Geomechanical Simulation of Structural Geology: More Than Just a Boundary Value Problem?

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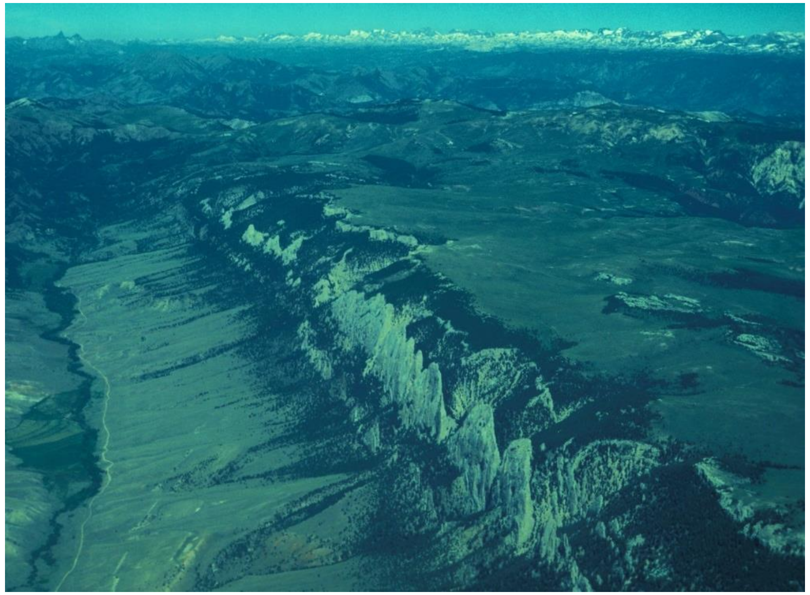
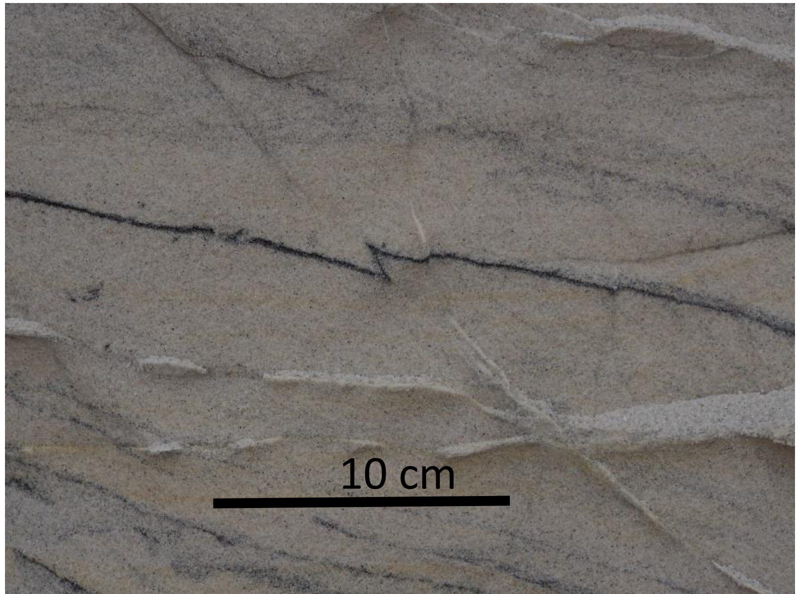
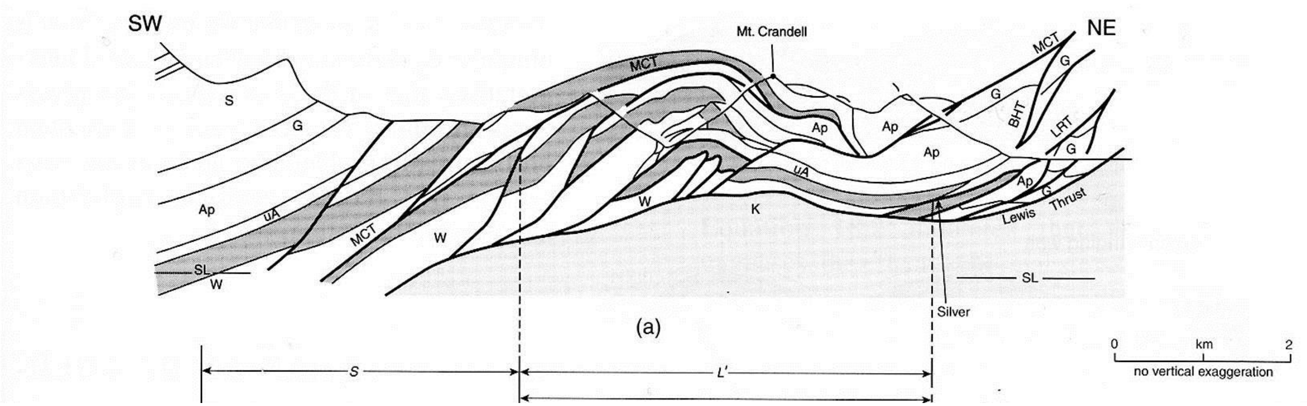
ALERT Workshop 5 October 2016 – Fault Session

