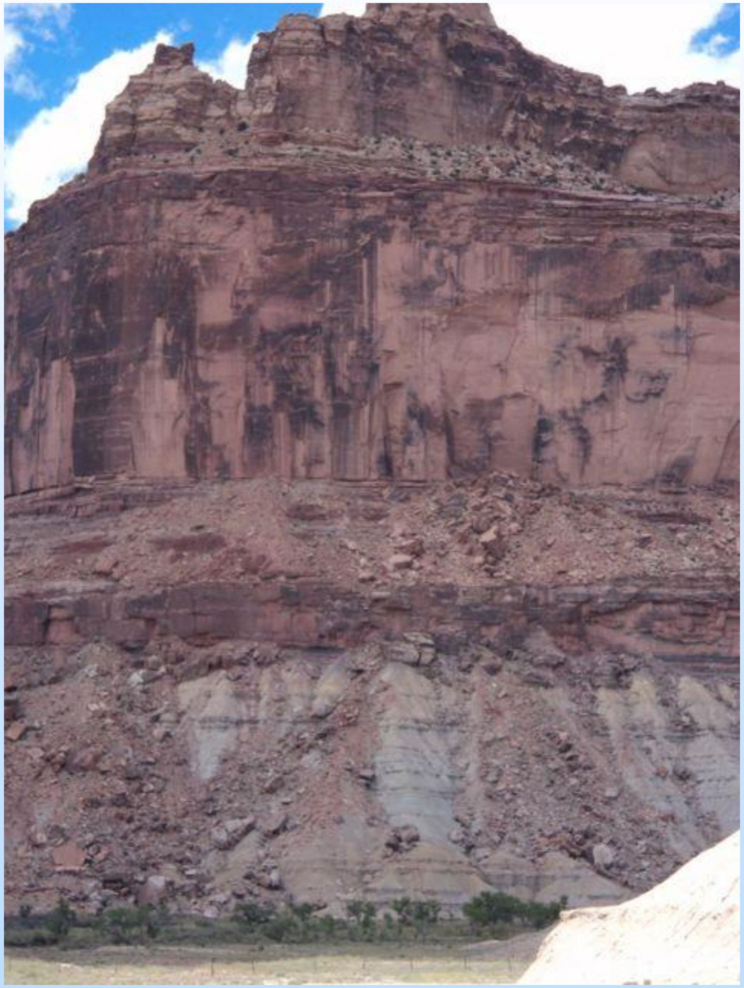
Introduction

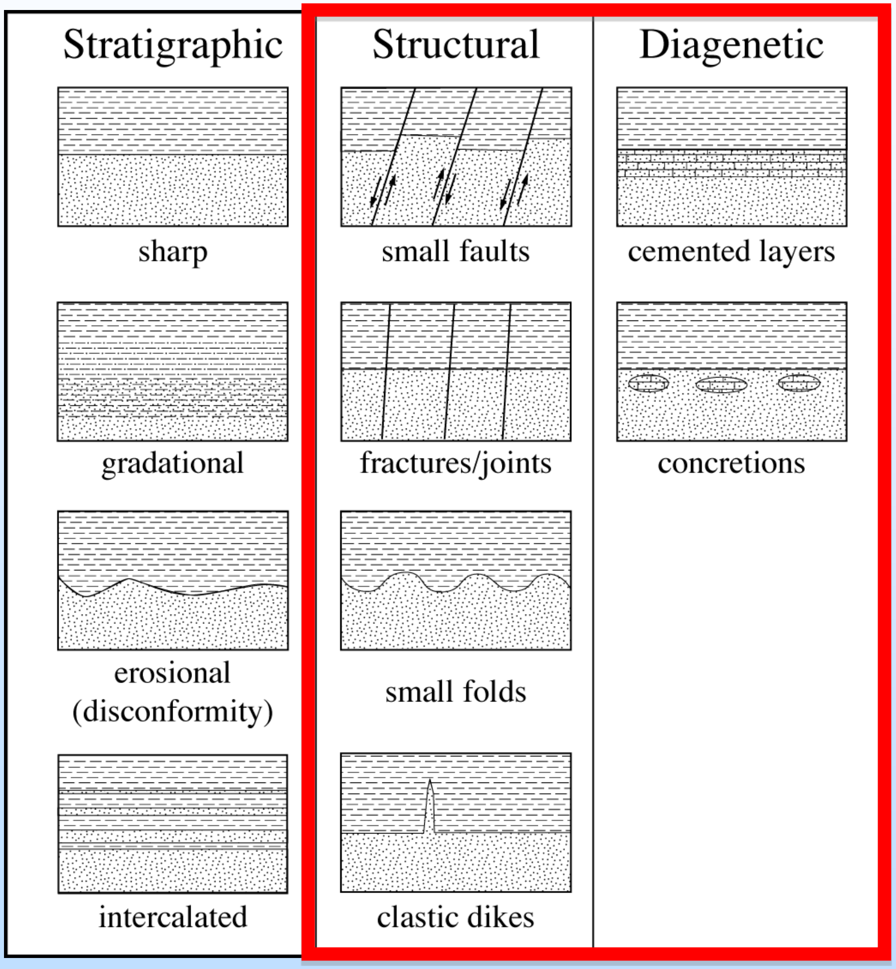
- Most storage modeling studies involve a caprock/reservoir interface, and assume a discrete contact with simple (uniform) flow conditions.
- We address the question of whether or not heterogeneities at the interface influence transmission of CO_2 into the caprock

