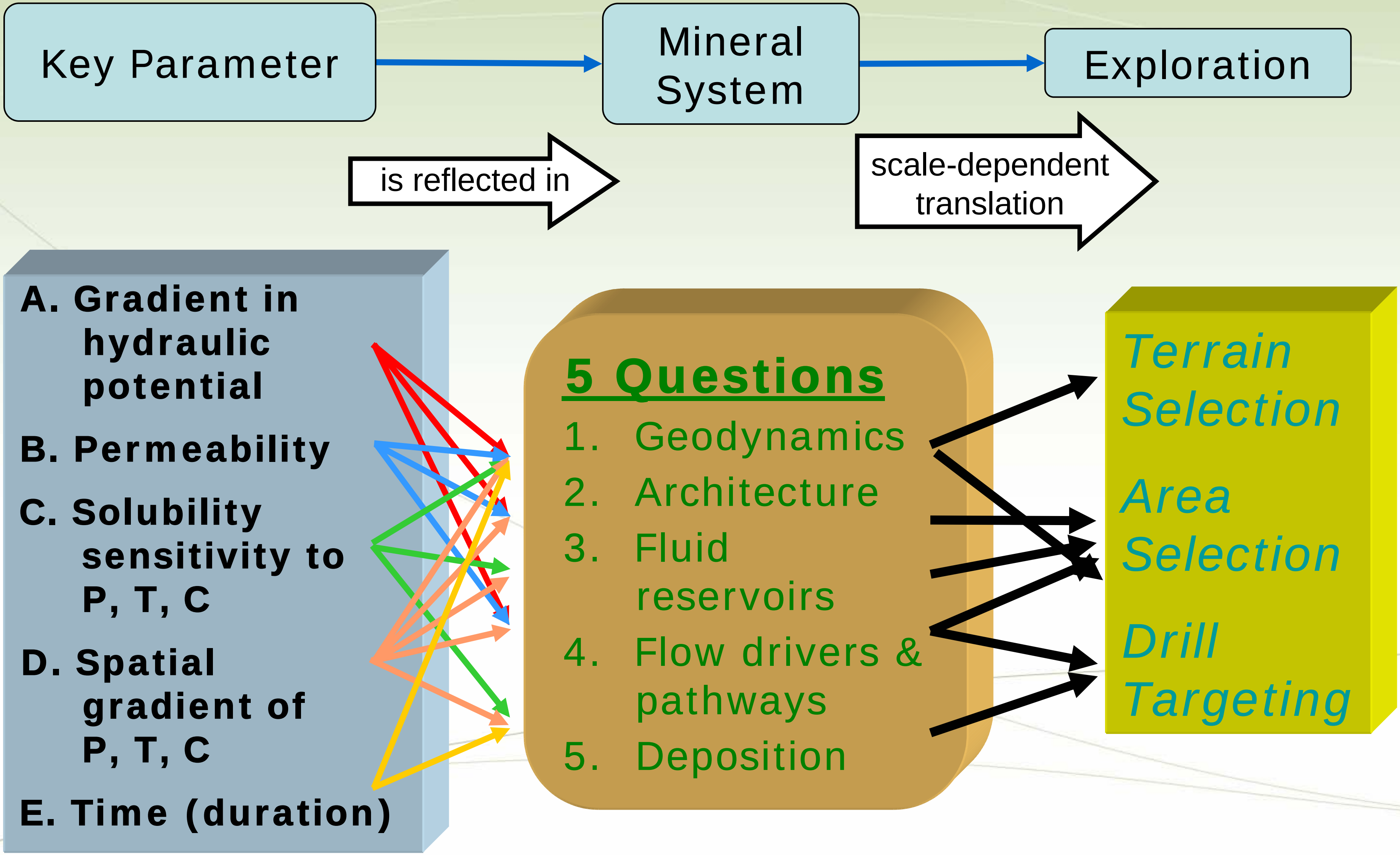
Enabling Technologies

Mechanical Modelling


Key Parameter
is reflected in
Mineral System
scale-dependent translation
Exploration
A. Gradient in hydraulic potential
B. Permeability
C. Solubility sensitivity to P, T, C
D. Spatial gradient of P, T, C
E. Time (duration)
5 Questions
1. Geodynamics
2. Architecture
3. Fluid reservoirs
4. Flow drivers & pathways
5. Deposition
Terrain Selection
Area Selection
Drill Targeting

Deformation & Fluid Flow

Deformation exerts a crucial control on the permeability of a fluid-rock system.

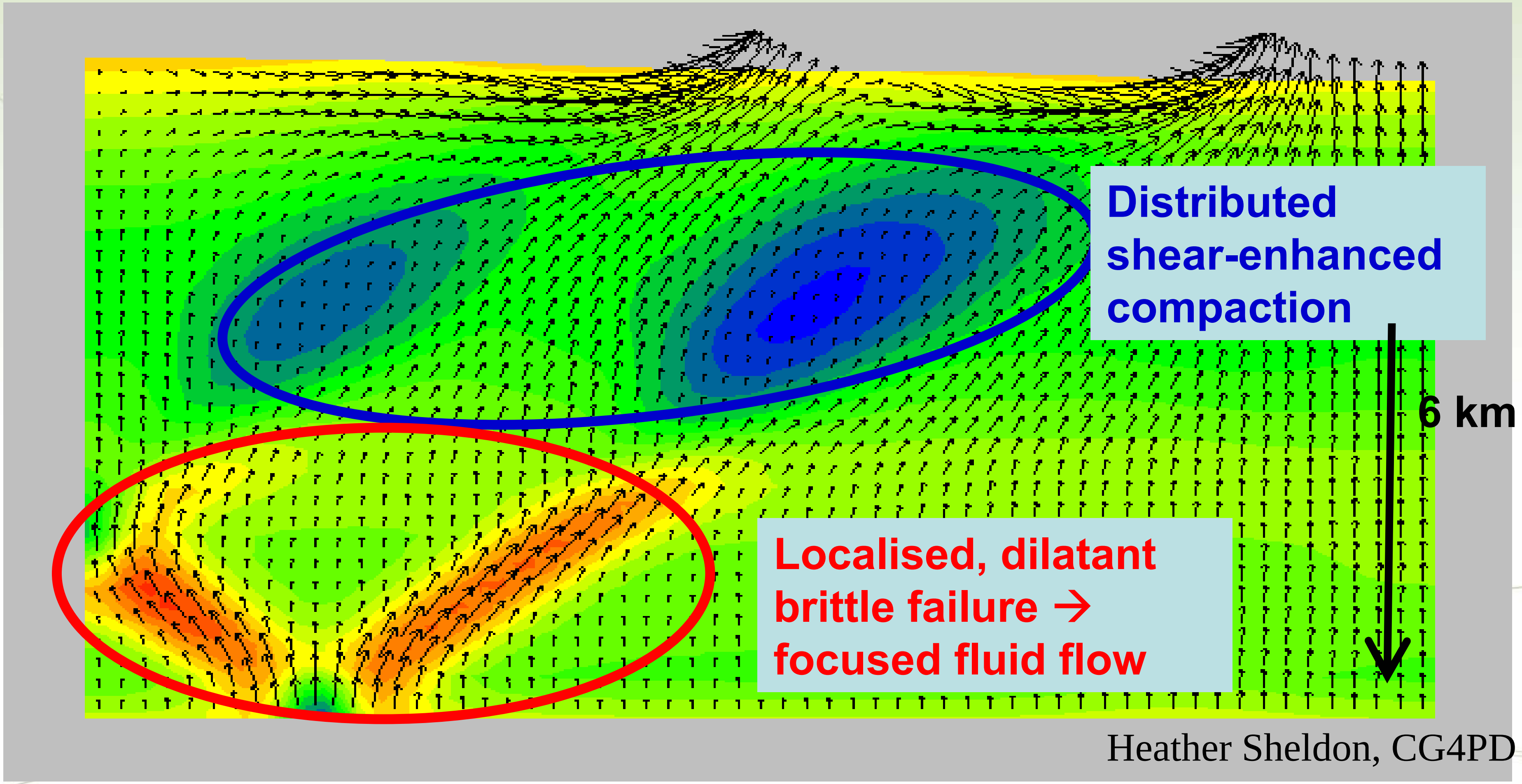
Understanding deformation processes is essential to predict the permeability evolution of the system at conceptual and simulation level.

Existing and emerging structure define permeability structure through localisation and reactivation.

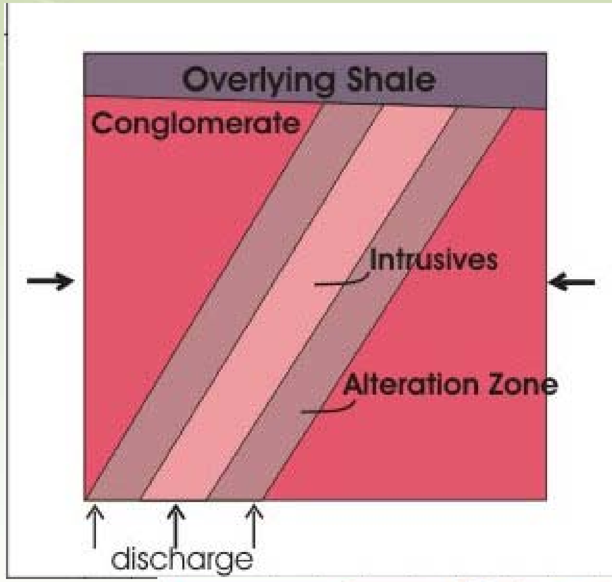
Compaction and dilation can be different responses to similar causes.