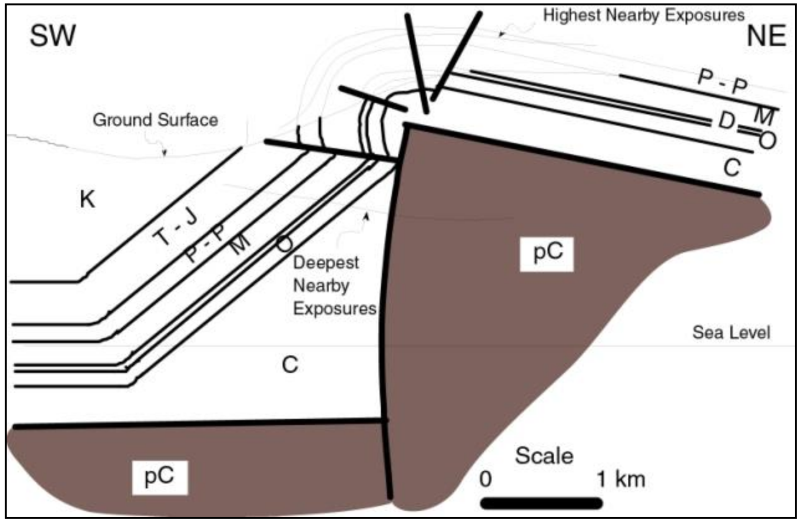
Some real Geology structures

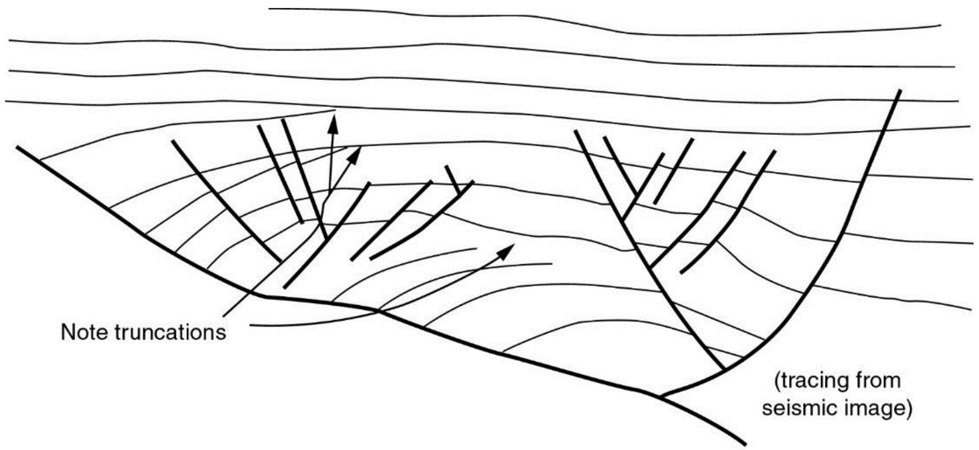


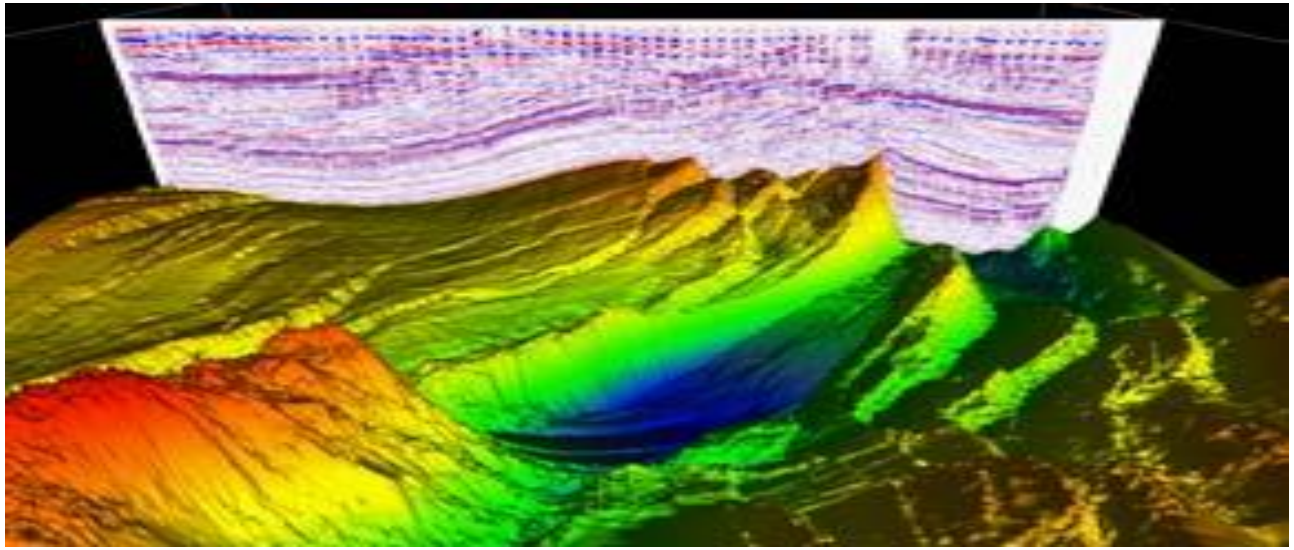


And their representation









Practical objective – deformed rock characteristics

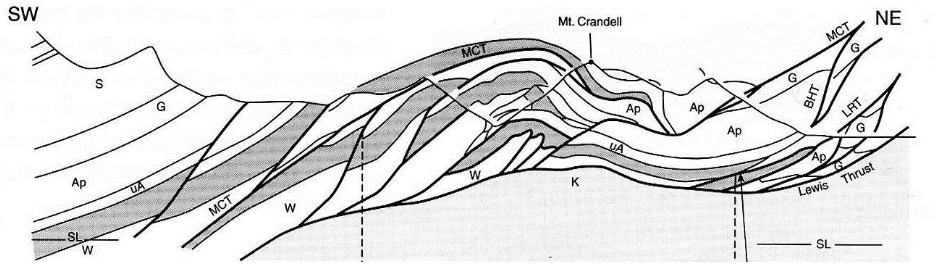
- Simulate, experimentally replicate or otherwise represent spatial distribution of strain field, evolved stress field, rock damage sensu largo (e.g. grain breakage / crushing – cataclasis)

- From these, measure or calculate emergent properties – acoustic, petrophysical, fluid flux, (heat-flux)

- Main toolset is experimental deformation or simulation – making fault systems, often with folds and fractures

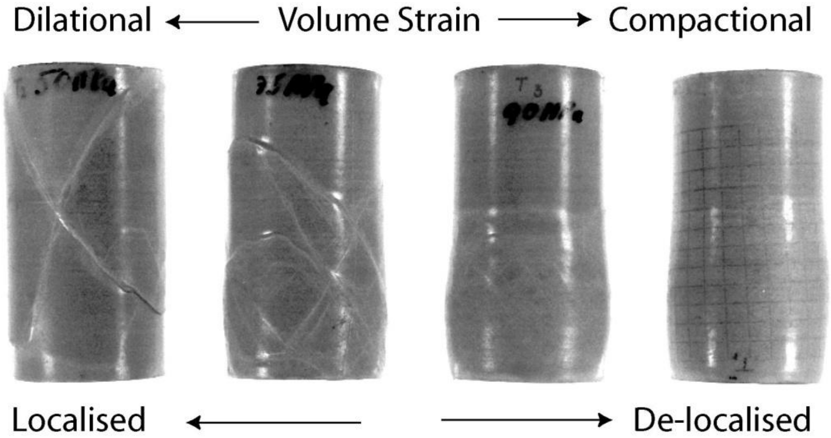
A boundary value problem?

- Yes it has to be – but not "just" a boundary value problem
  - Where are the boundaries?
  - WHEN were the boundaries there?
  - What happened at the boundaries (loads)



- Yes material(s) need to be well described – constitutive law, parameters

- But geometry of system and loading much more complex



Issues

1. Need to identify where to put the boundaries in PAST GEOMETRY

2. Need to identify boundary conditions for PAST EVENT

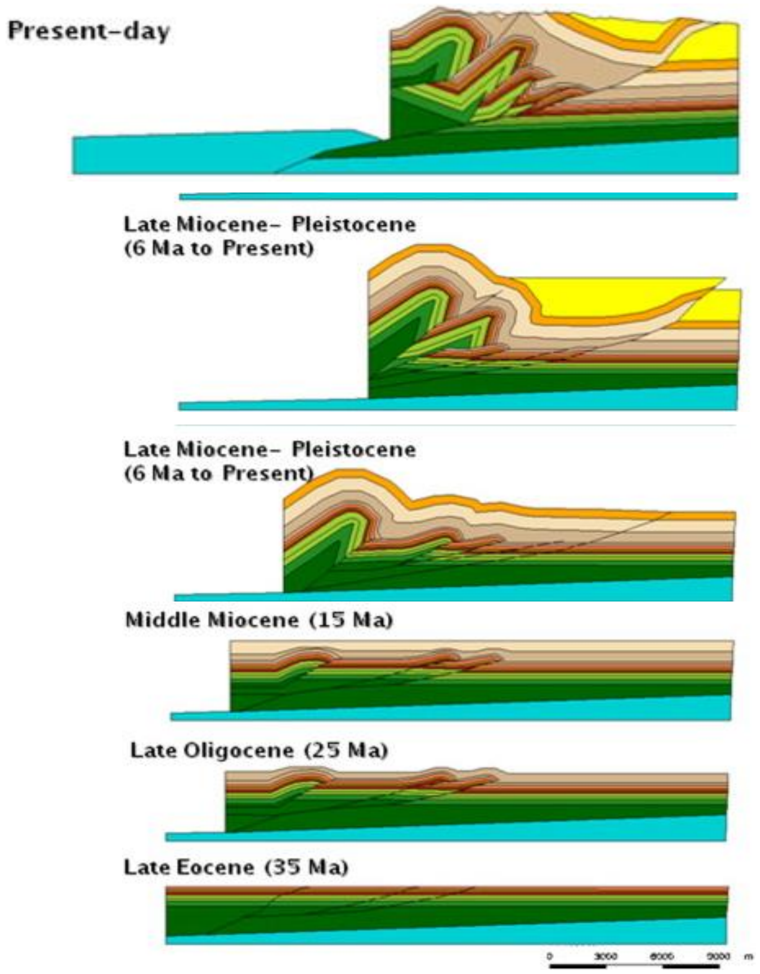
3. NO real boundaries……

4. Need to identify rock properties/ constitutive behaviour in PAST

5. And dealing with a system of materials

Geology - Past Geometry and Boundary Conditions

- Huge topic – hit only highlights
  - Restore to prior shape
  - Identify where can place these artificial boundaries
  - Normally constrain system using kinematics – displacement or displacement rates.