Introduction

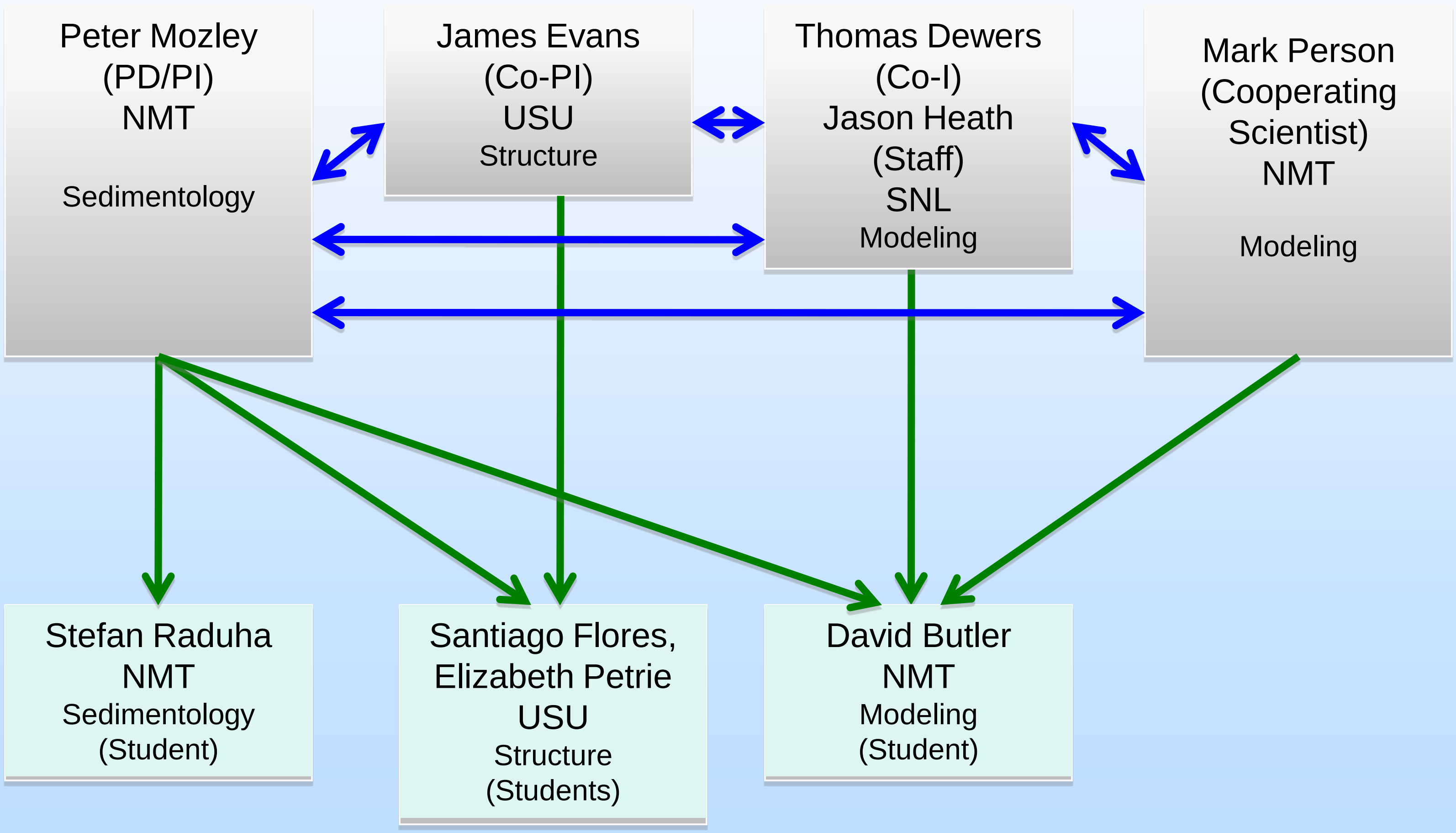
The nature of reservoir/caprock interfaces



Triassic-Jurassic Strata, San Rafael Swell, UT



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 existing codes used to predict 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 and core
- 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

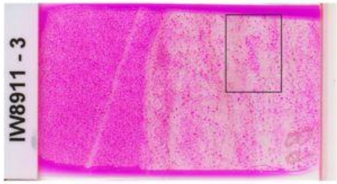
Deformation Bands

- The most common strain localization feature found in porous sandstones

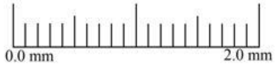
- Form by: grain reorganization and/or fracture during overall dilation, shearing, and/or compaction

- Typically 1 – 3 orders of magnitude lower K than host sand

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?

Challenges to Caprock Description

- Poor outcrops
- Identifying subsurface fracture networks
- Estimating fracture permeability

Our Approach

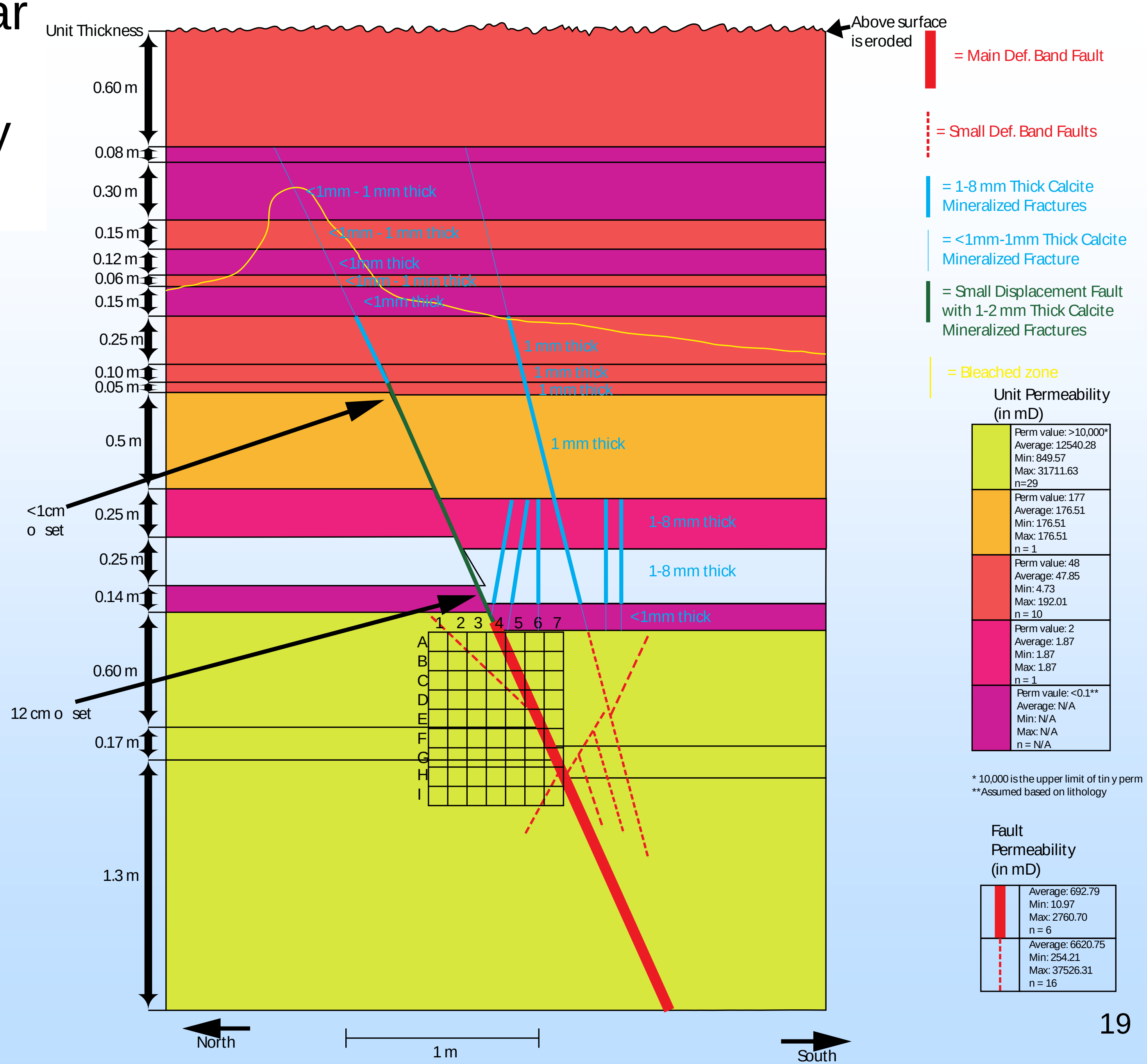
- Use diagenetic alteration to constrain fracture origin and subsurface aperture
  - Carbonate cementation
  - Bleaching

