Reservoir Geomechanics and Faults

Dr David McNamara – National University of Ireland, Galway

david.d.mcnamara@nuigalway.ie

@mcnamadd

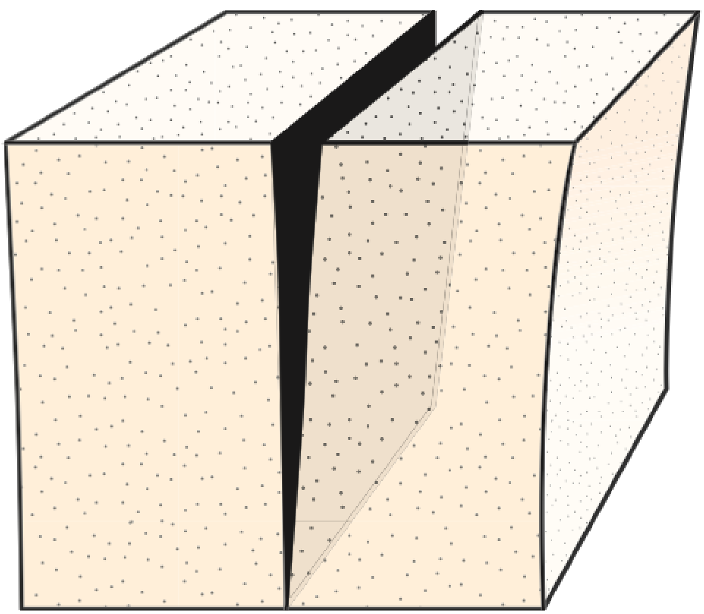
NUI Galway
OÉ Gaillimh

What is a Geological Structure?

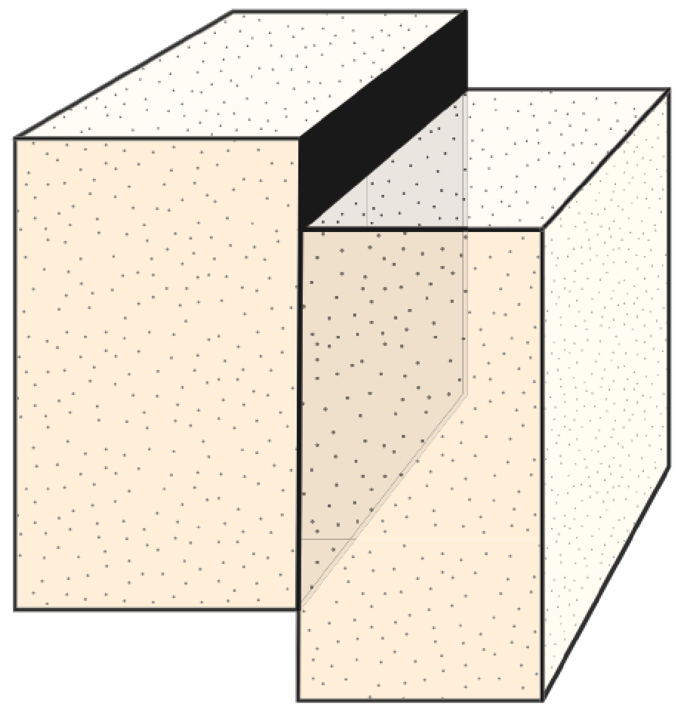
Geological structures include **fractures** and **faults**.

They are discontinuities or breaks in a rock formation.

Two main types of structure:



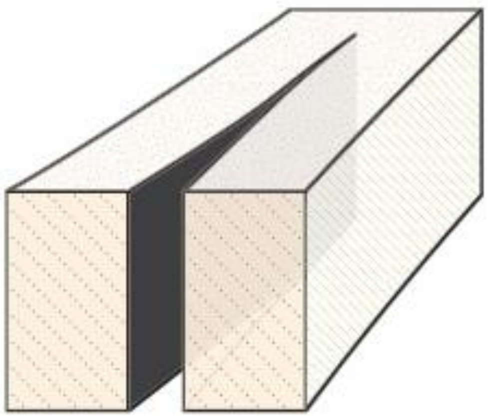
Extension fracture:



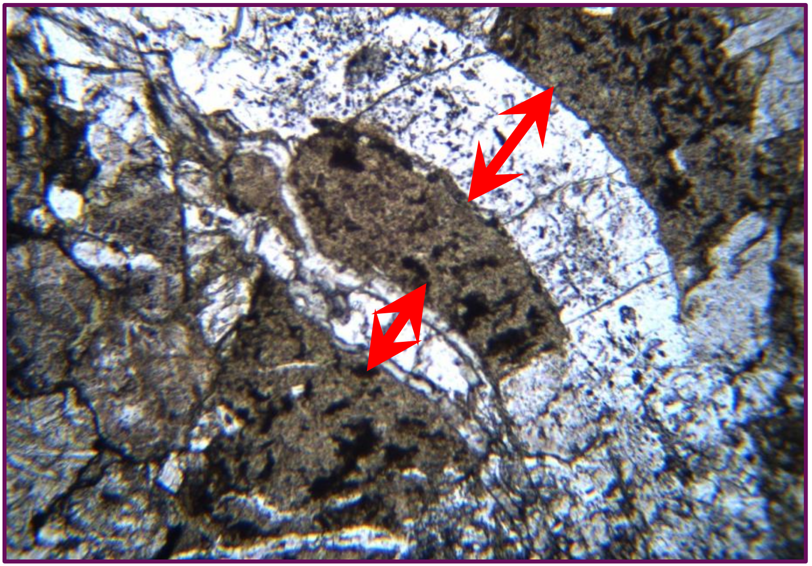
Shear fracture

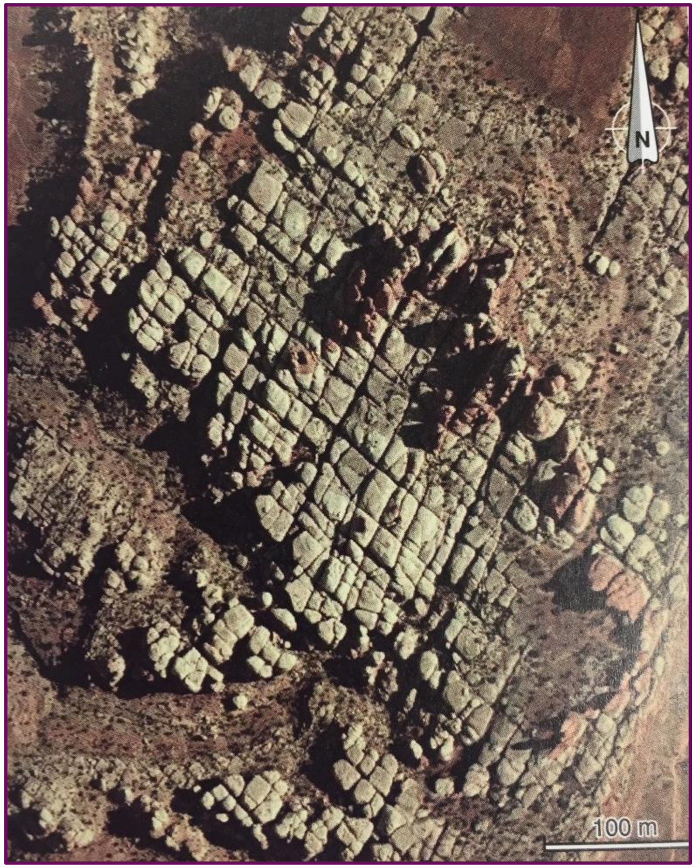
Extension Structures

Extension structures are fractures that open in a rock mass but have very little or no displacement across them.



Mode I
(opening)