Geology - Past Geometry and Boundary Conditions

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Less is more

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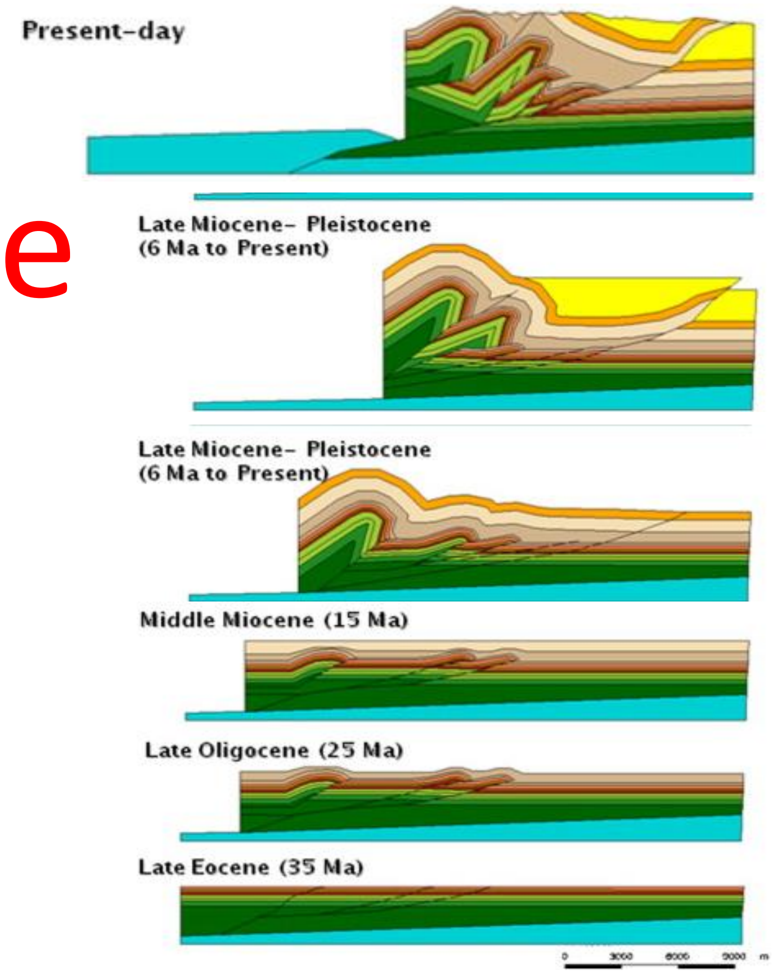

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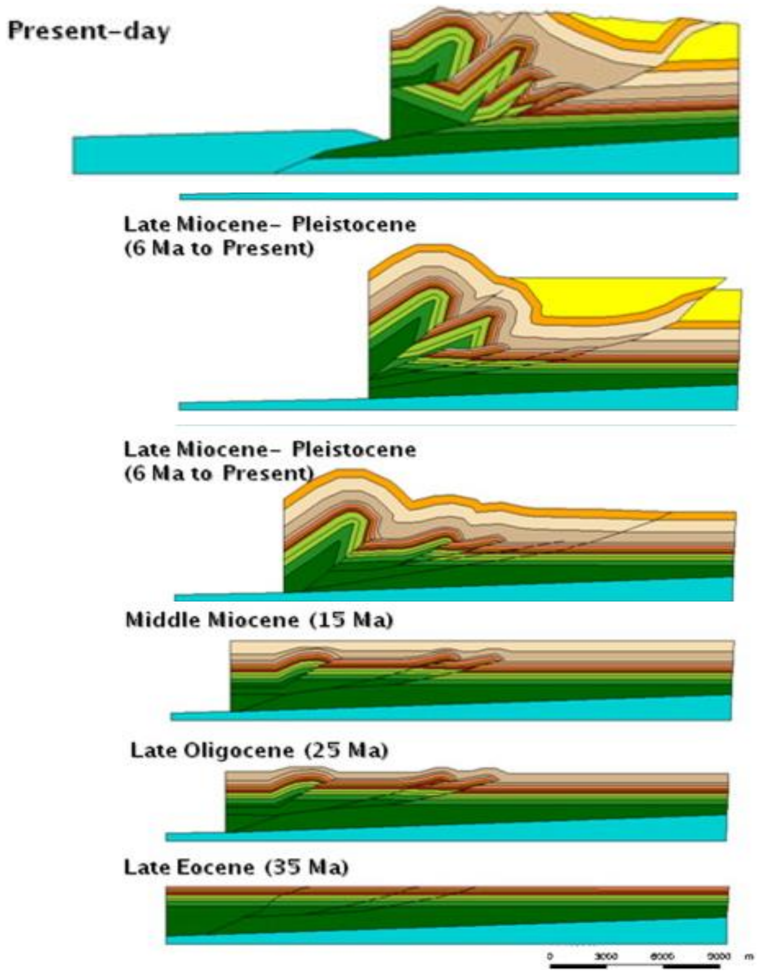
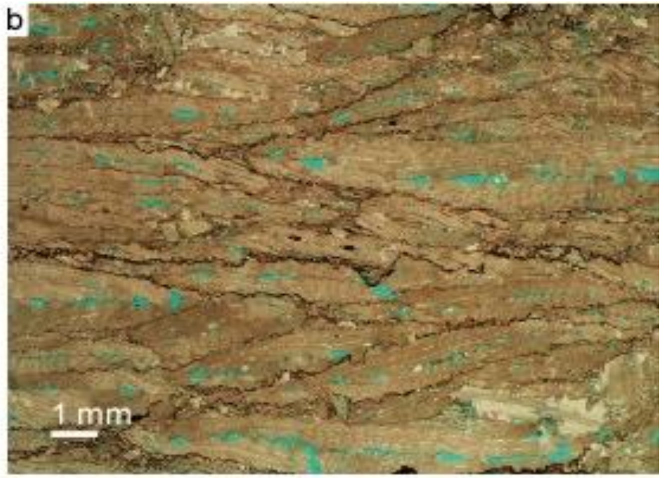


Geology - Past Rock Properties

- Hit only highlights
  - Remove diagenesis (chemical reactions change minerals)
  - Remove “compaction” – loss of pore space by rearrangement under rock weight
  - Remove (some) cement
  - Remove consequences of folding, faulting, fracturing
  - Normally impractical so find suitable analogue to rock you have identified you need



10 cm

Geology and Mechanics – System of Materials

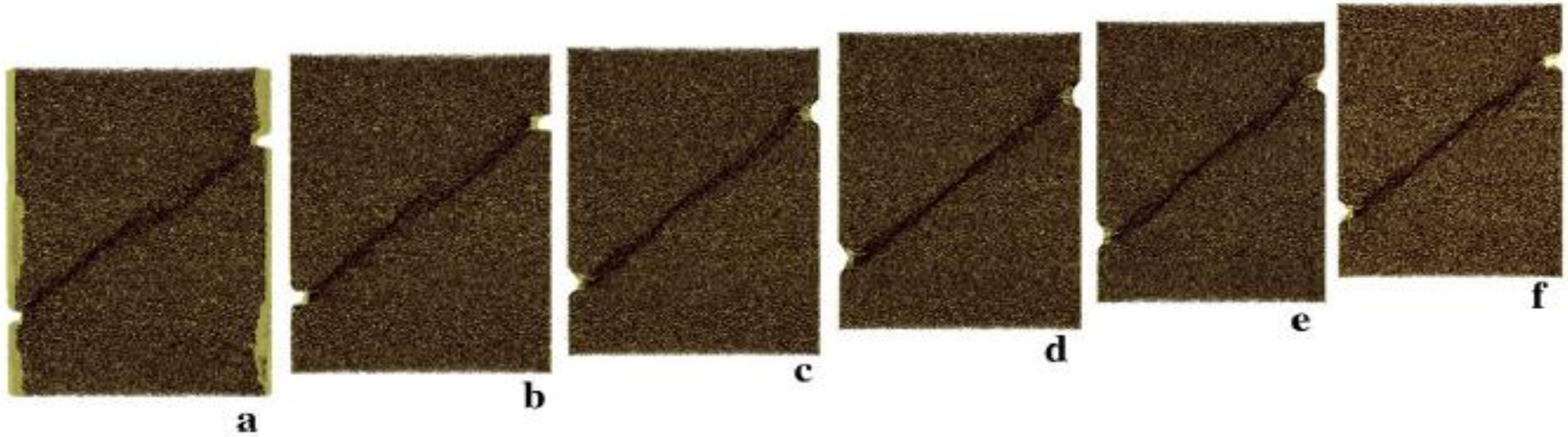
- Sequence of rock layers with variable thicknesses and properties plus derived boundary conditions

- Materials (rocks) response known moderately well for individual shapes, without interfaces.