Deformation Band/Fracture Transition, Slickrock/Earthy

Deformation Band/Joint to Fracture Transition, Navajo/Carmel

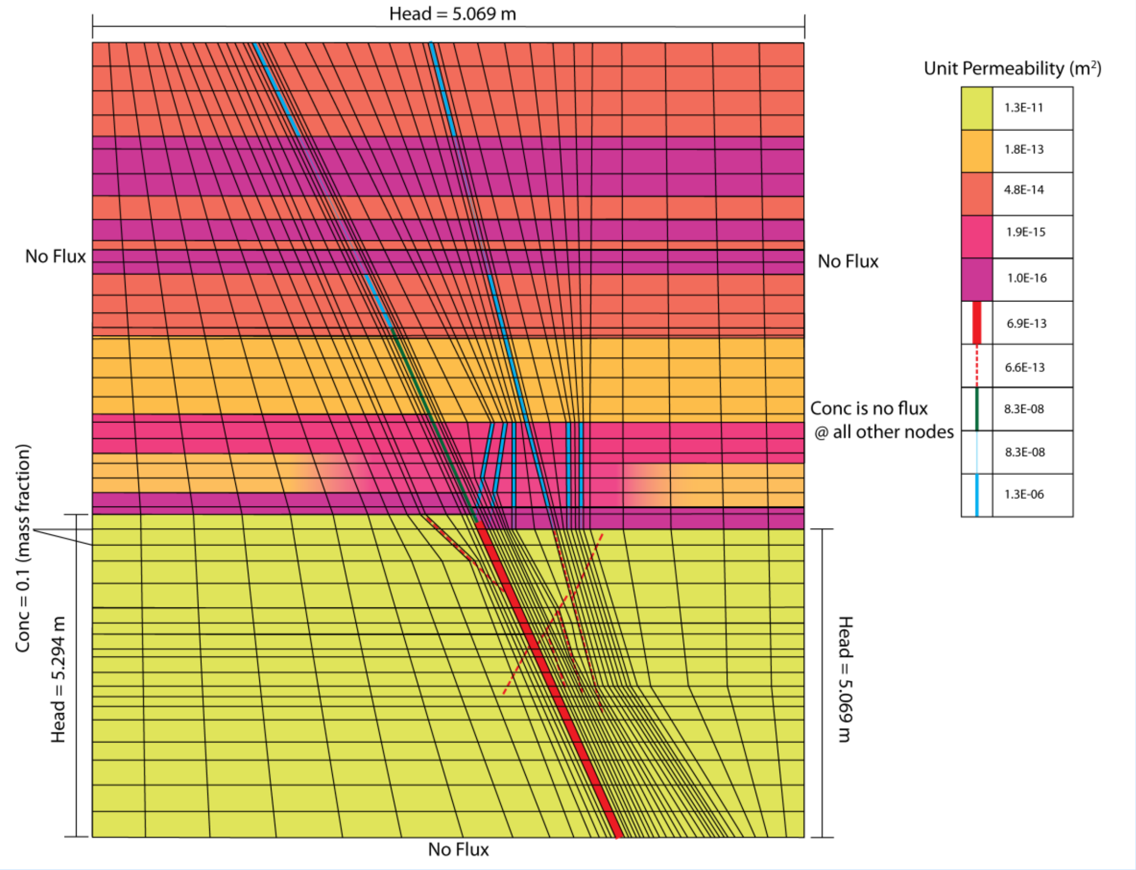
3 cm thick!
UM-31312-2
UM-31312-3
UM-31312-5
UM-31312-1
TP5
TP 4
<1mm
<1mm