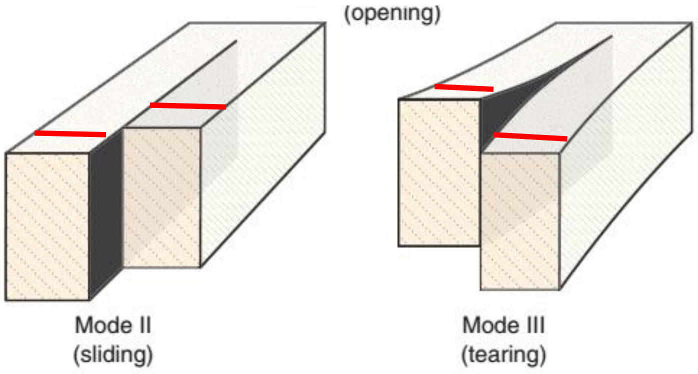




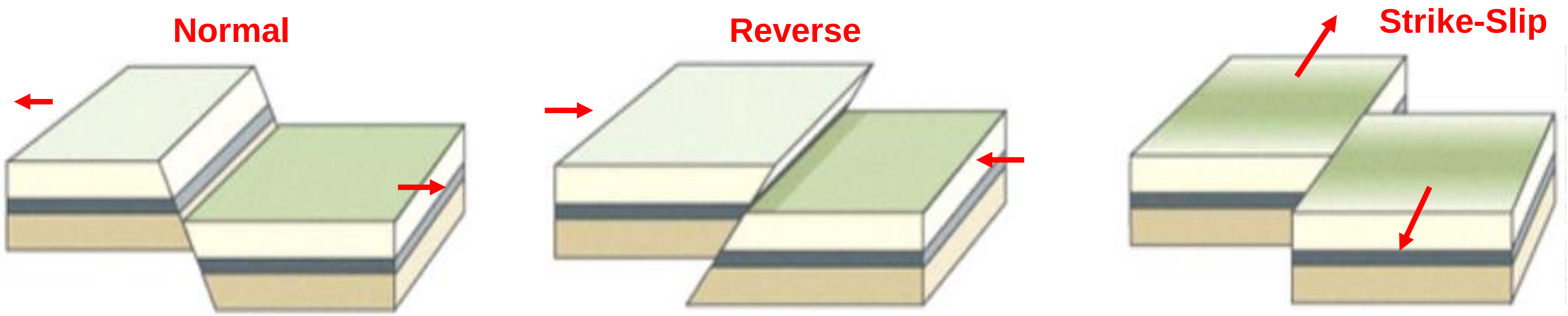
Joint system in Canyonlands National Park, Utah

Shear Structures

Mode 2 and 3 Type



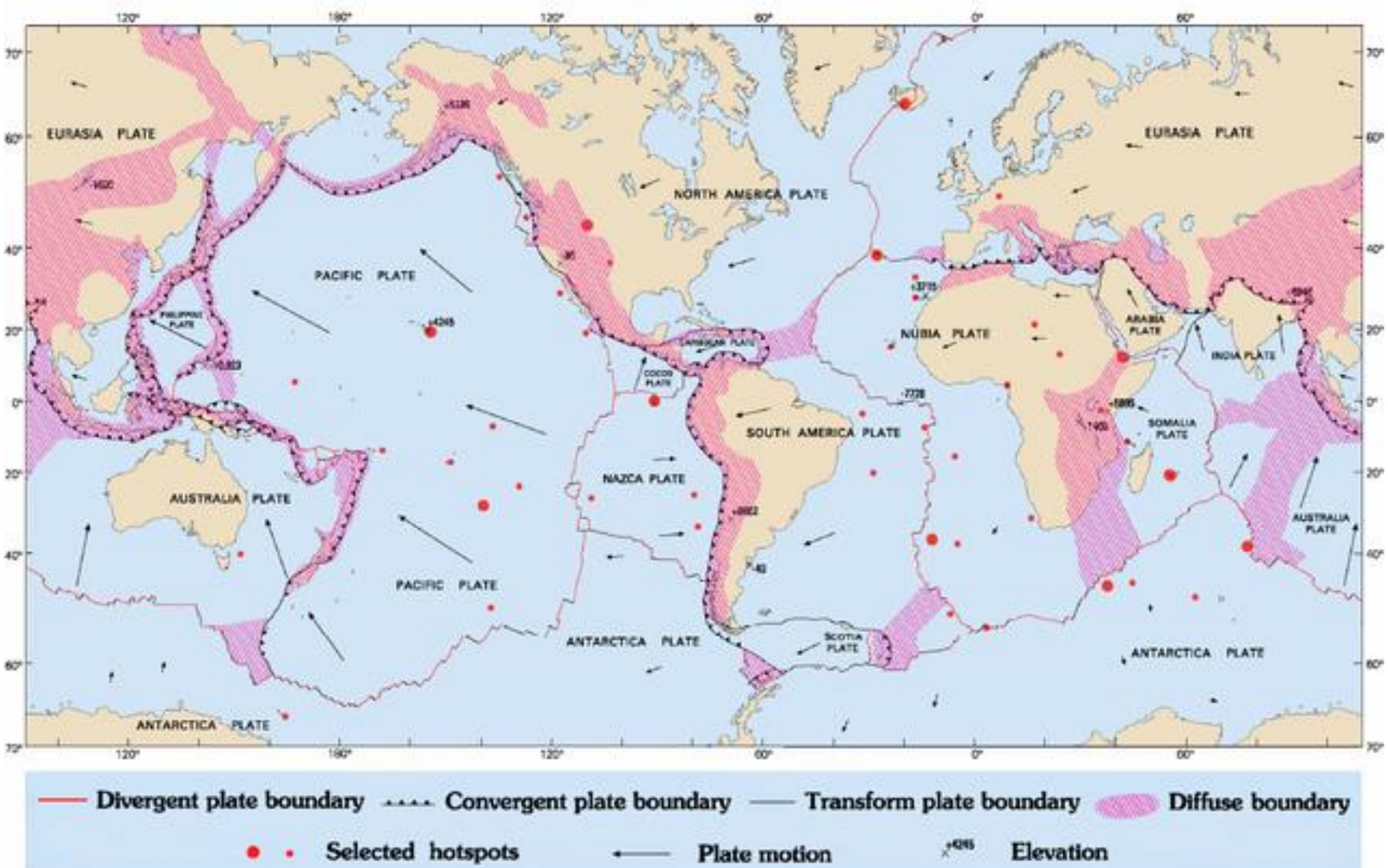
Structures that show displacement across them are shear fractures – this type of structure includes **faults**.