- But response of multi-layered system with complex geometries and material interfaces not simple addition of individual material responses.

Simple Faulted System - Experimental

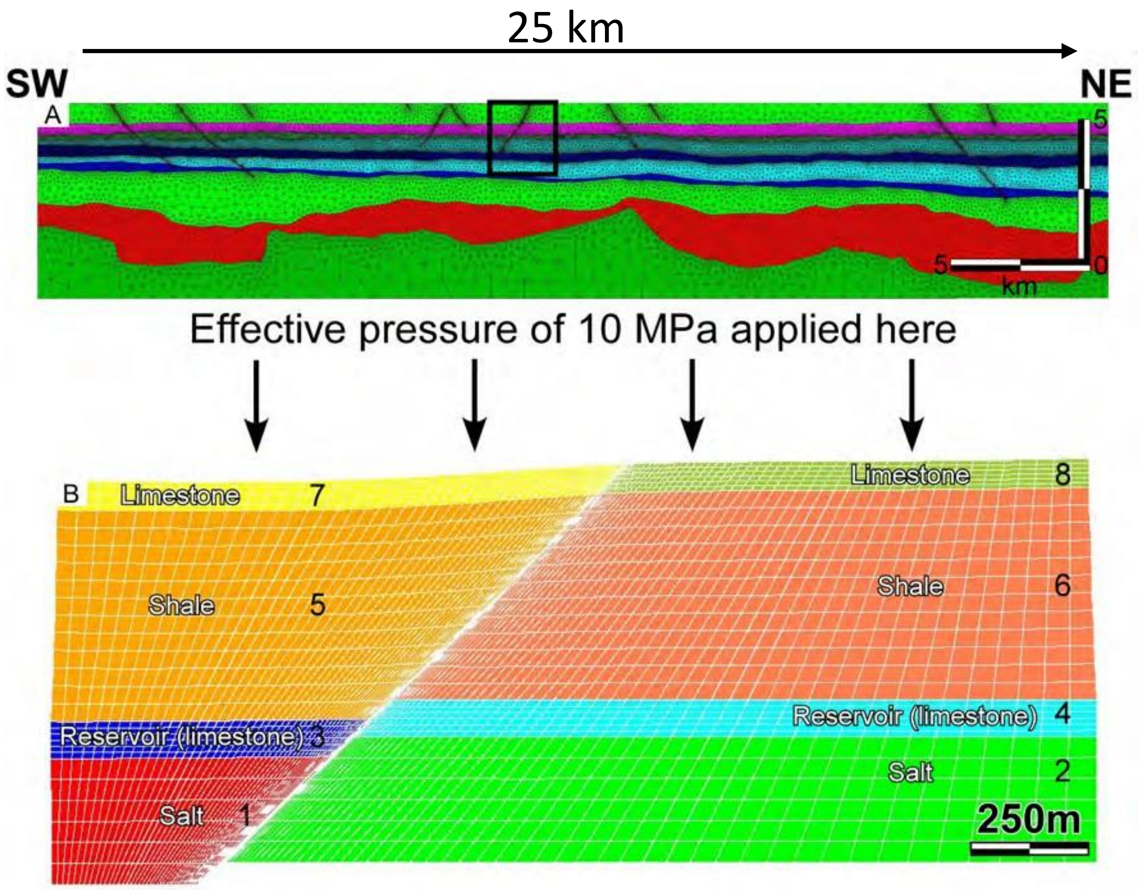
- Sandstone cylinder deformed in triaxial compression various Pc
- Sample notched to locate shear bands (successfully)
- One material, no interfaces, but even this simple variant takes sample from a material to a system?



Vertical slices from X-ray tomographic images of the Vosges Sandstone experimentally deformed sample. After Charalampidou et. al., 2011.

Fold in a complex fold-fault-fold system

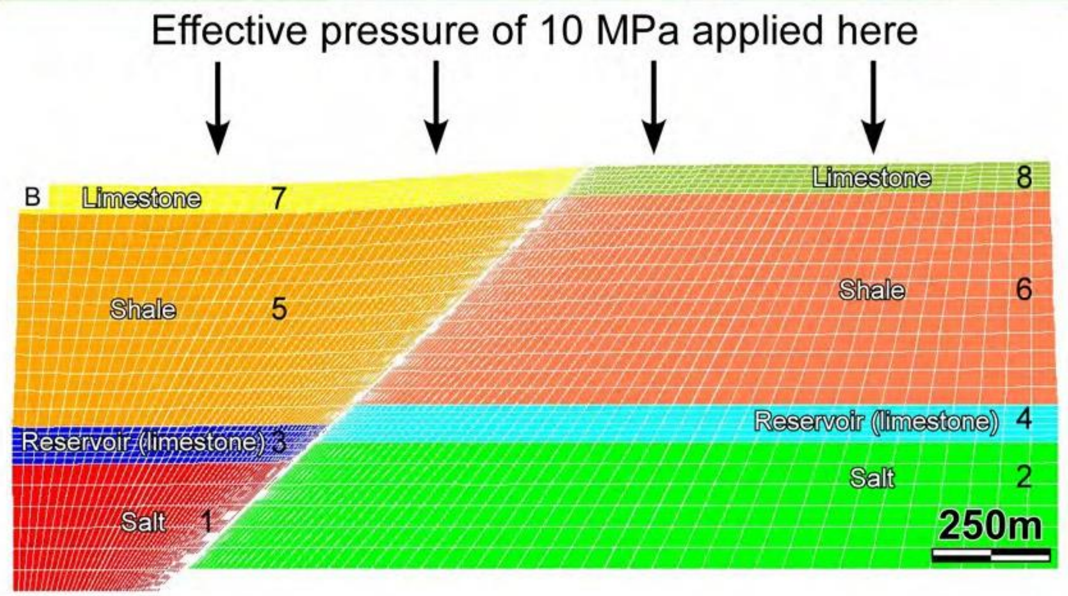
- Large region been restored to get geology 30my ago.
- Sediment and rock properties back-calculated
- What is needed is fault zone petrophysical properties (porosity, permeability)
- So this needs a geomechanical FE simulation