Slickrock/Earthy Permeability Model

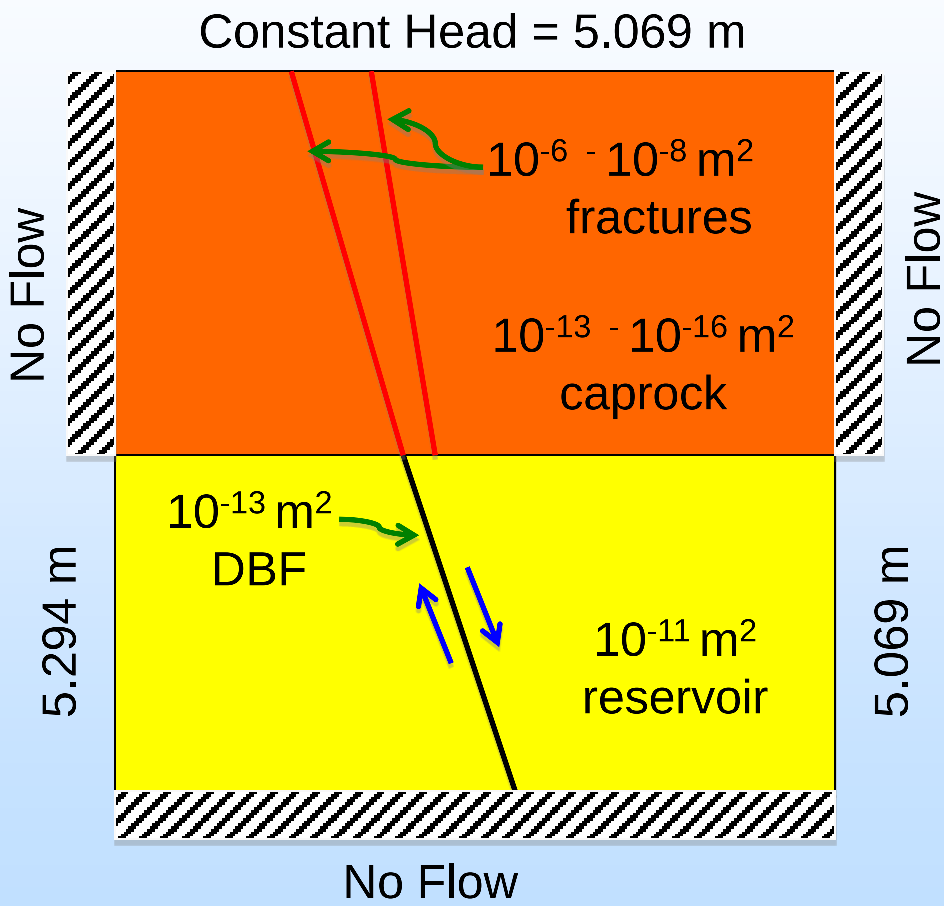


Preliminary Modeling

- FEMOC (finite element method of characteristics) code



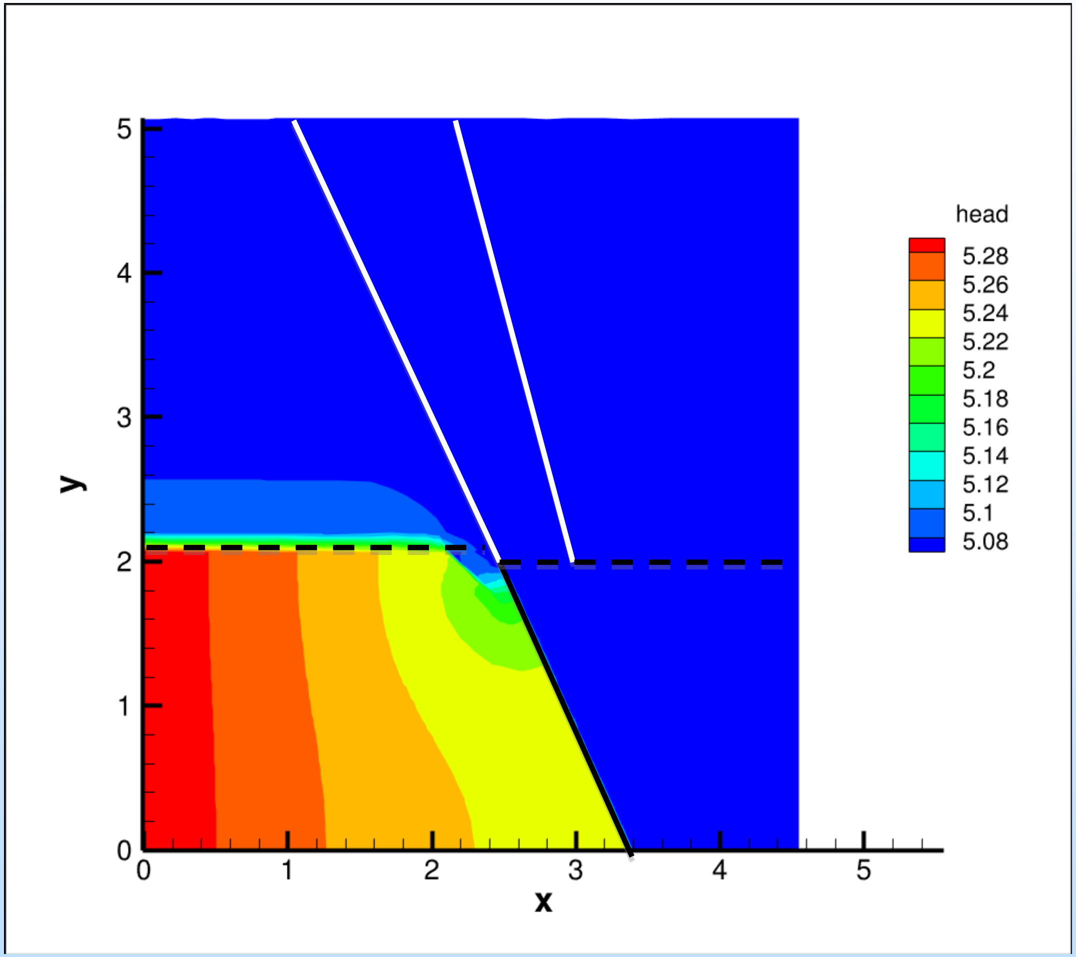
Preliminary Modeling



We will vary:

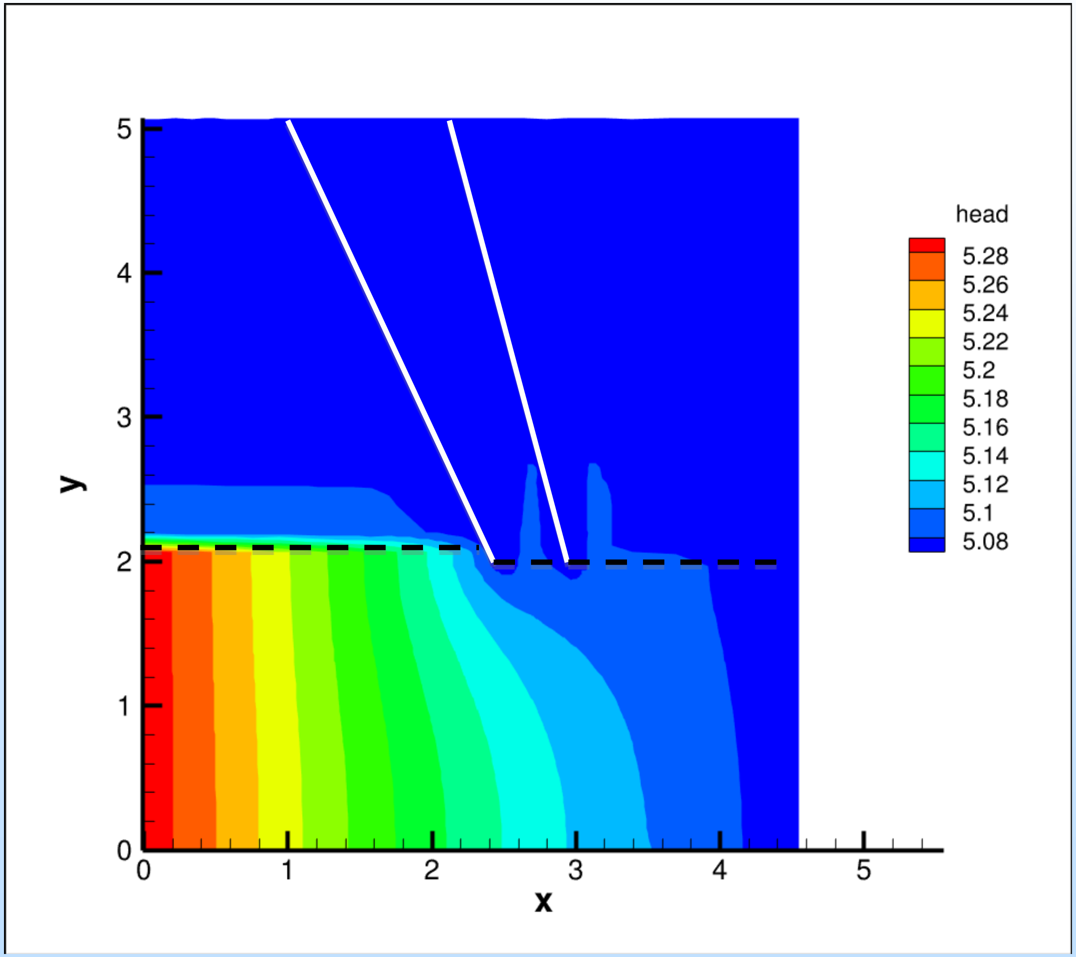
- Permeability of fractures
  - High
  - Med (= res sand)
- Presence or absence of deformation bands