Fracturing and plastic dilation can occur in the same architecture because of different hydraulic regimes and different rock properties

Cam Clay Constitutive model

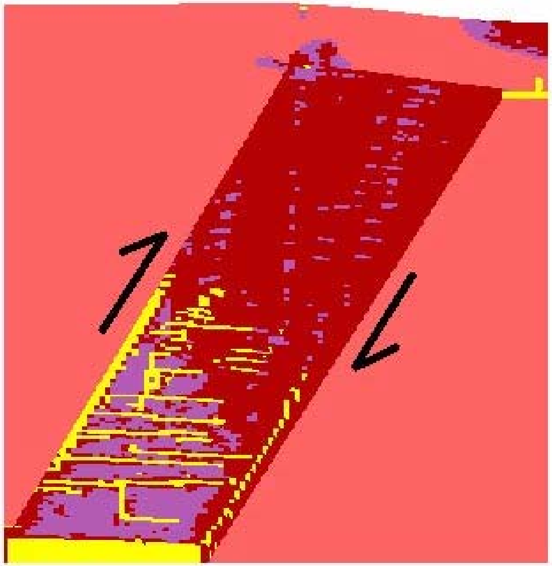


2 types of modelling

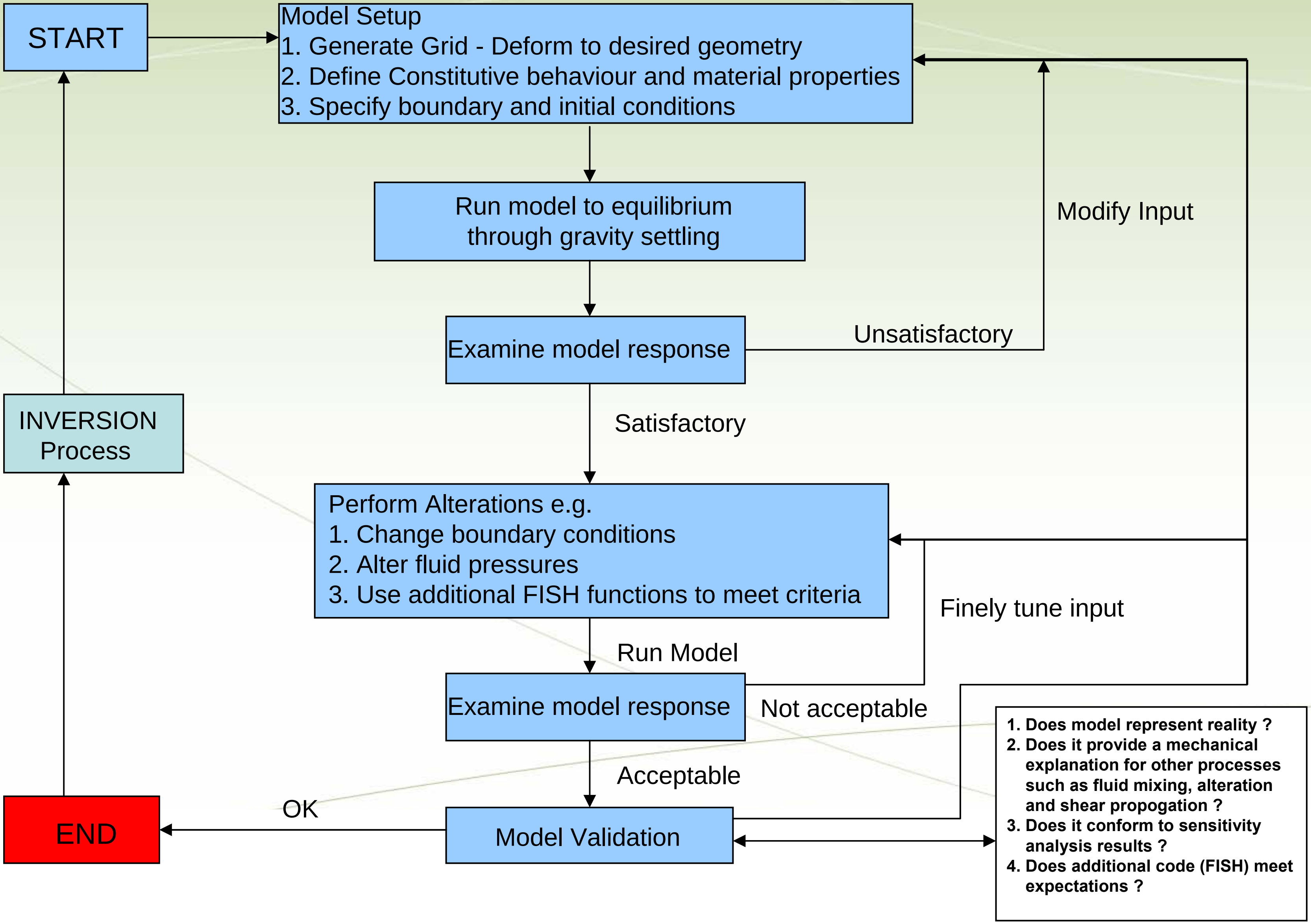


Conceptual models ('soft model')
- little quantitative description
- Initial understanding of the system (behaviour and potential processes)

Numerical models
- to test and improve this understanding
- Inputs may be tuned to satisfy the original conceptual model
- OR modify inputs to test new outcomes



Iterative process:
- testing, validation and identifying key critical parameters


START
Model Setup
1. Generate Grid - Deform to desired geometry
2. Define Constitutive behaviour and material properties
3. Specify boundary and initial conditions
Run model to equilibrium through gravity settling
Examine model response
Unsatisfactory
Modify Input
Satisfactory
INVERSION Process
Perform Alterations e.g.
1. Change boundary conditions
2. Alter fluid pressures
3. Use additional FISH functions to meet criteria
Finely tune input
Run Model
Examine model response
Not acceptable
Acceptable
OK
END
Model Validation
1. Does model represent reality ?
2. Does it provide a mechanical explanation for other processes such as fluid mixing, alteration and shear propogation ?
3. Does it conform to sensitivity analysis results ?
4. Does additional code (FISH) meet expectations ?

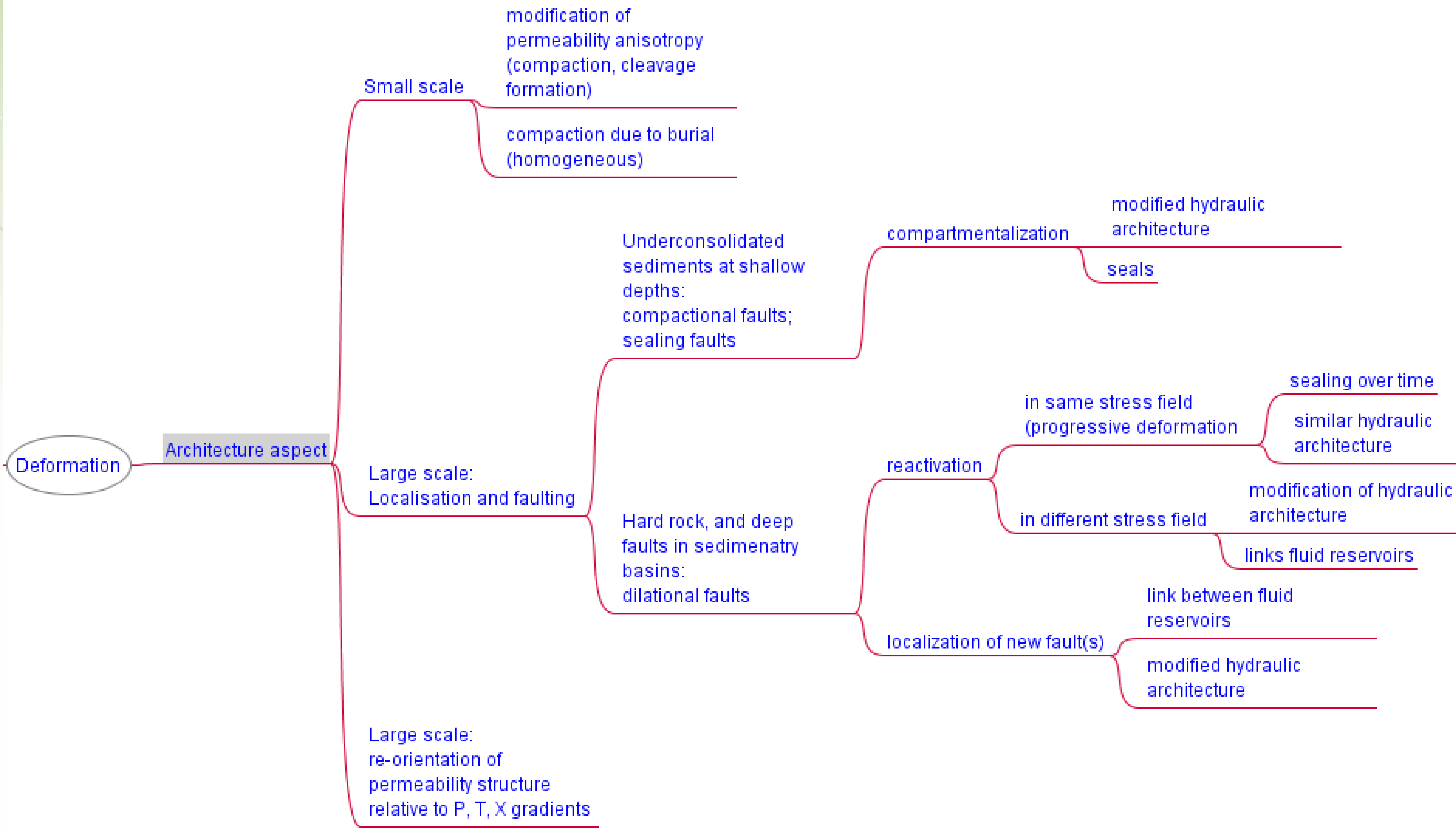
2 Approaches

Continuum modeling (e.g. FLAC)

- Smoothing of physical reality based on continuum mechanics
- Suitable for e.g. behaviour of geological material, porous media flow
- Mohr-Coulomb for most rocks (other constitutive models Cam-Clay, Drucker-Prager)
- 1. Differential approach (finite difference)
- 2. Integral approach (finite element)