Mangione, PhD thesis 2016

Fault in a complex fold-fault-fold system

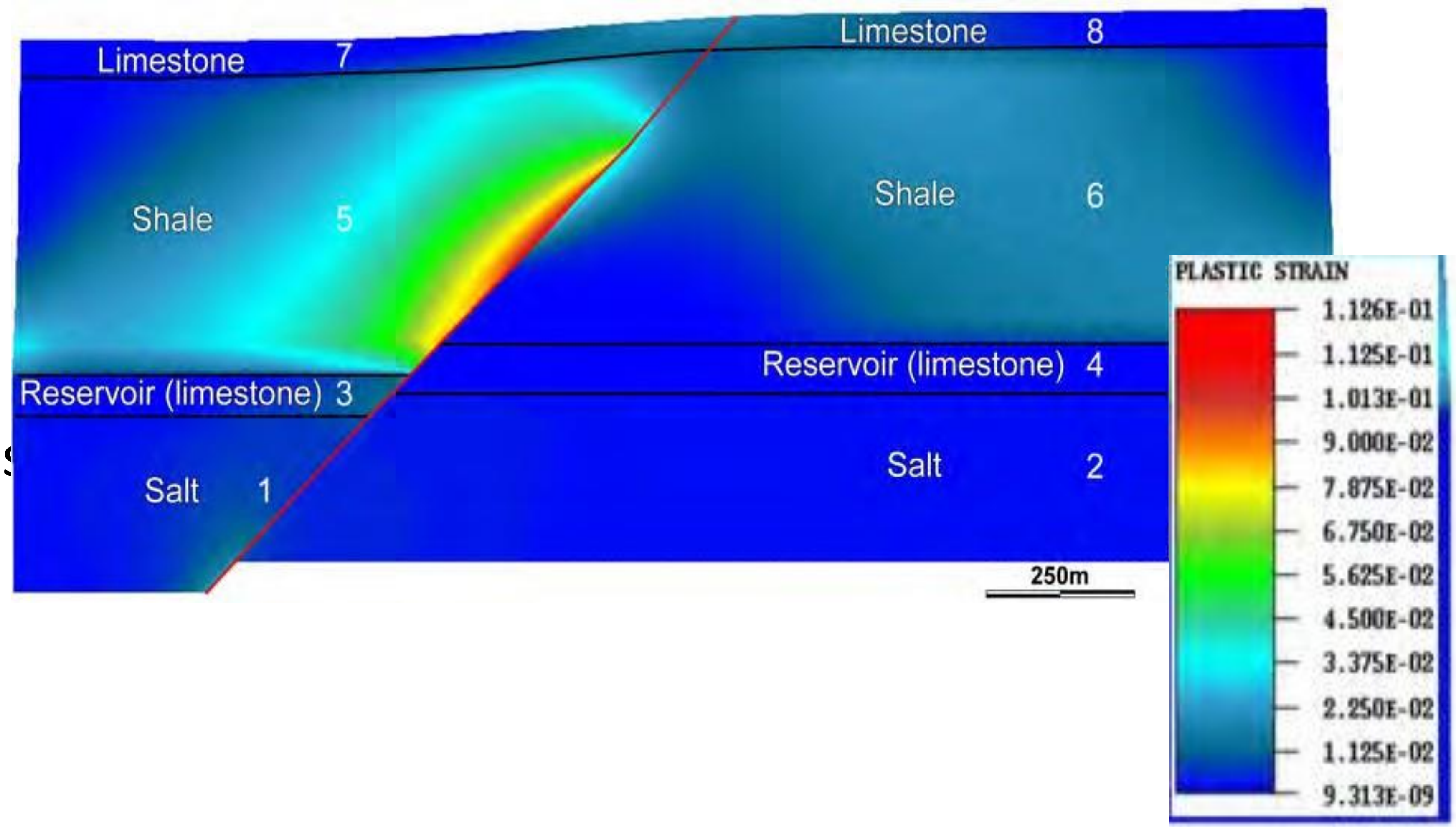
- Image shows different rock layers (simplified)
- 10MPa pressure at top surface ~ weight of overburden
- Other edges constrained by calculated fault displacement
- Fault is frictional
- Use analogue materials