Head with deformation bands, high K (10^{-6} – 10^{-8} m^2) fractures



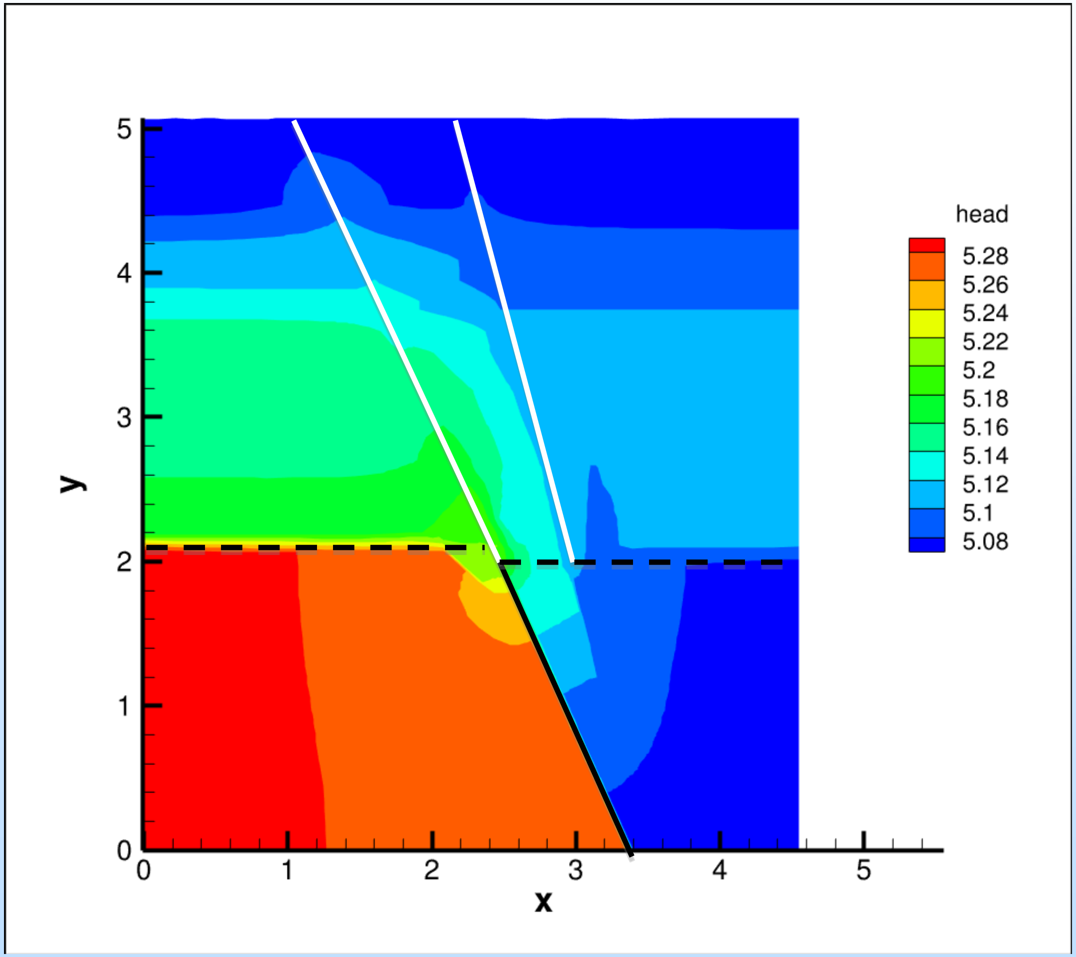
- Head compart-mentalization
- Low head at fracture tip

Head without deformation bands, high K (10^{-6} – 10^{-8} m^2) fractures



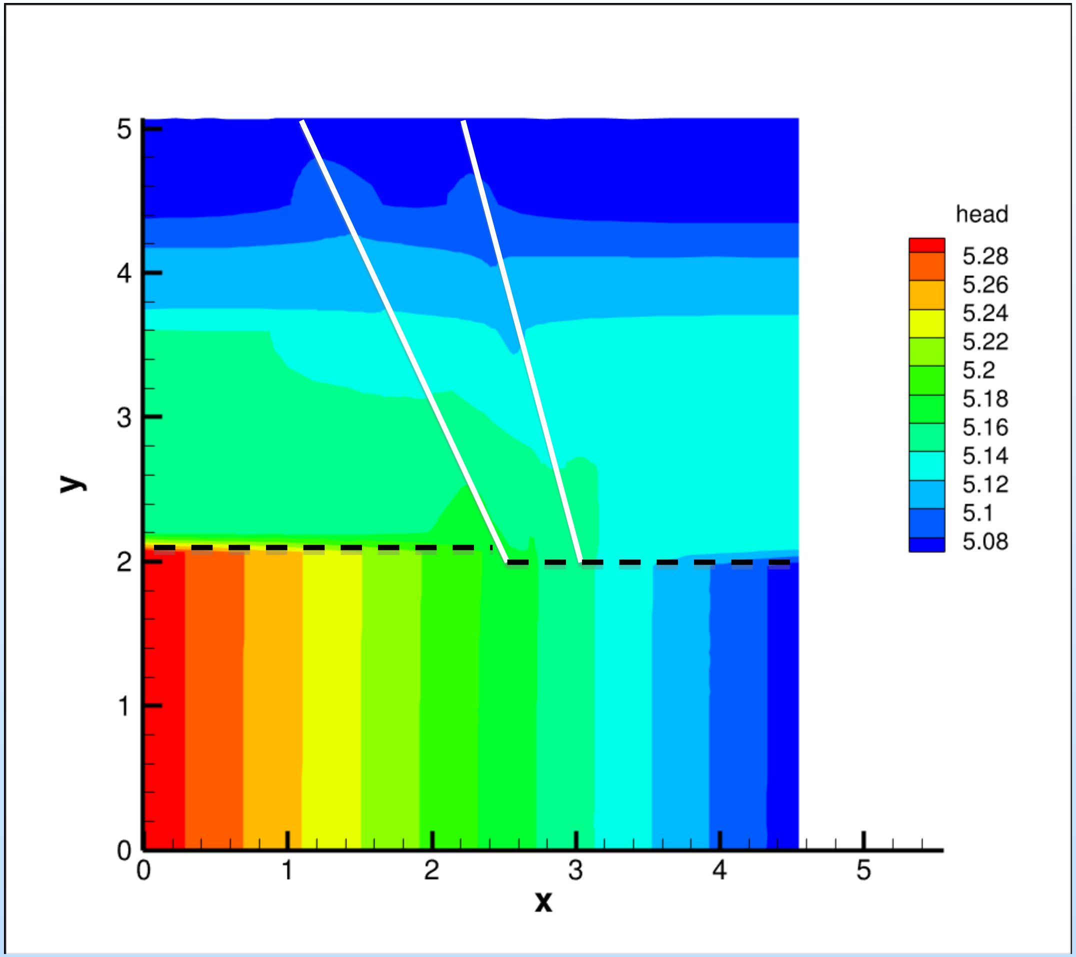
- High K fractures decrease head near fracture tips