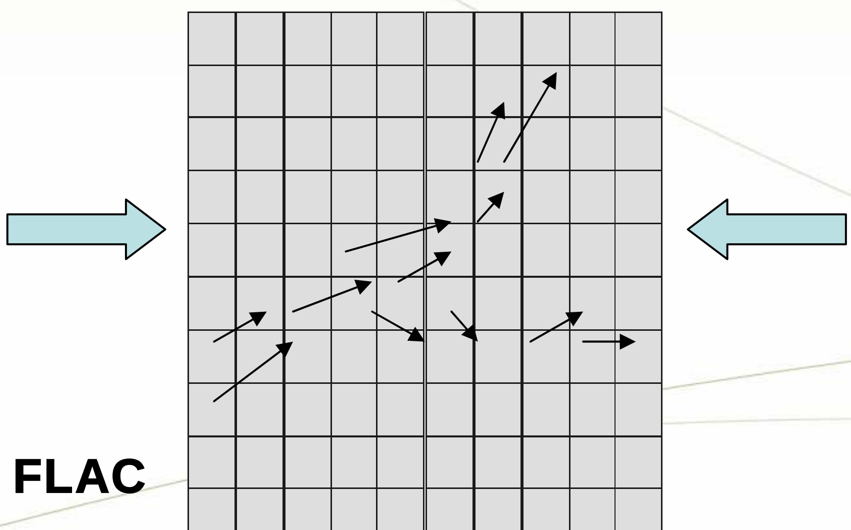
Discontinuum modeling (e.g. UDEC)

- Modelling of interfaces or contacts between rigid bodies
- 1. Behaviour of discontinuities
- 2. Behaviour of the solid material
  - → rigid or deformable
- Distinct element method

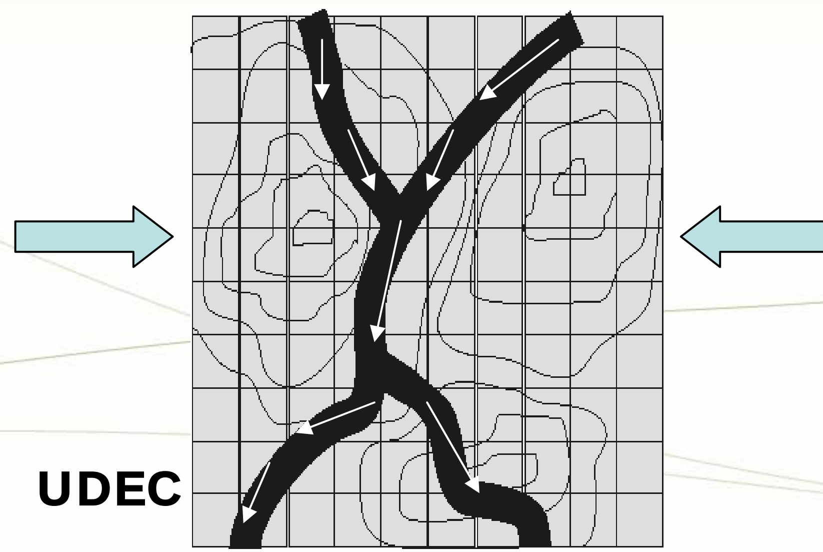

Deformation
Architecture aspect
Small scale
modification of permeability anisotropy (compaction, cleavage formation)
compaction due to burial (homogeneous)
Large scale: Localisation and faulting
Underconsolidated sediments at shallow depths: compactional faults; sealing faults
compartmentalization
modified hydraulic architecture
seals
Hard rock, and deep faults in sedimenatry basins: dilational faults
reactivation
in same stress field (progressive deformation
sealing over time
similar hydraulic architecture
in different stress field
modification of hydraulic architecture
links fluid reservoirs
localization of new fault(s)
link between fluid reservoirs
modified hydraulic architecture
Large scale: re-orientation of permeability structure relative to P, T, X gradients

Fluid flow in fractured rocks

1. Cracks are main permeability, rocks impermeable
2. Continuum approach, treats fractures by averages, determines bulk fractured rock permeability
3. Discontinuum approach, flow must be described relative to individual fractures or fracture sets



FLAC



UDEC

Some types of codes

Continuum codes:
- **Finite difference**
- **Finite element**

Distinct element codes

Particle codes

Computational Fluid Dynamics (CFD) codes

Particle in cell codes

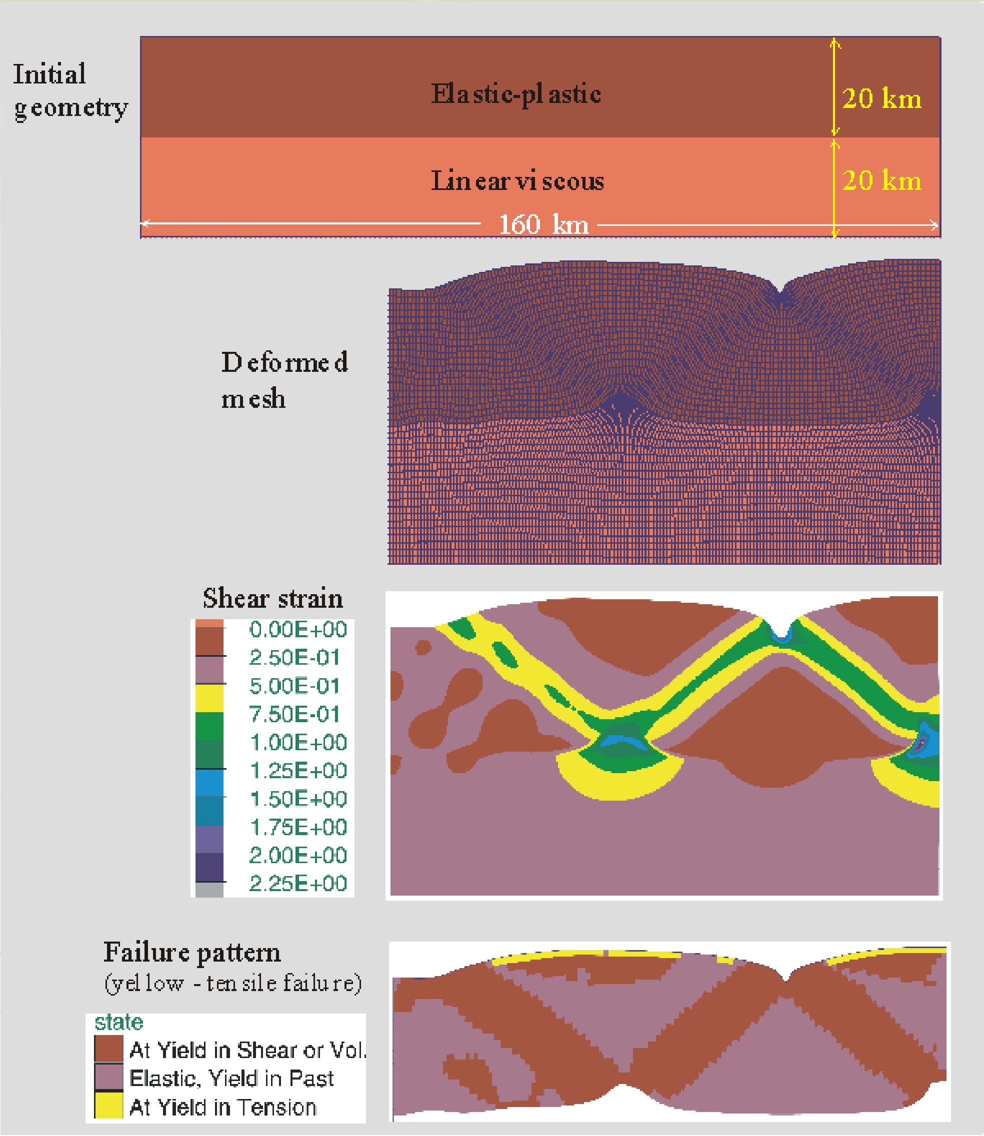
Boundary element-finite element combinations

Reactor-style chemical codes

Reactive transport codes

Continuum Models

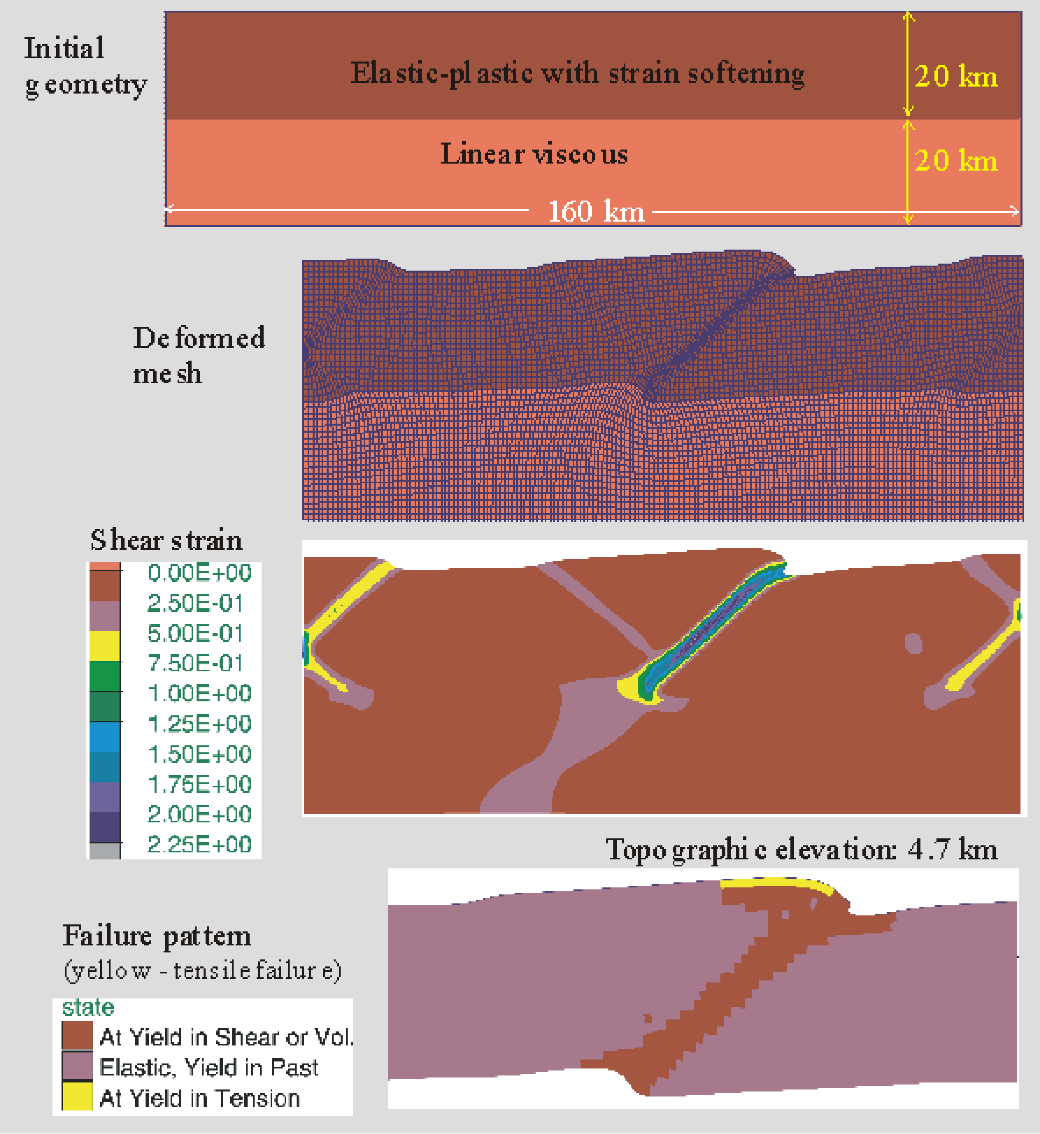
A two-layer crust subject to horizontal shortening