How are Structures Created?

- Rocks are hard… require massive forces and energy to deform them.

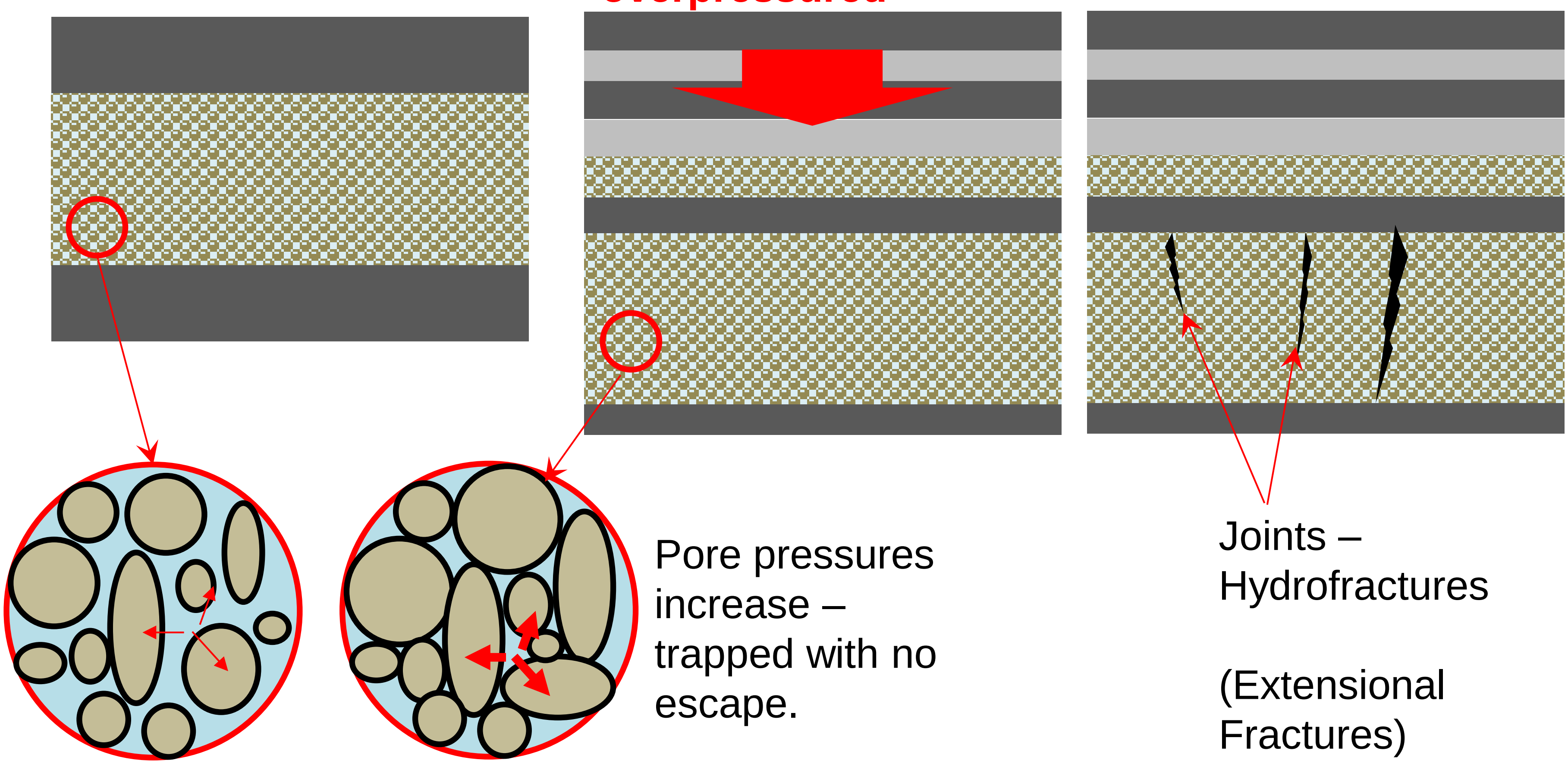
- The most important forces arise from plate motions - the engine that drives geological change.