Head with deformation bands, med K (10^{-11} m^2) fractures



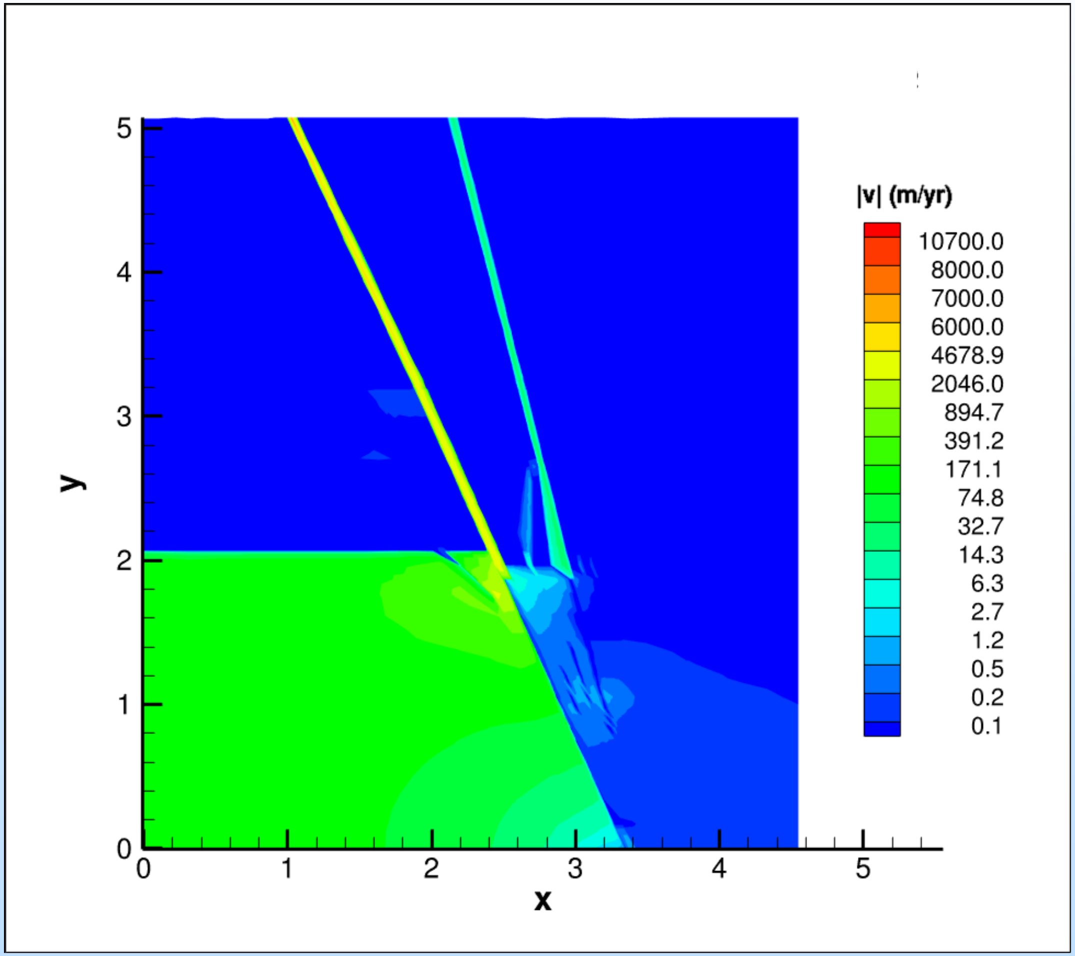
- Med K case (e.g., partial cementation)
- Decreasing fracture K increases compart-mentalization and head adjacent to fracture tip

Head without deformation bands, medium K (10^{-11} m^2) fractures



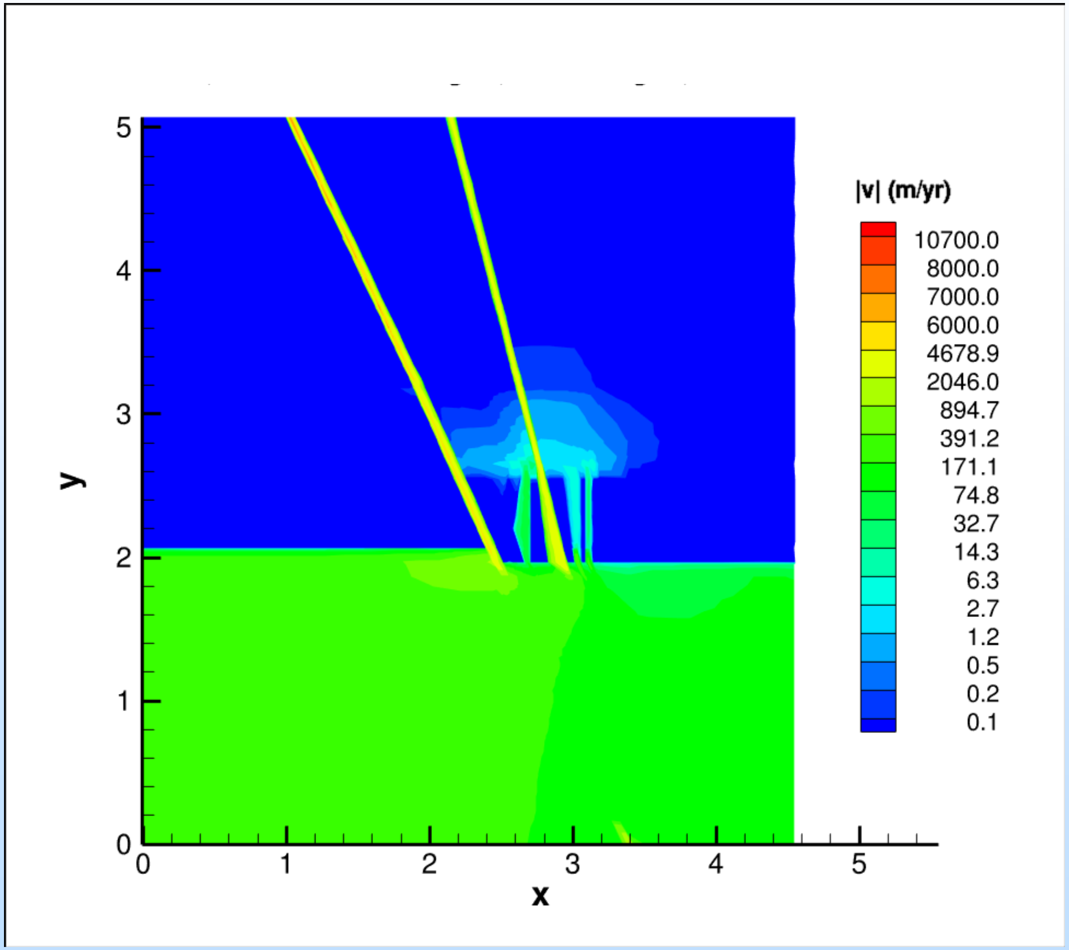
- Head in reservoir essentially unaffected