Continuum Models

A two-layer crust subject to horizontal shortening

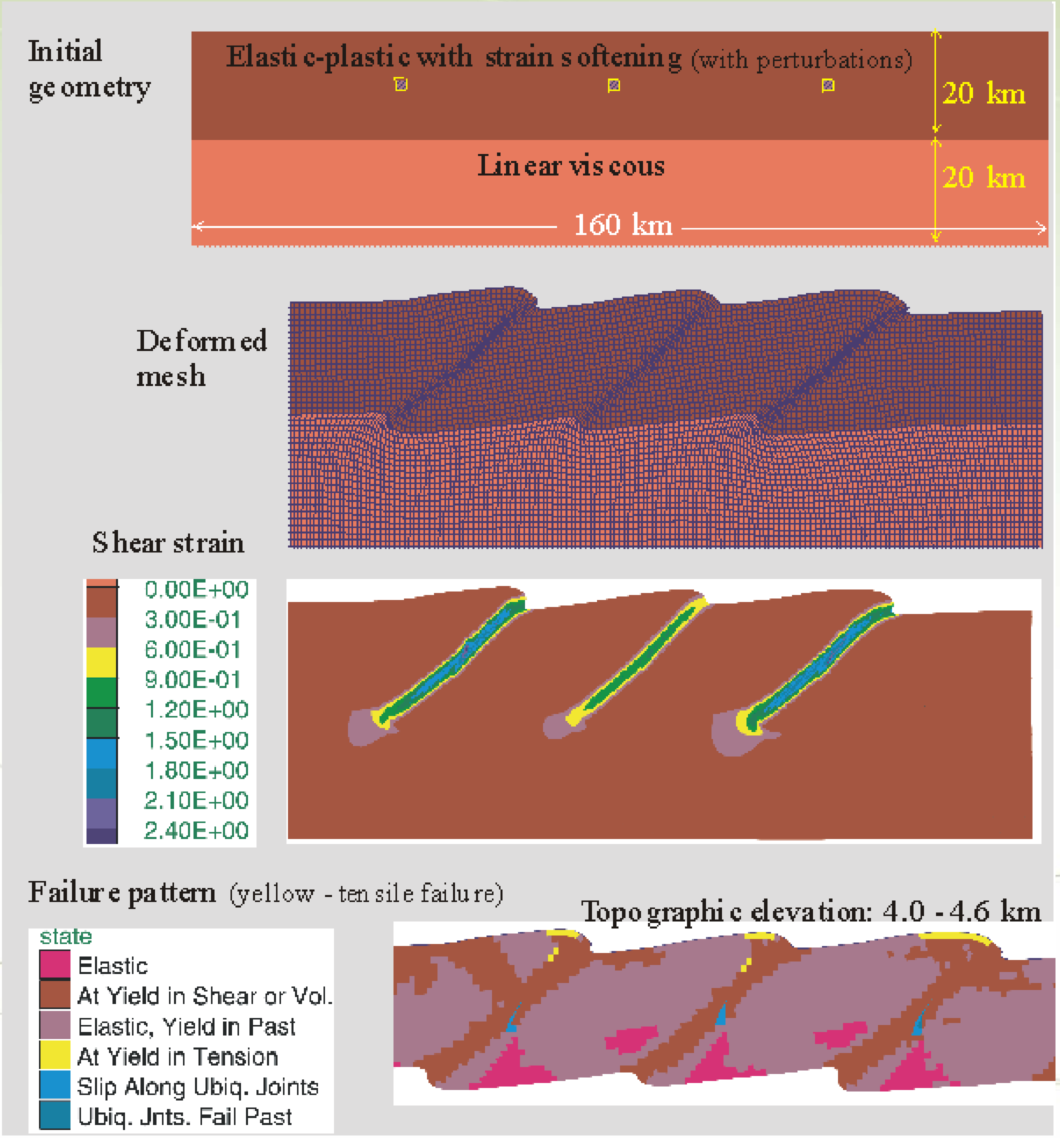
Strain softening is incorporated, which accelerated the development of one thrusting fault



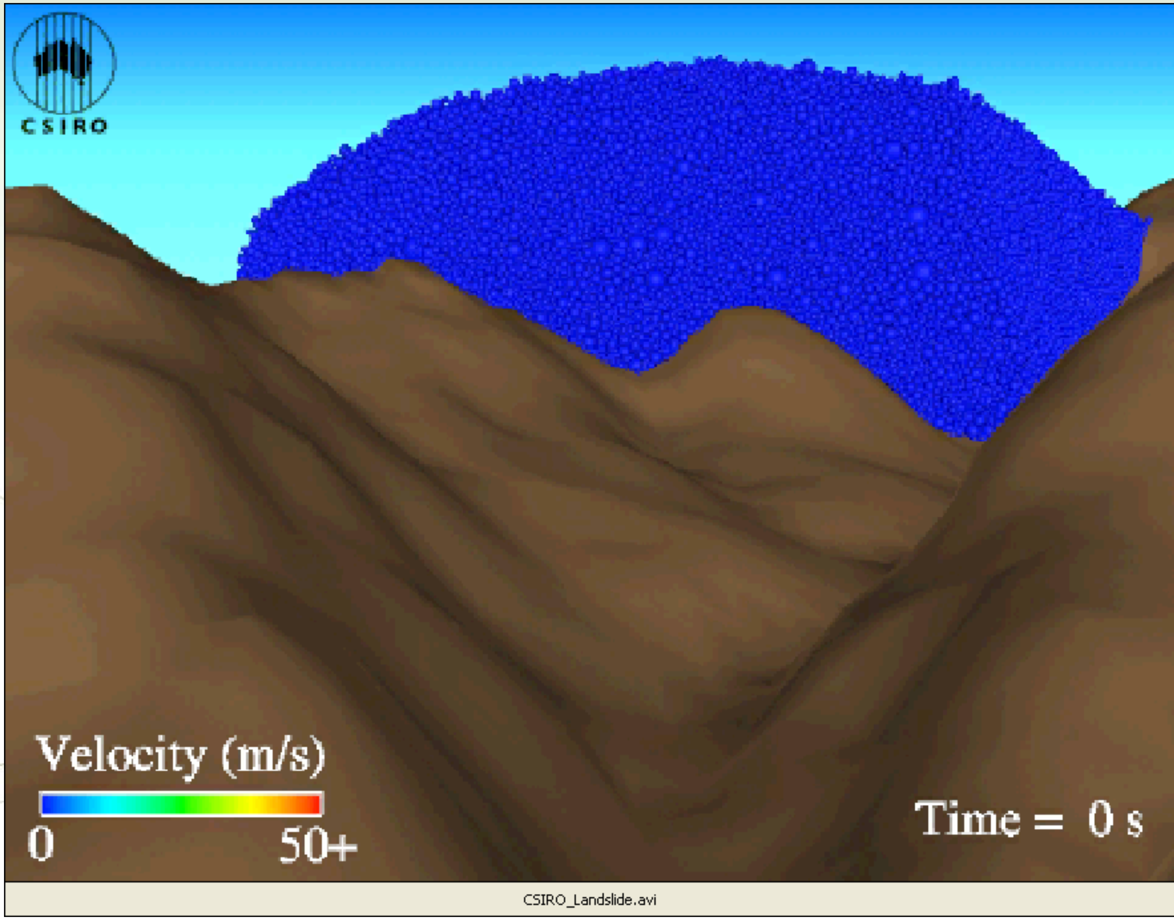
Continuum Models

A two-layer crust subject to horizontal shortening

Strain softening is incorporated and initial mechanical perturbations are seeded in the model.



FE, CFD & Particle Codes



Representative Elementary Volumes (REV's)

Darcy's law is a macroscopic relation

Volume must be large enough to represent a meaningful statistical average of the continuum (scale dependent)
→ large relative to the scale of microscopic heterogenity, but small relative to the entire domain of interest

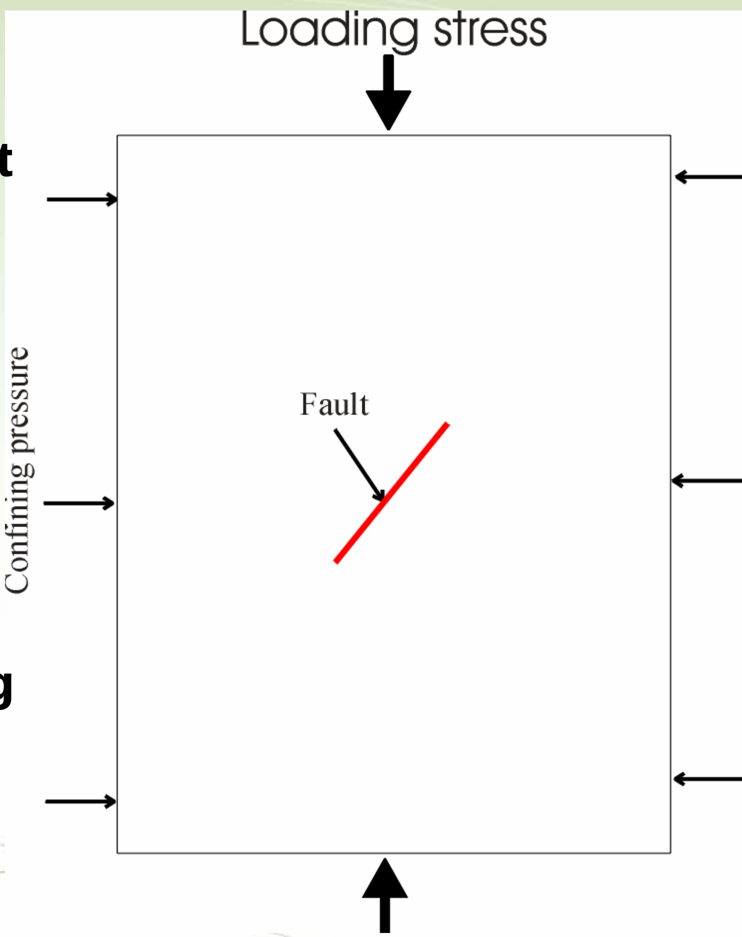
How much volume of the material (e.g. fractures rock) is representative of the whole rock in a continuum sense?