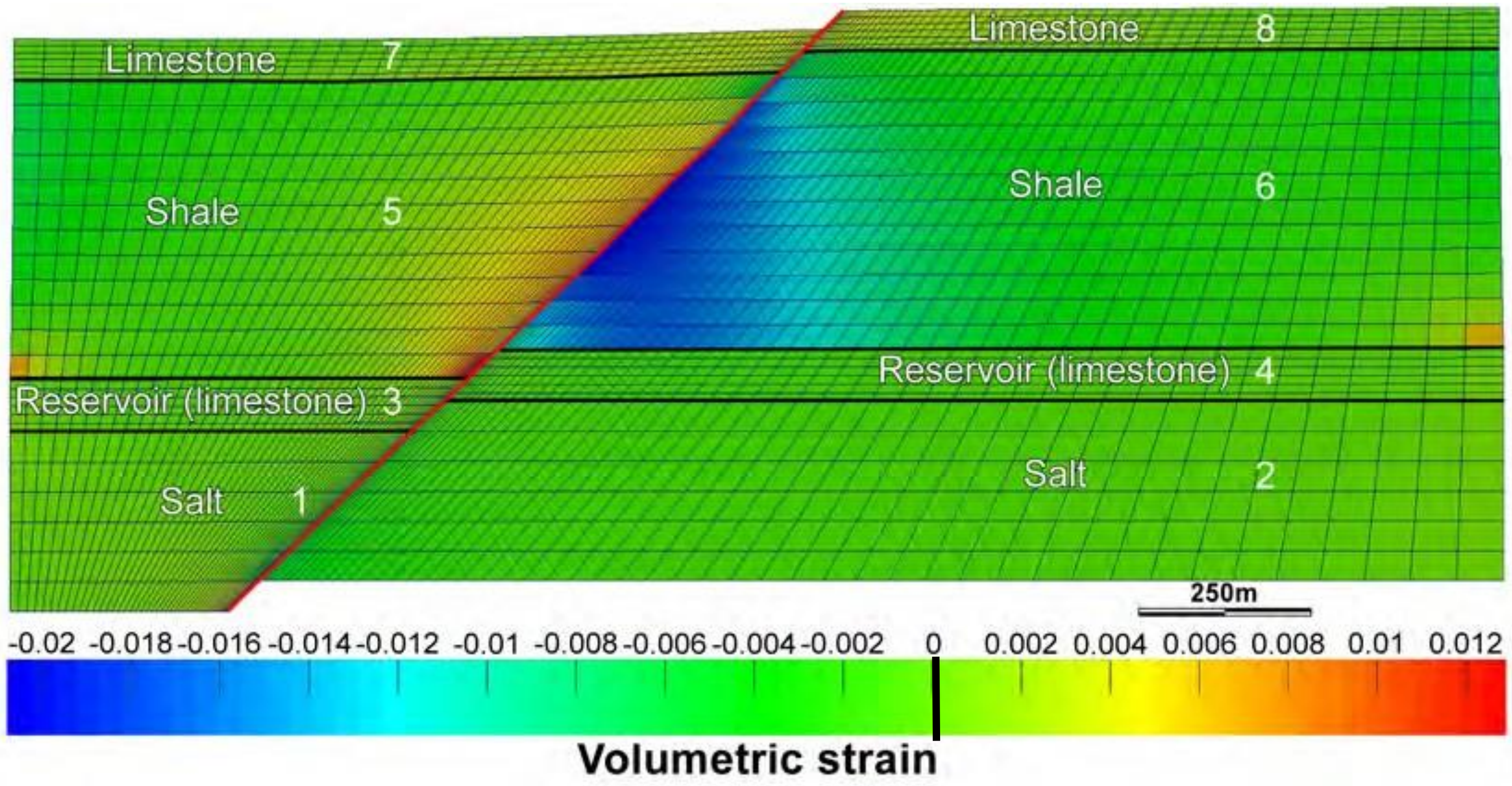
Plastic strain magnitude

- Majority of permanent strain in shales and around fault

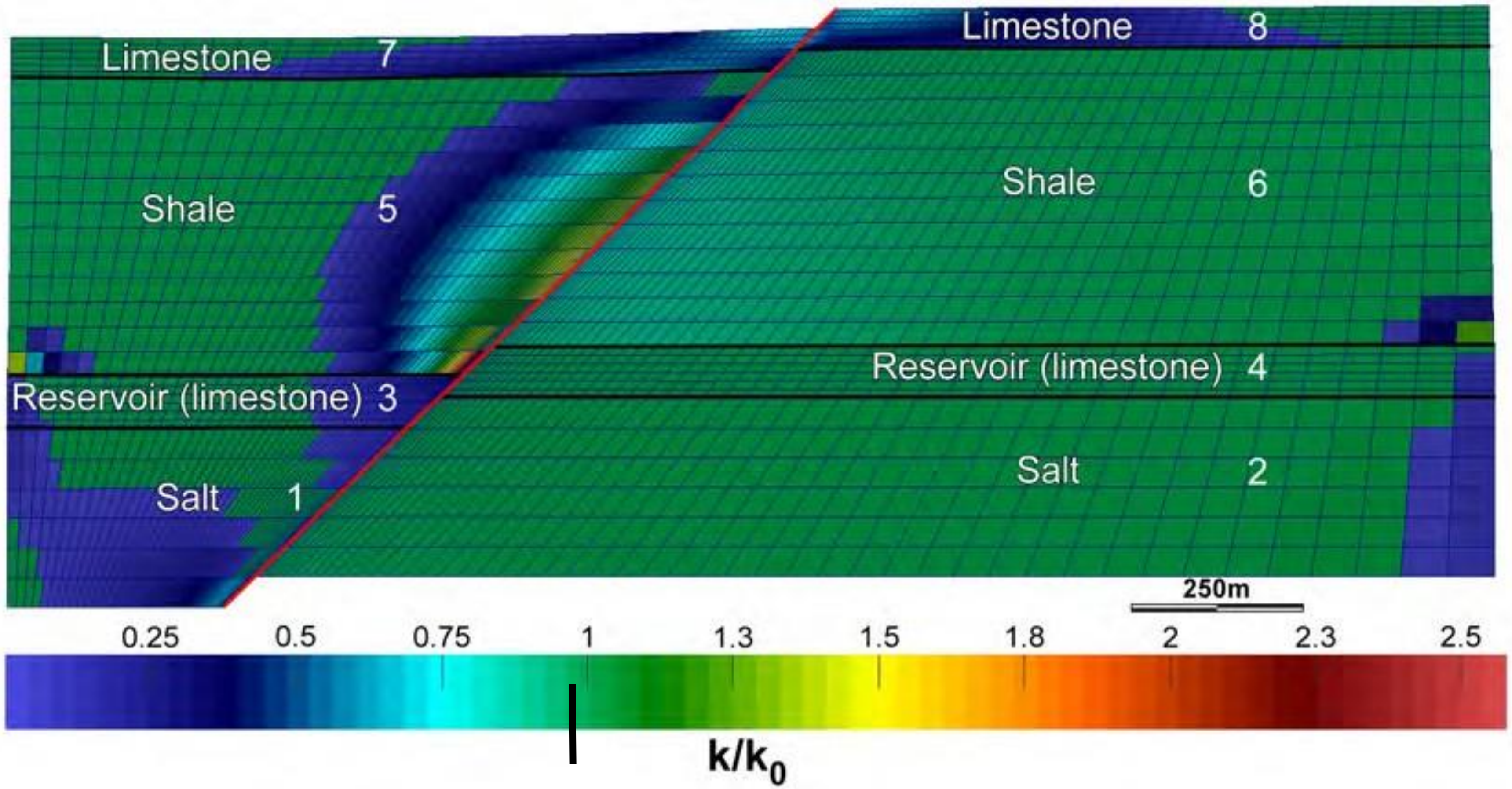
More on downthrown side as expected



Calculated volumetric strain



Change in permeability

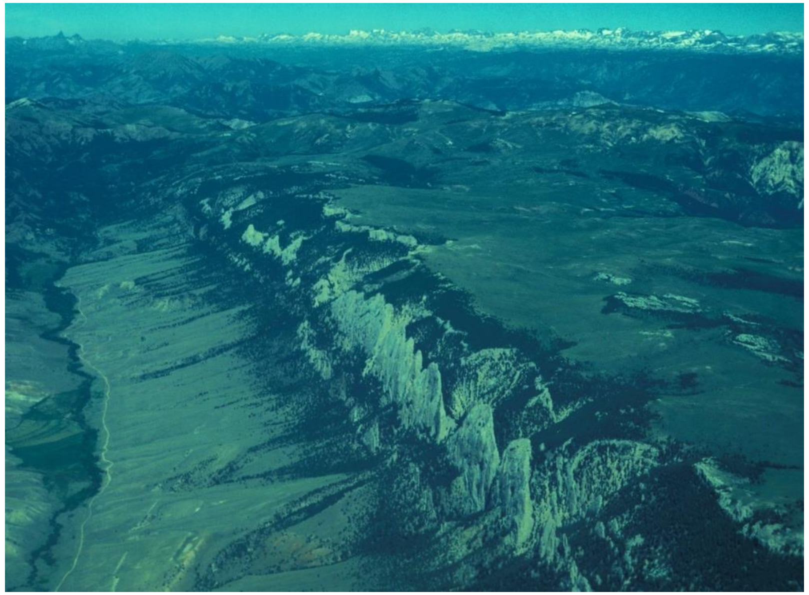


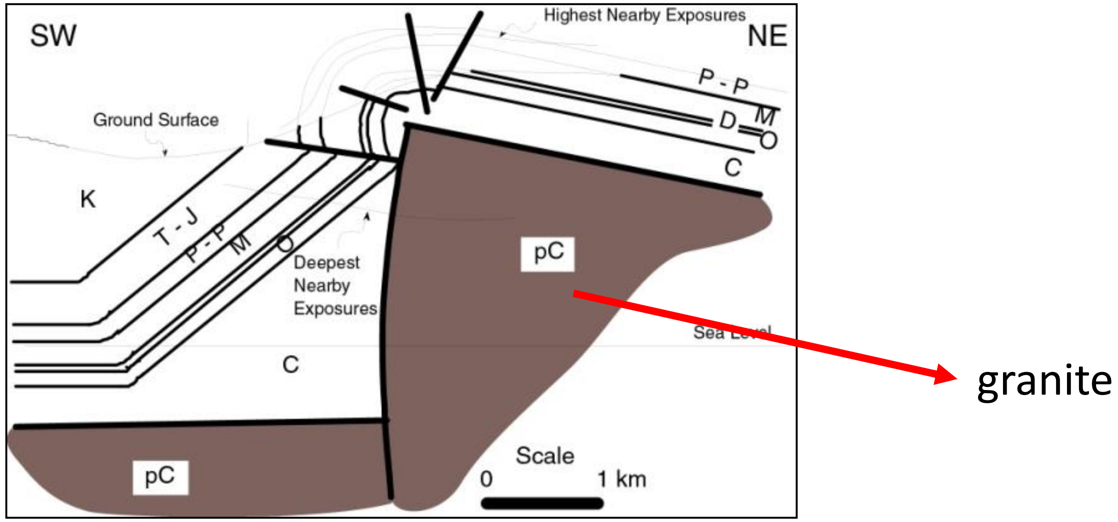
These permeability values then used in fluid- and heat-flow simulation

Fold over Fault System Rattlesnake Mountain

- Rock scale model deformed triaxially at 3km burial depth equivalent

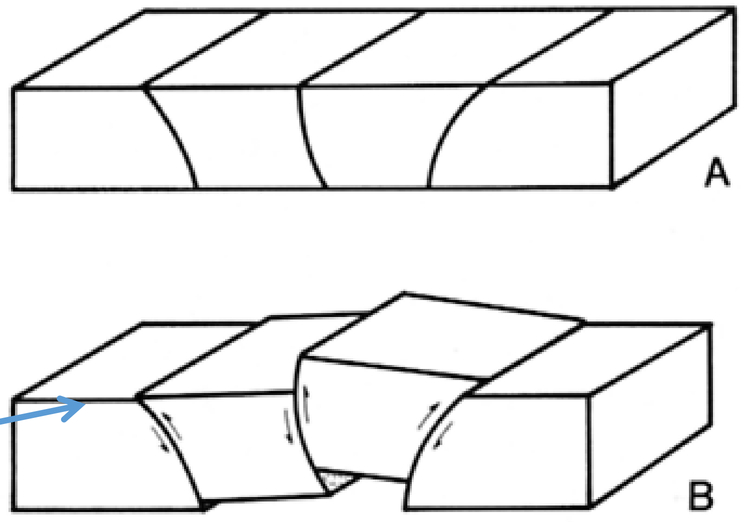
- FE simulation





Design of the "Basement" Model

- A set of steel blocks whose contacting faces are perfect cylinders (to allow rotational sliding)
- Centres of cylinders offset, so when set is shortened, the blocks displace and rotate
- The "main" block operates like the basement block beneath Rattlesnake Mtn