Flux with deformation bands, high K (10^{-6} – 10^{-8} m^2) fracture

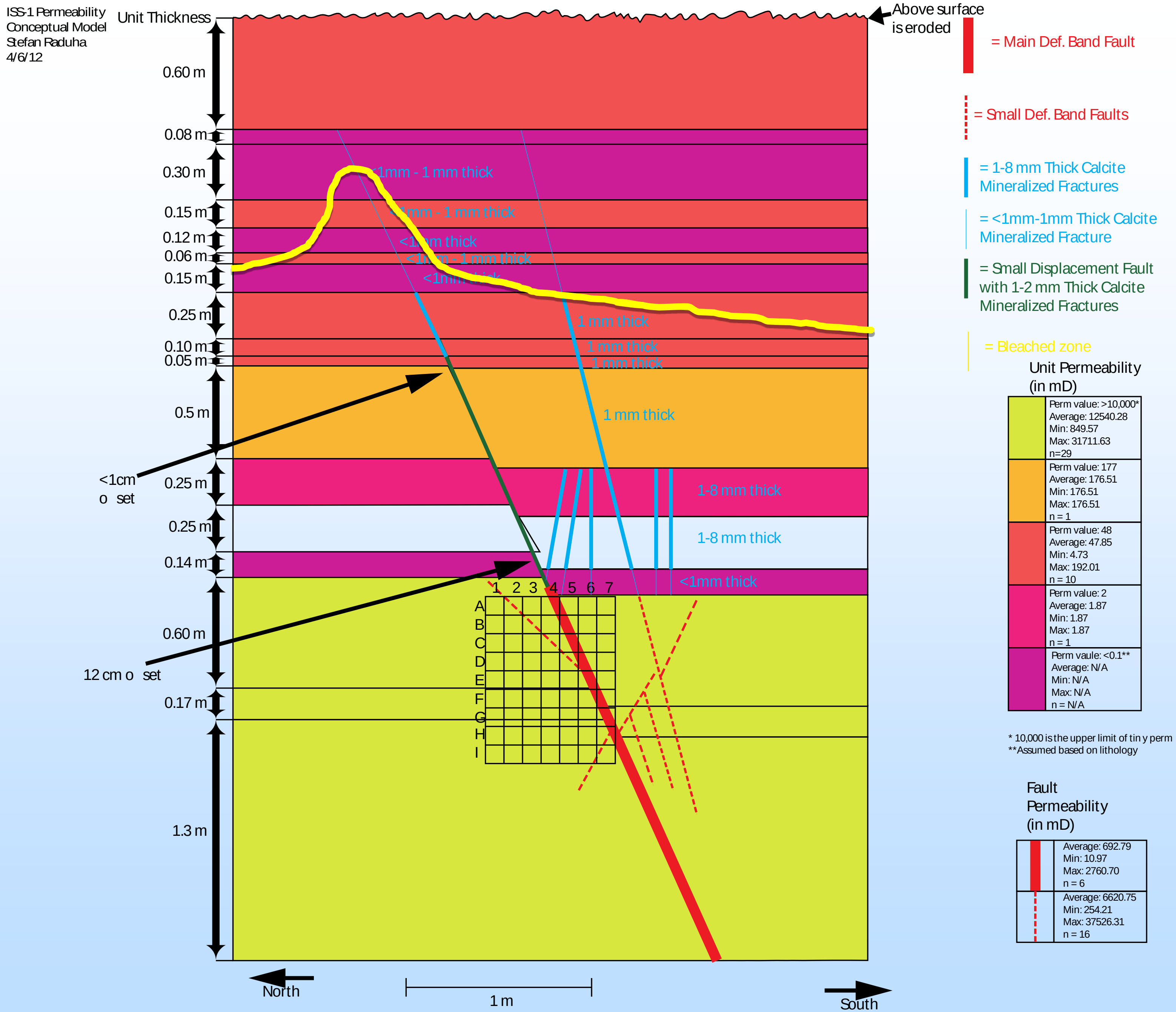


- Asymmetrical fluxes

Flux with no deformation bands, high K (10^{-6} – 10^{-8} m^2) fractures

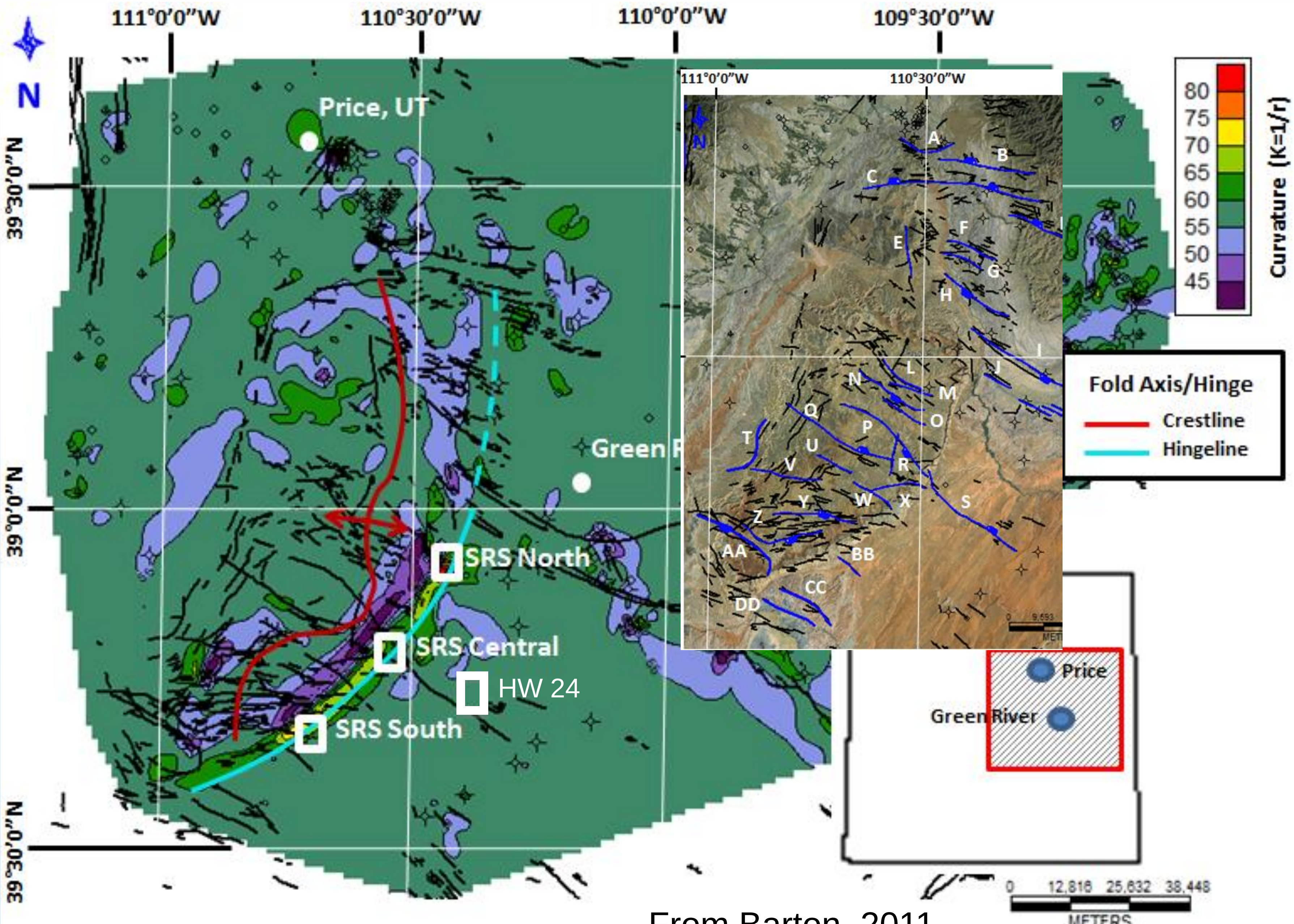


- Symmetrical fluxes
- Any mineralogical evidence to support asymmetry?