Stress Transfer Models

used to identify areas around a fault that have been brought closer to failure as a consequence of slip on that fault

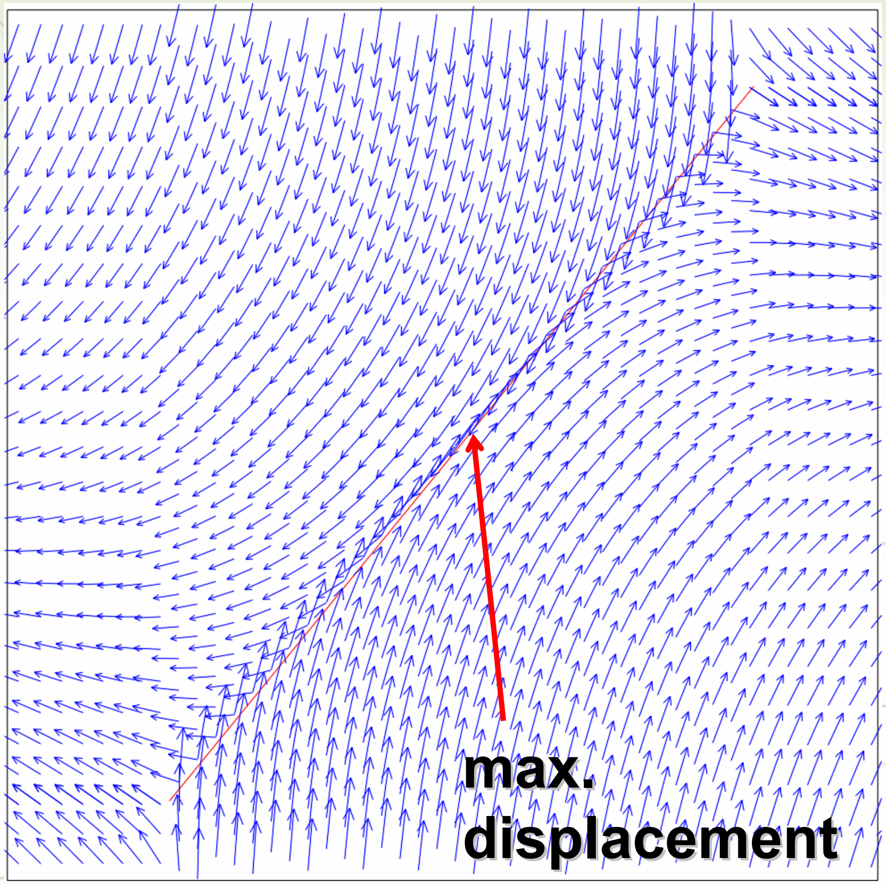
static stress transfer - stress is "transferred" from the fault to the wall rocks (Fault slip produces a change in elastic strain, and hence a change in effective stress, in the rocks surrounding The fault.)

STM can tell us <u>where</u> deposits are located
(Suggests relationship between mineralisation and aftershocks)