How are Structures Created?

2) Burial of Rock Layers

Porous sandstone with fluid → Additional layers added – compresses layers below - **overpressured** → Build up of pore pressure overcomes rock strength and fractures

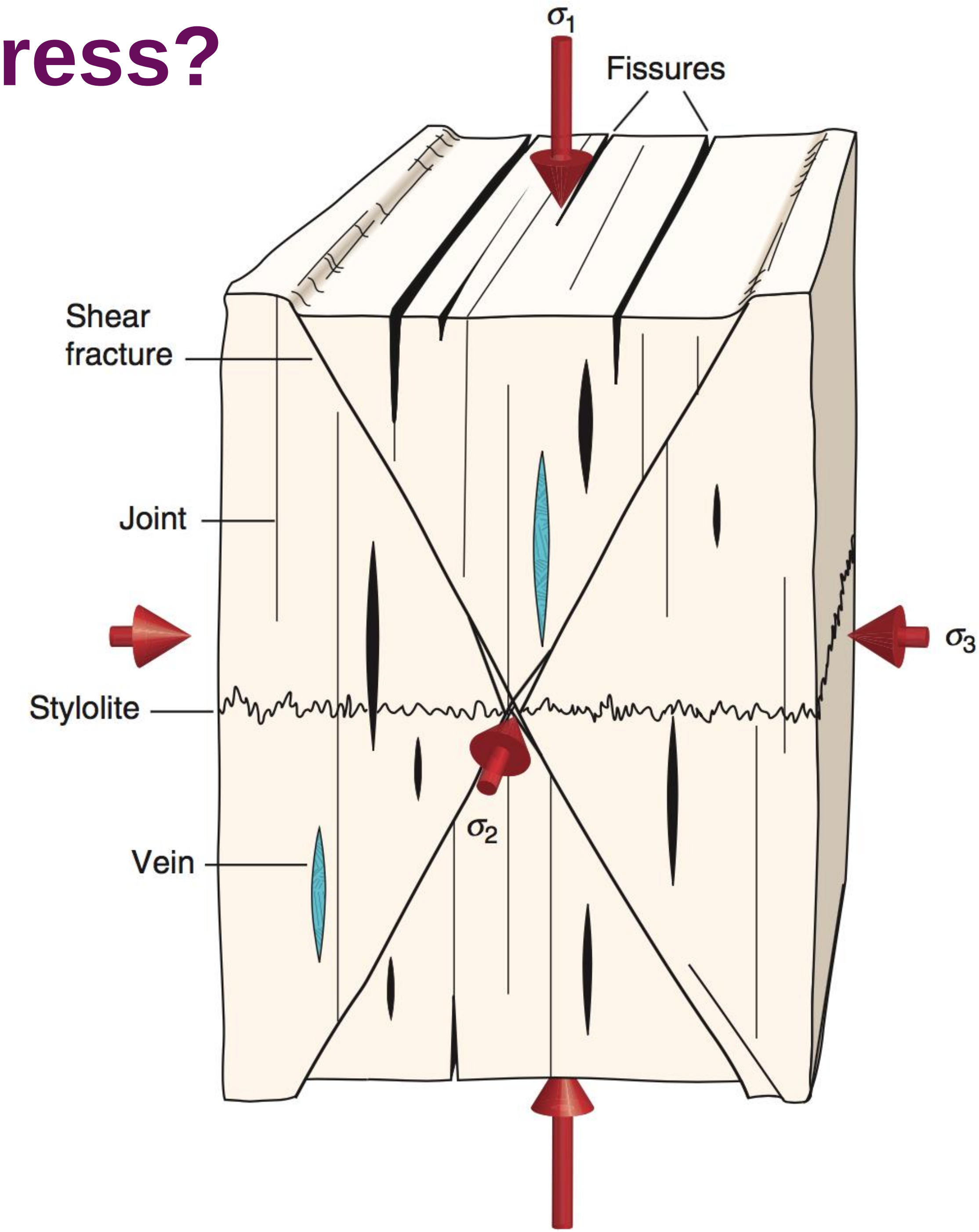


Structure and Stress?

Different fracture types relate to the Earth's stress field in different ways.