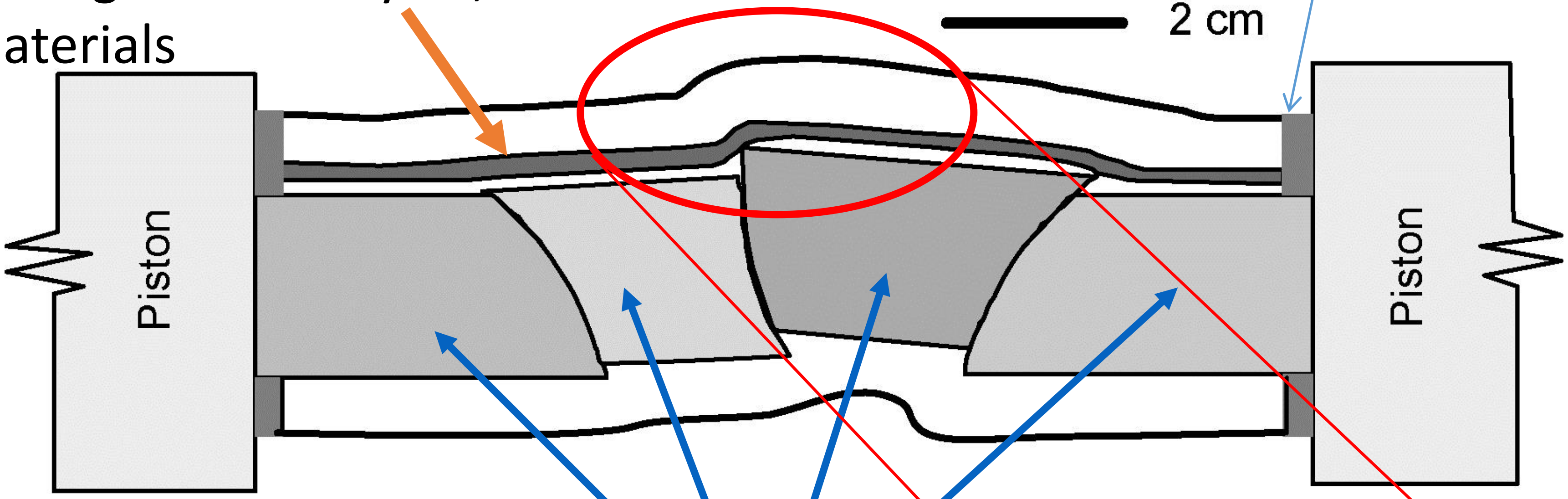


(Weinberg 1979)

The Complete Model

No end-loads imposed on layers

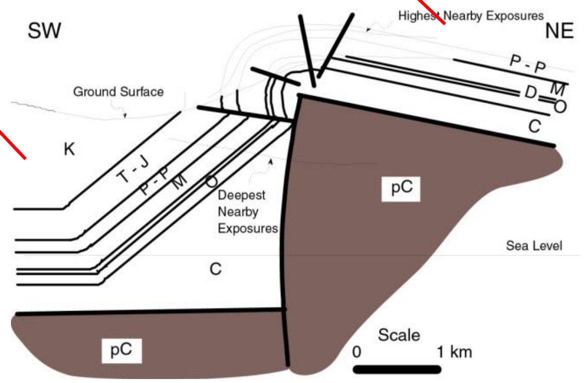
Package of rock layers, and other materials



Steel blocks (pre-existing surfaces machined to be perfectly cylindrical)

Couples et al., 1994

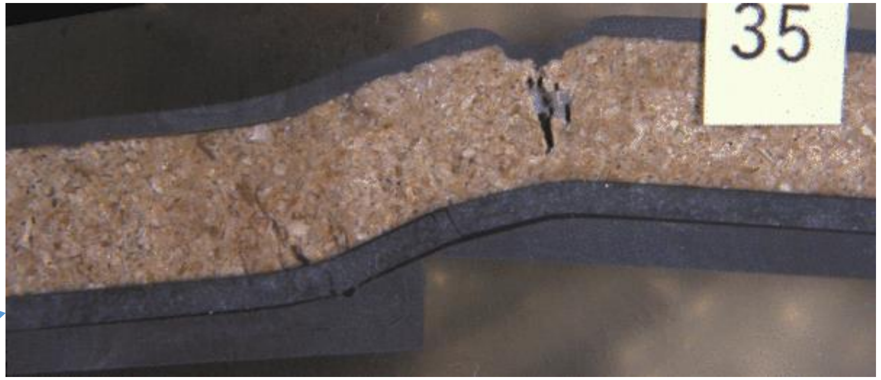
This is the configuration after loading

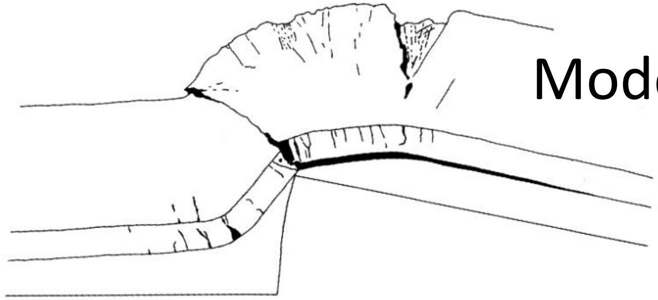


The prototype

Typical Experimental Outcome

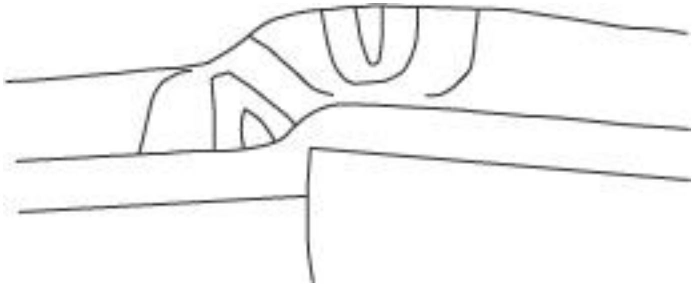
- Lowest layer is lead (very ductile), representing the Cambrian shales
- Next layer up is dolostone (very stiff, and "brittle"), representing the carbonates
- Next layer is porous limestone (moderately stiff), representing the Mesozoic clastics