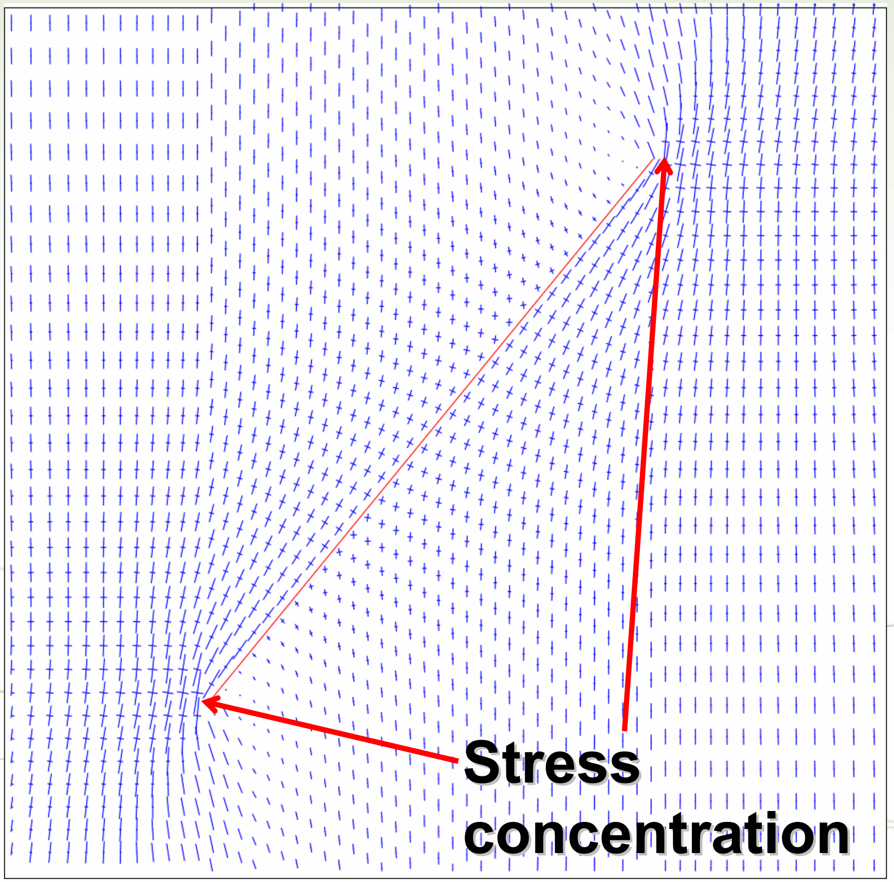


Stress Transfer Models

Distribution of displacement vectors near the fault

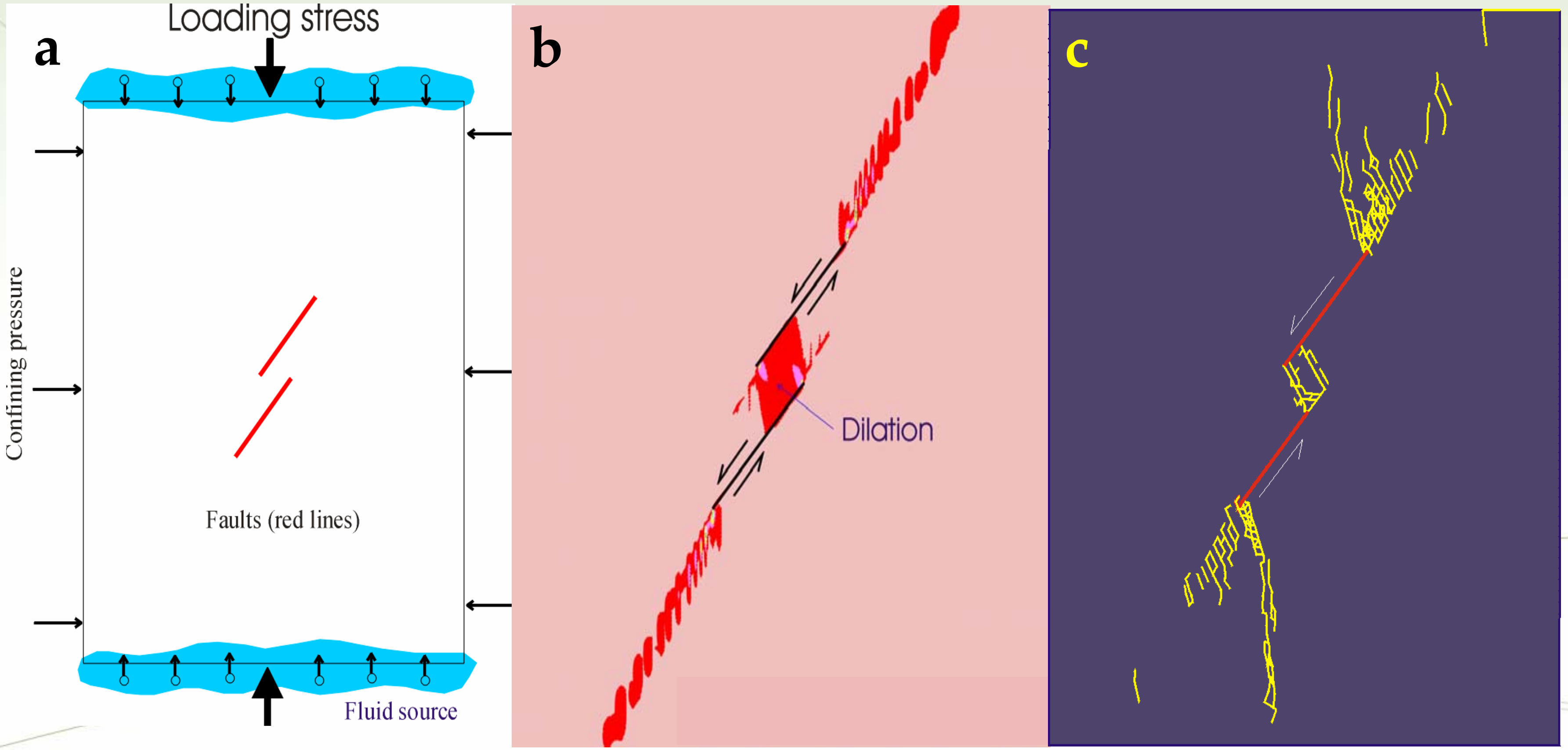


Principal stress vectors



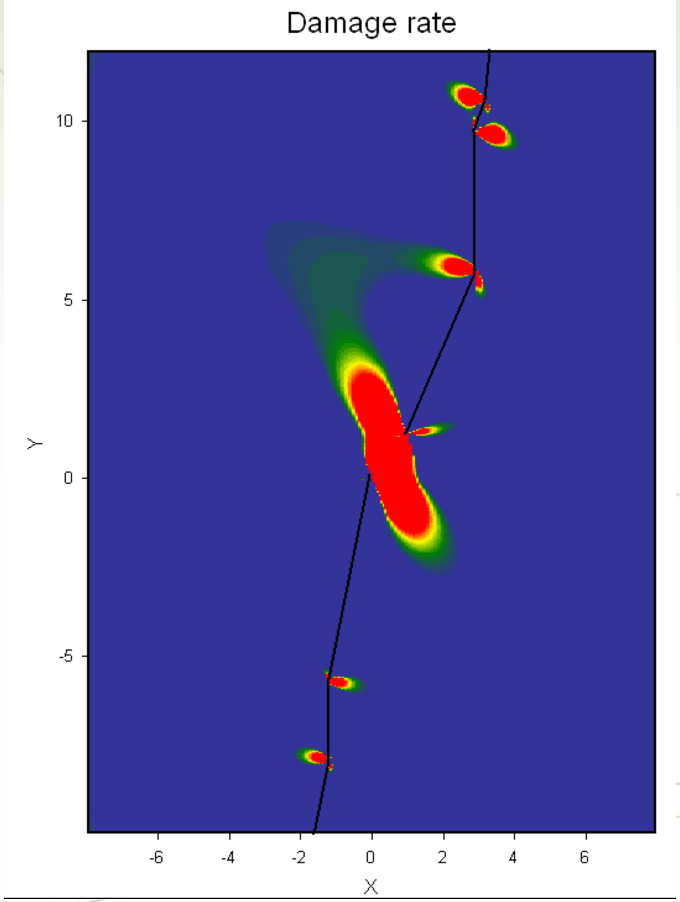
Stress Transfer Models

Fault propagation and, dilatancy and vein formation

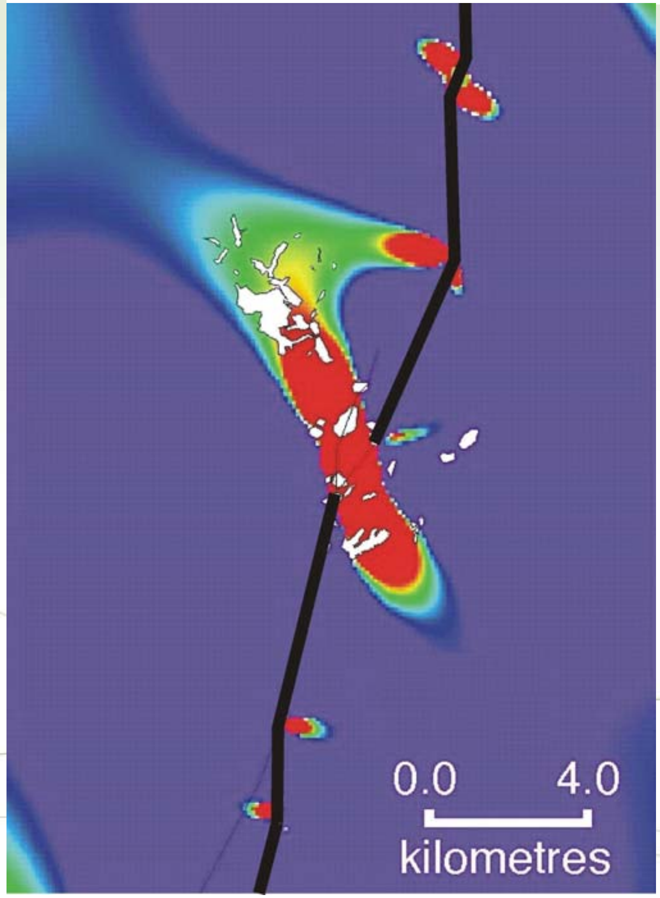


Example

Damage mechanics (damage rate > 0)

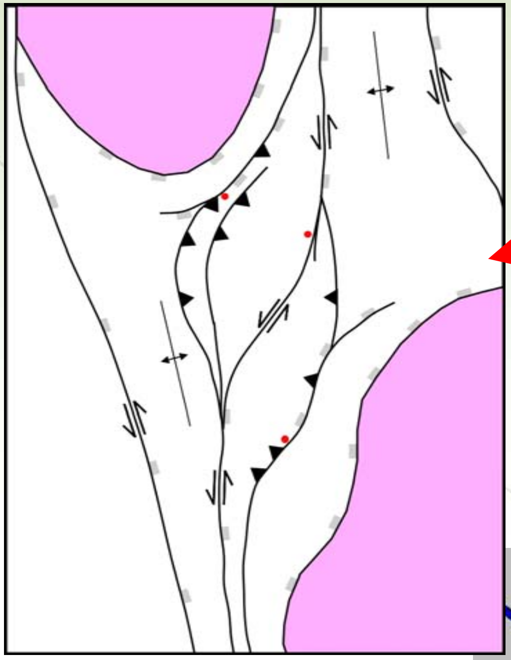


Stress Transfer Modelling (ΔCFS > 0)