Three principle stress directions and magnitudes:

$\sigma_1 > \sigma_2 > \sigma_3$

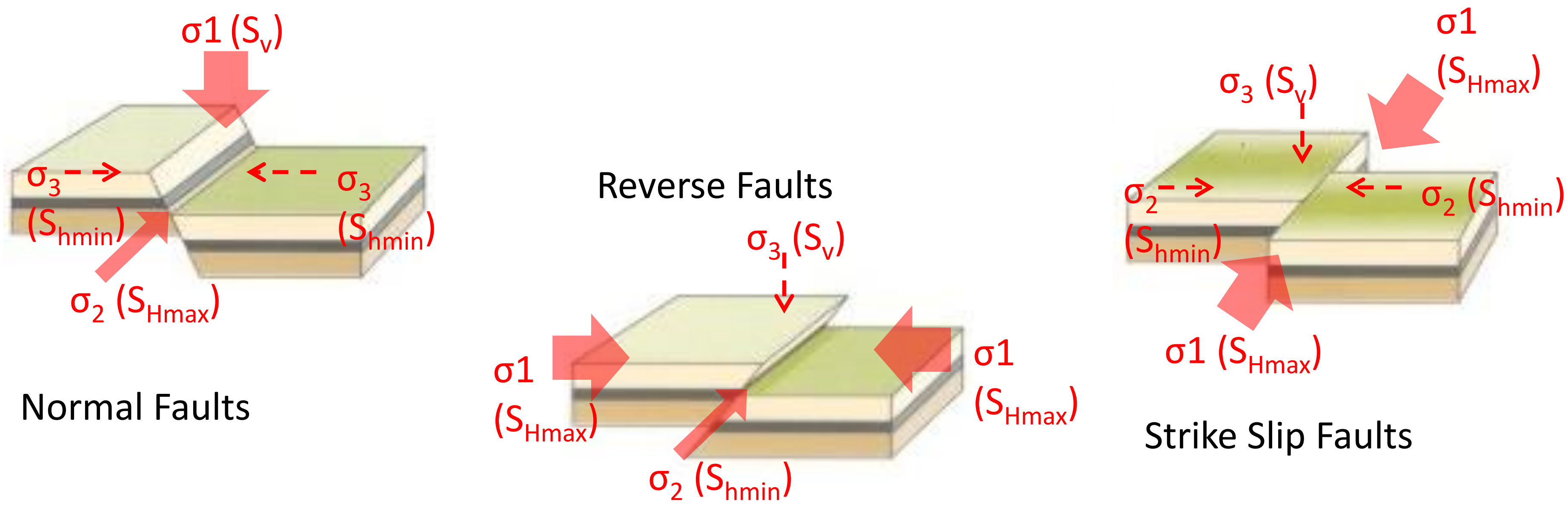


Shear Fractures and Stress

$$\sigma_1 > \sigma_2 > \sigma_3$$

S_v = vertical stress
S_{hmax} = maximum horizontal stress,
S_{hmin} = minimum horizontal stress