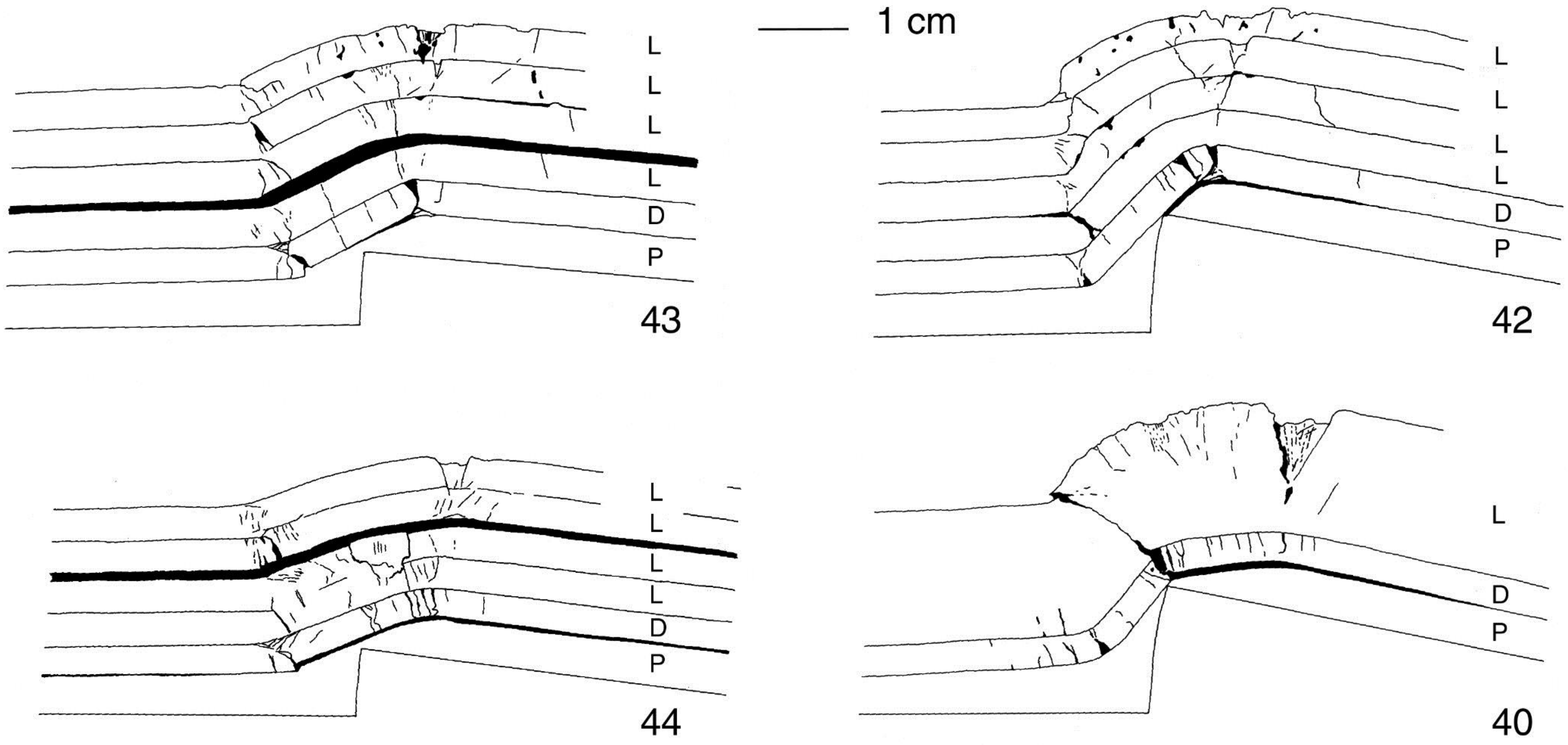
Model 46

Using petrofabric studies, we can map the stress trajectories



Couples 1996; Couples and Lewis 1998, 2000

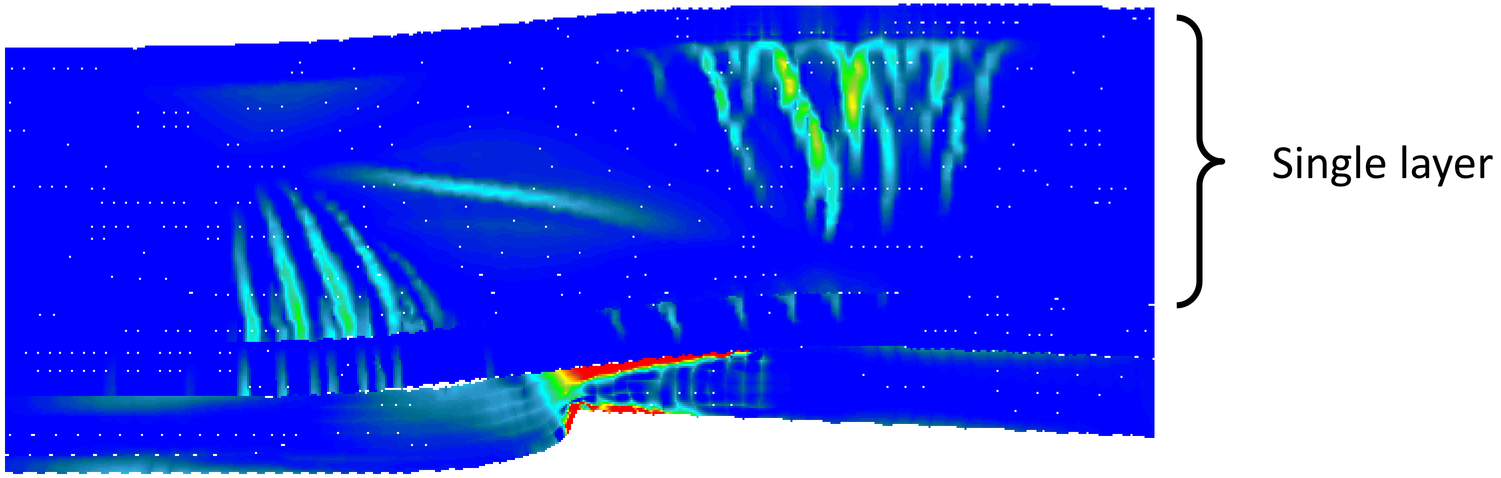
Observed Multilayer Fabrics



Availability of slip surfaces results in major change of strain pattern

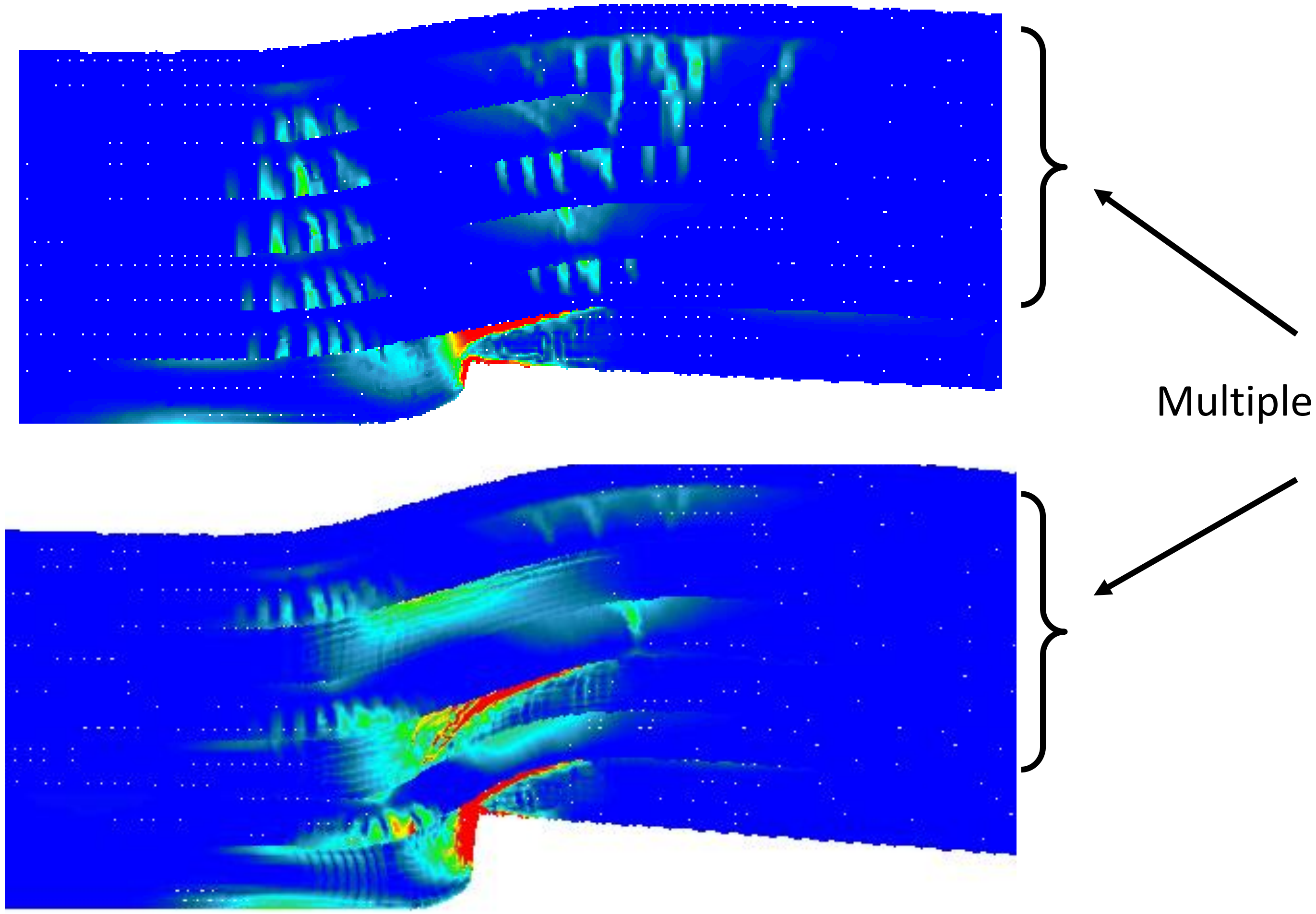
Couples and Lewis 1998, 2000

Fold over Fault System Rattlesnake Mountain- Single Limestone Layer



Plastic strain

Fold over Fault System Rattlesnake Mountain- Multiple Limestone Layers



Conclusion?

- Geomechanical processes within the earth are solvable boundary value problems

  - Even though we no longer have the shapes or the materials
  - And even though we don't actually have the boundaries

  - To do this you don't have to be a geologist, but you do need to understand their world….

    …and particularly understand that awkward step from qualitative to quantitative geology – is the basis to cross the gap.