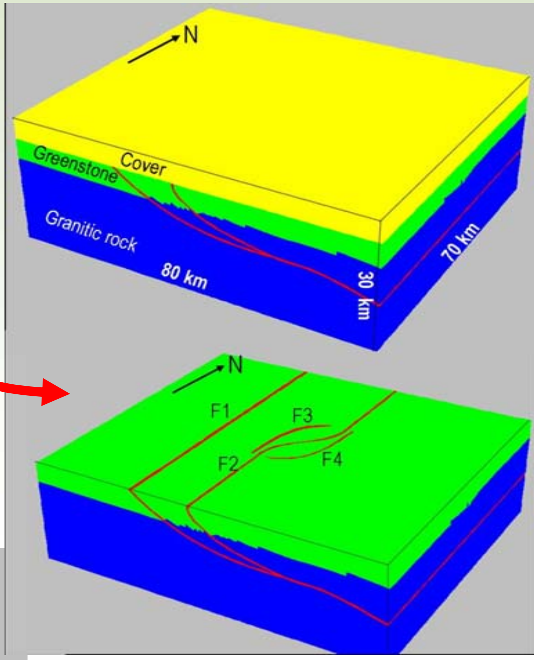
Micklethwaite & Cox 2006

Example Laverton

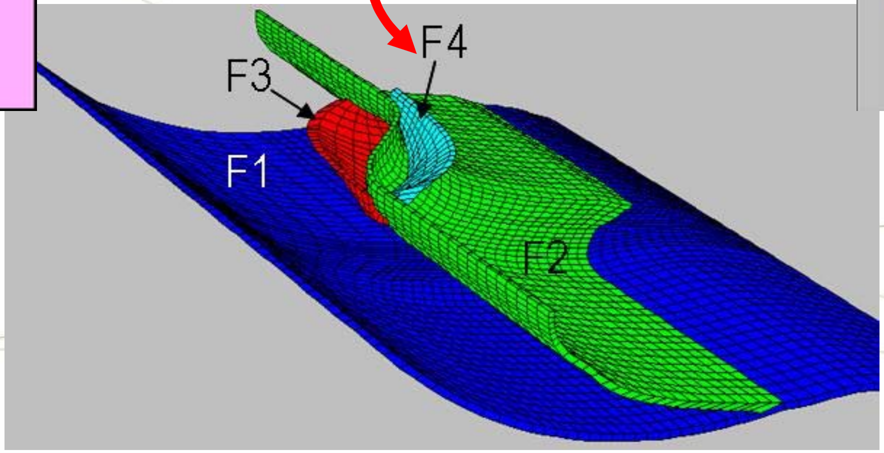


Laverton model concept

Laverton model geometry in FLAC3D



Laverton model faults

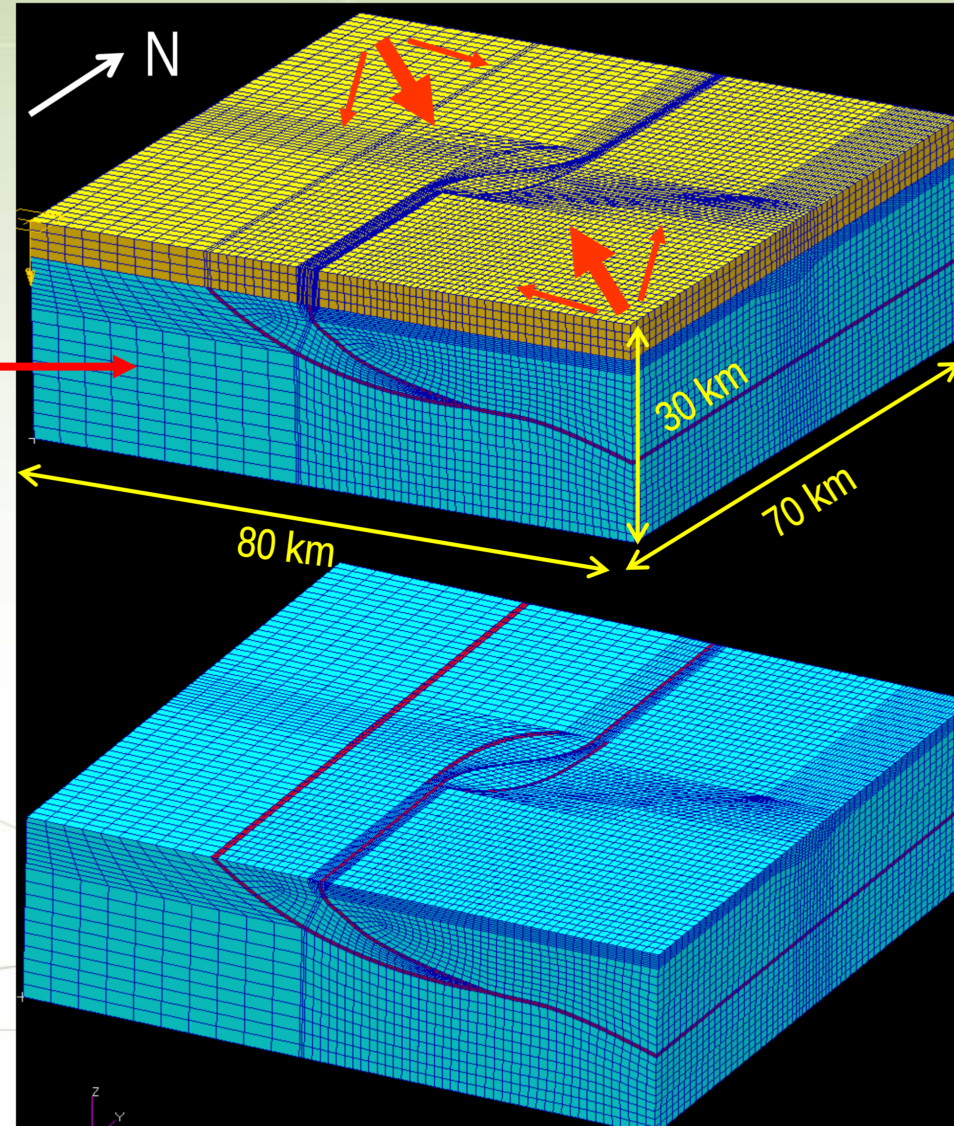


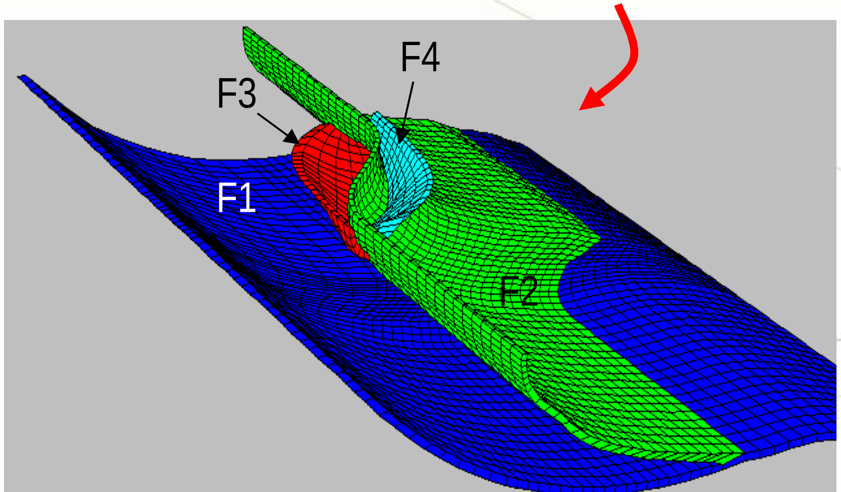
Example Laverton

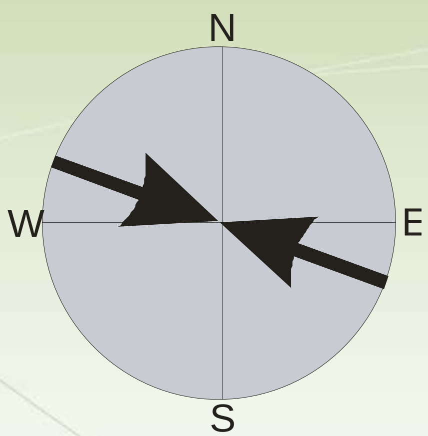
A generic numerical model

The numerical mesh

The model is explored for a range of far-field stress (shortening) orientations

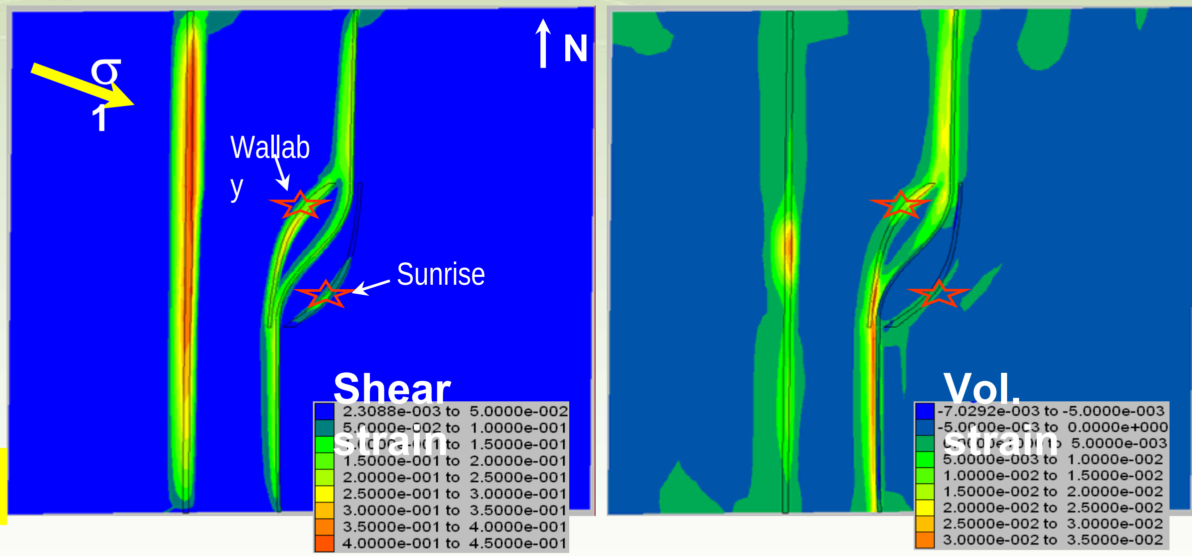






~3% shortening (290°-110°, WNW-ESE)

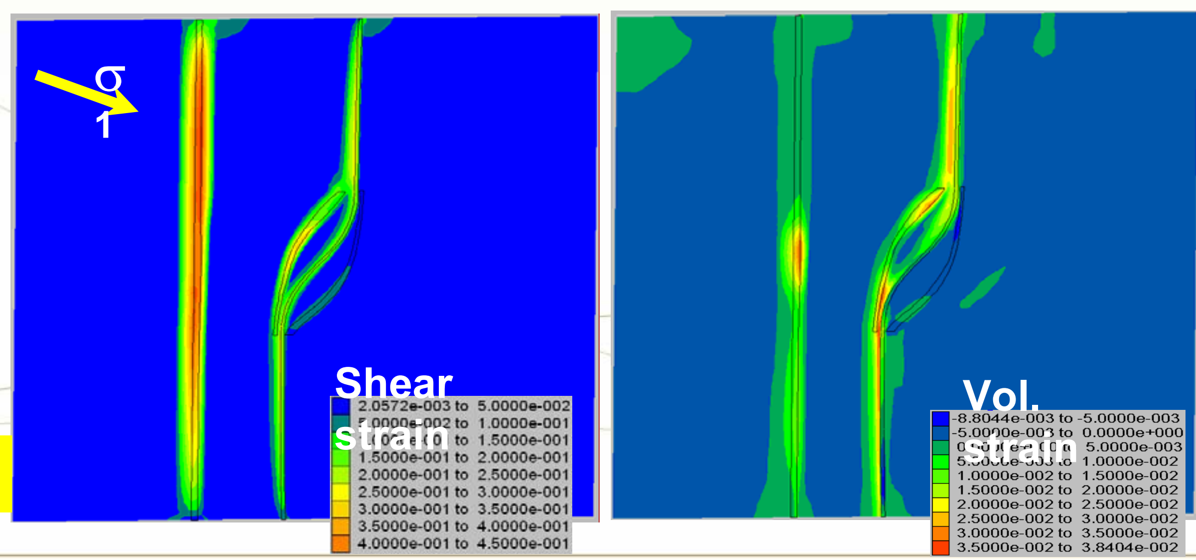
A)

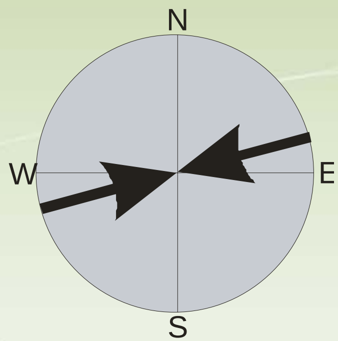


A), B) plan-views at 0.5 and 1.0 km below the top surface of greenstone

Greater shear and dilation localization at Wallaby than at Sunrise

B)