ISS-1 Permeability
Conceptual Model
Stefan Raduha
4/6/12
Unit Thickness
Above surface is eroded
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
<1cm o set
12 cm o set
<1mm - 1 mm thick
<1mm - 1 mm thick
<1mm thick
<1mm - 1 mm thick
<1mm thick
1 mm thick
1 mm thick
1 mm thick
1 mm thick
1-8 mm thick
1-8 mm thick
<1mm thick
1 2 3 4 5 6 7
A
B
C
D
E
F
G
H
I
North
1 m
South
= Main Def. Band Fault
= Small Def. Band Faults
= 1-8 mm Thick Calcite Mineralized Fractures
= <1mm-1mm Thick Calcite Mineralized Fracture
= Small Displacement Fault with 1-2 mm Thick Calcite Mineralized Fractures
= Bleached zone
Unit Permeability (in mD)
Perm value: >10,000* Average: 12540.28 Min: 849.57 Max: 31711.63 n=29
Perm value: 177 Average: 176.51 Min: 176.51 Max: 176.51 n = 1
Perm value: 48 Average: 47.85 Min: 4.73 Max: 192.01 n = 10
Perm value: 2 Average: 1.87 Min: 1.87 Max: 1.87 n = 1
Perm vaule: <0.1** Average: N/A Min: N/A Max: N/A n = N/A
* 10,000 is the upper limit of tin y perm
**Assumed based on lithology
Fault Permeability (in mD)
Average: 692.79 Min: 10.97 Max: 2760.70 n = 6
Average: 6620.75 Min: 254.21 Max: 37526.31 n = 16

Structural context of study sites



From Barton, 2011

Eardley Site

- North of Eardley Canyon the Navajo/Carmel contact changes dip angle in a zone of high curvature.

South facing view of the high curvature zone north of Eardley Canyon. We examine Six sites across the transition from steep to shallow dips, and adjacent to a Larger fault. Red arrows indicate approximate location of sites

Accomplishments to Date

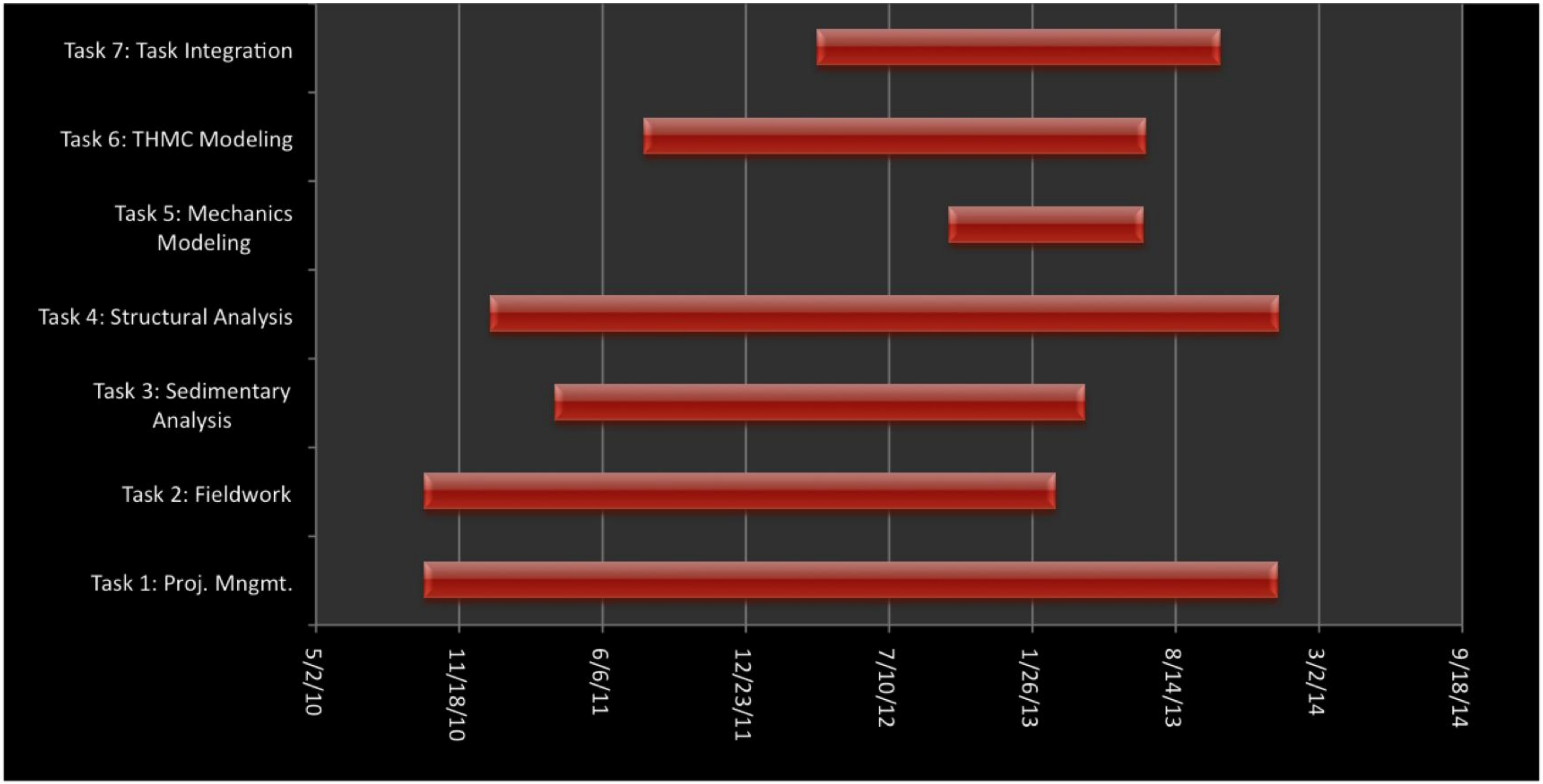
- Navajo/Carmel, Earth/Slickrock
  - Geologic description and conceptual models of interfaces for 6 Utah sites
  - Descriptions of 71 thin sections
  - 10s of km fracture density and orientation data
  - Mechanical variability across the interface quantified at numerous sites
  - Single-phase modeling results for one site
- Mt. Simon/Eau Claire
  - Core description, petrographic analysis and mercury porosimetry competed for 180 ft of Mt. Simon/Eau Claire

Summary

- Key Findings
  - Deformation-band faults often link to transmissive fracture networks in the caprock
  - Such faults can compartmentalize the reservoir adjacent to the interface
- Lessons Learned
  - Close collaboration between geologists and modelers in an iterative manner is essential
- Future Plans
  - Multiphase flow modeling using Tough2
  - Additional laboratory permeability (e.g., mercury porosimetry)
  - Additional modeling (single and multiphase)
  - Collection of smaller scale descriptive data (e.g., laser confocal microscopy)
  - Use fracture density data to determine leakage potential across the interface (upscale to reservoir scale)
  - Additional analysis of Mt. Simon/Eau Claire

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

Bibliography

No peer reviewed publications generated from project yet.