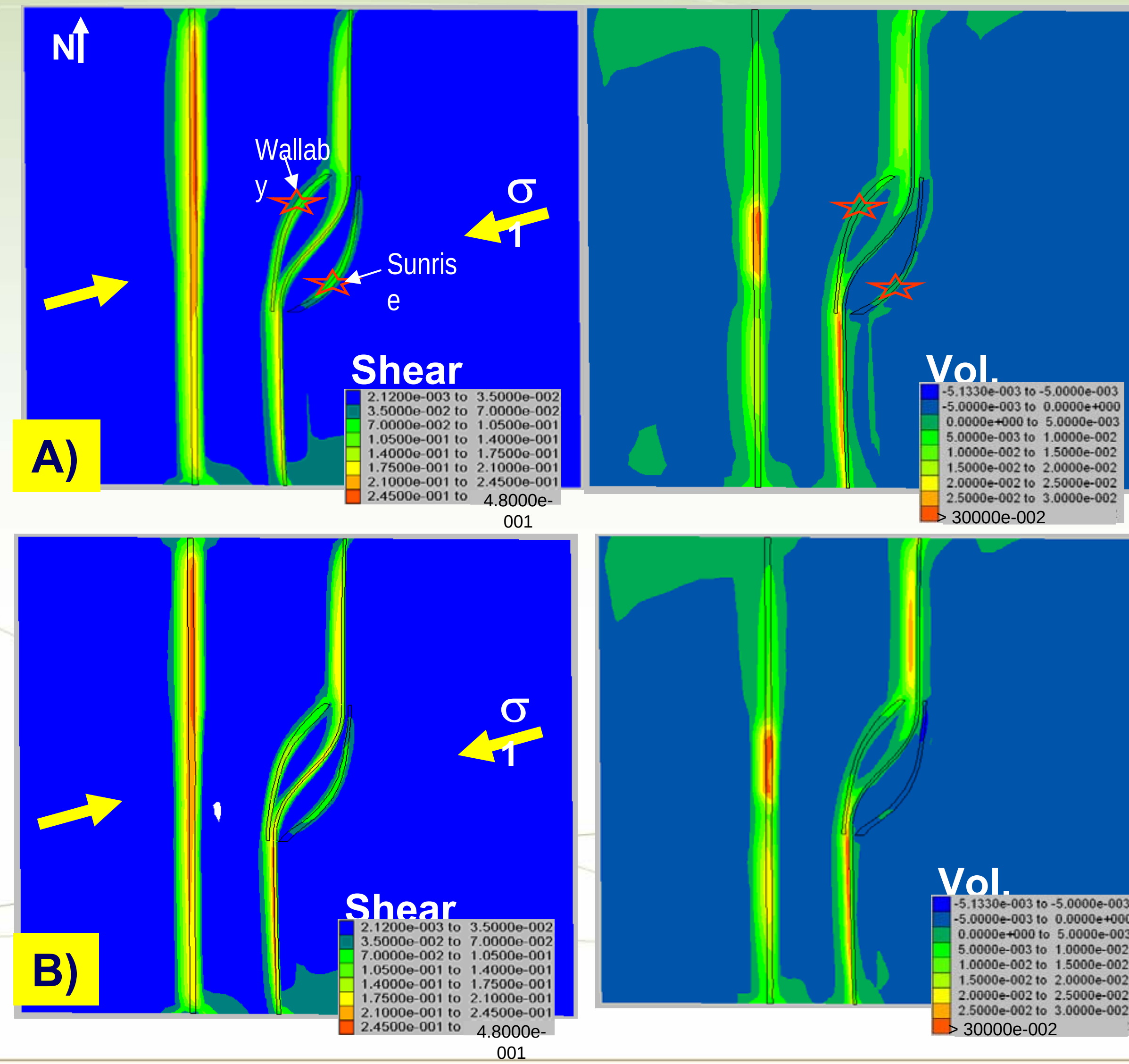


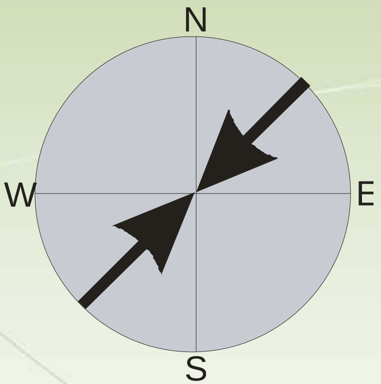


~3% shortening (75°-255°, ENE-WSW)

A), B) plan-views at 0.5 and 1.0 km below the top surface of greenstone

Faults through Wallaby and Sunrise sites show clear shear localization and also dilation – note less shear and dilation at Wallaby than in the NW-SE shortening case.

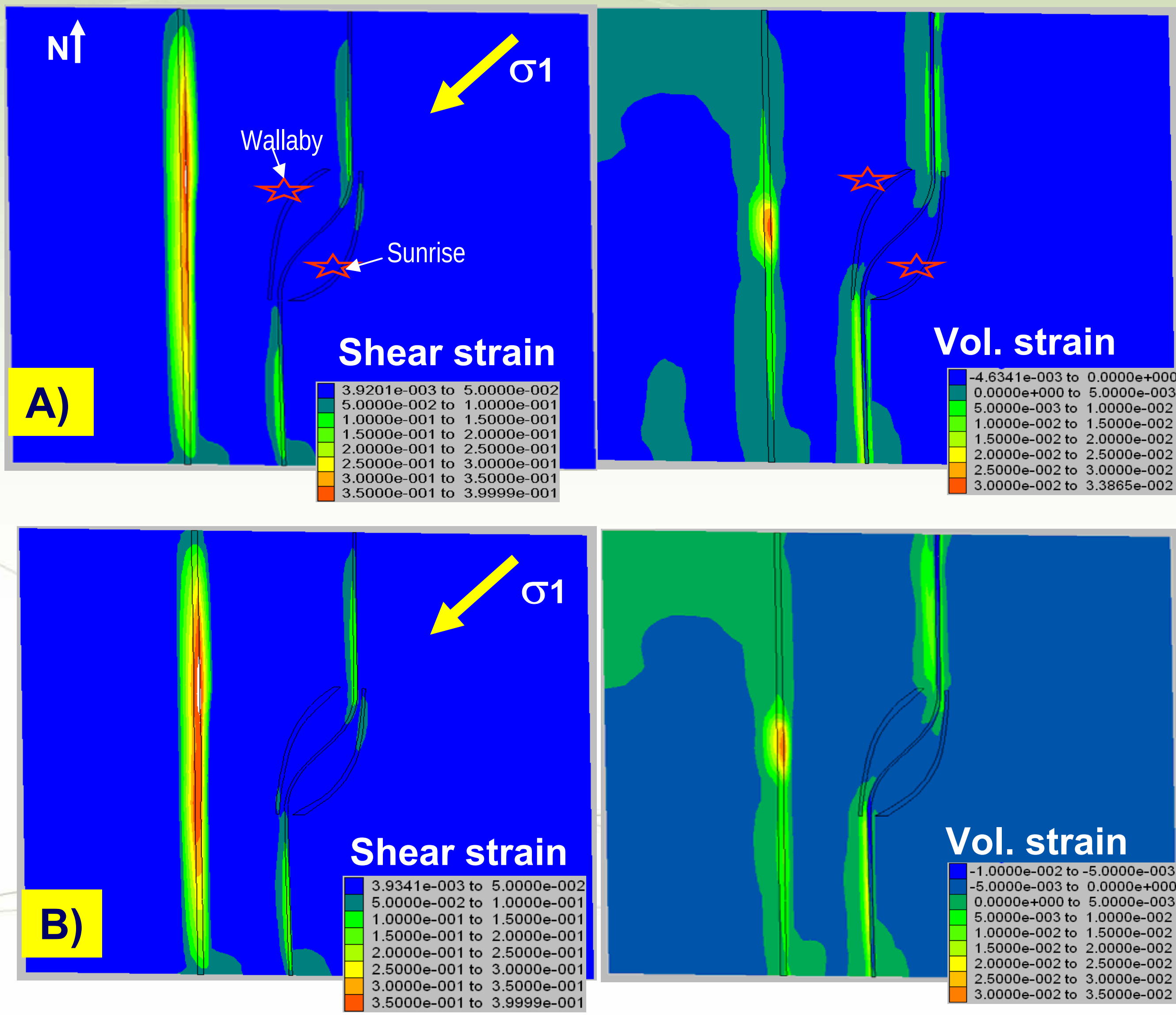




~3% shortening (45°-225°, NE-SW)

A), B) plan-views at 0.5 and 1.0 km below the top surface of greenstone

No clear shear localization or dilations at both Wallaby and Sunrise sites

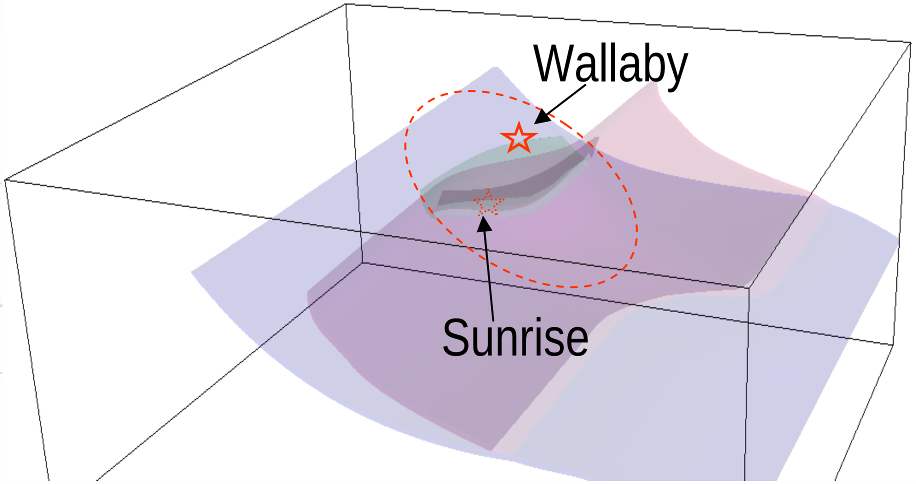


Example Laverton

Summary of key points

A wide range of possible shortening orientations from NW-SE to NNW-SSE seems to be clearly favourable for structural reactivation (Shear & dilation) of the Wallaby system and mineralization. Sunrise site also shows some shear localization and dilation under such conditions but to a much less degree.

A ENE-WSW shortening orientation (75 to 255 degree) led to enhanced shear and dilation at Sunrise. Wallaby now shows weakened activities.

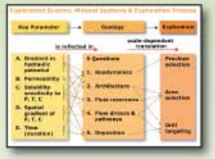


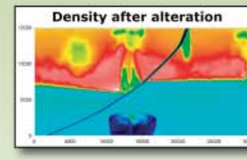
Shortening orientations around NE-SW are unfavourable.

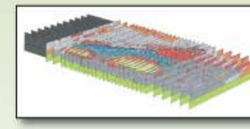
MECHANICAL SIMULATIONS ARE USED TO SIMULATE THE DEFORMATION OF ROCKS UNDER STRESS. METHODS VARY ACCORDING TO PRESSURE, TEMPERATURE, AND SPATIAL AND TEMPORAL SCALE. FLOW DRIVEN BY DEFOEMATION DRIVEN CHANGE IN HYDRAULIC HEAD.

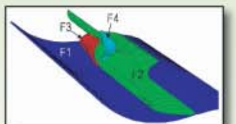
*predictive mineral discovery*Cooperative Research Centre*

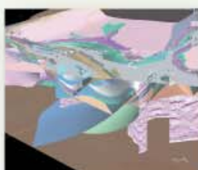
A legacy for mineral exploration science

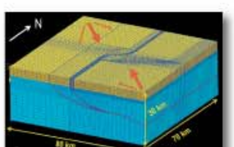


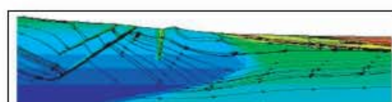


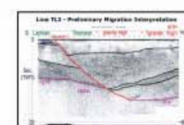


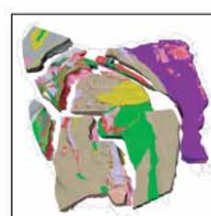












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