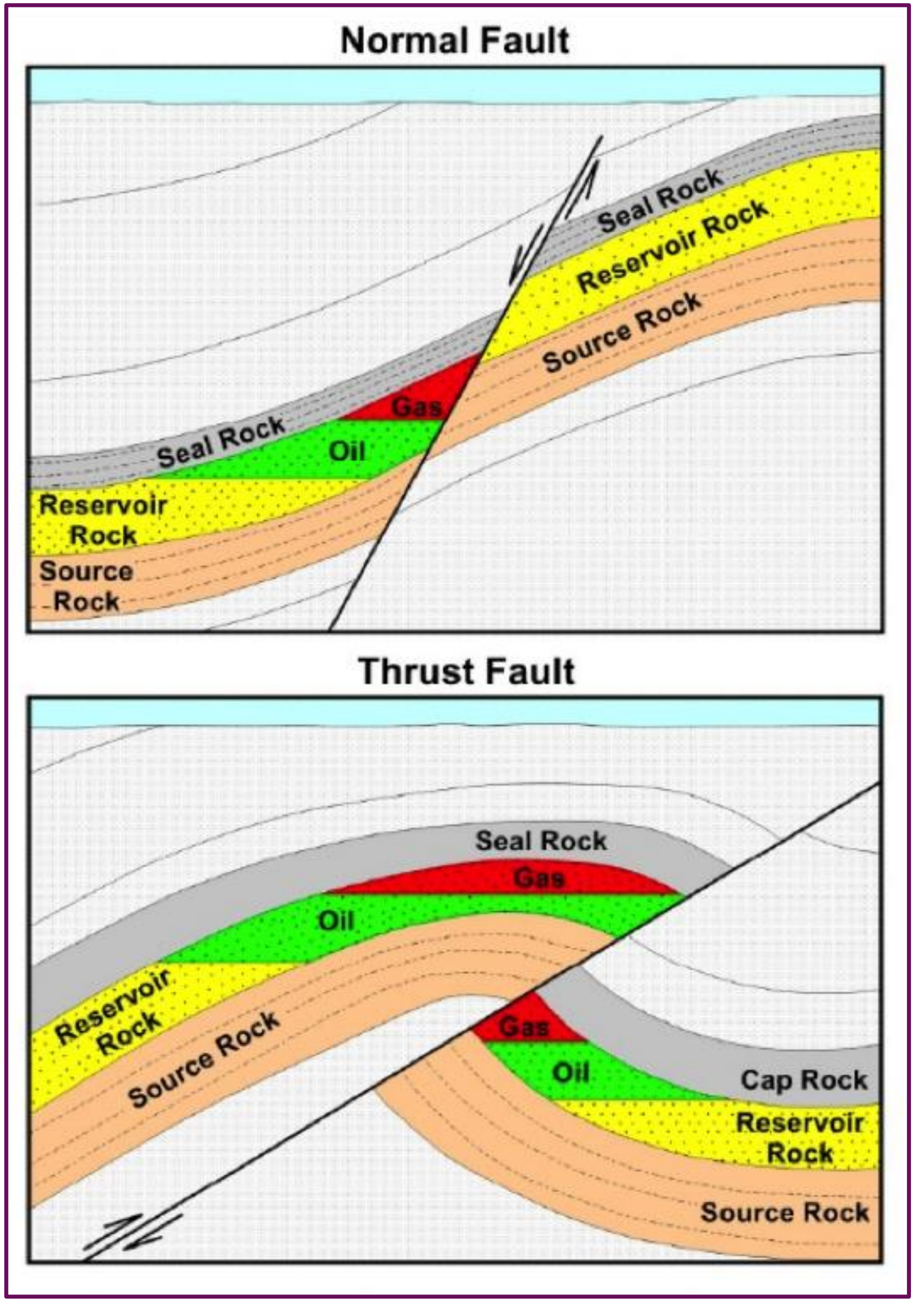
Which stresses are vertical and which are horizontal is determined by the tectonic setting – **Anderson's Classification of Tectonic Stress**



Structure and Fluid Flow

- Fractures and faults are potential fluid flow pathways or barriers through rock.

- When structures allow fluid flow in rock we call it secondary permeability.



E-Mail: david.d.mcnamara@nuigalway.ie

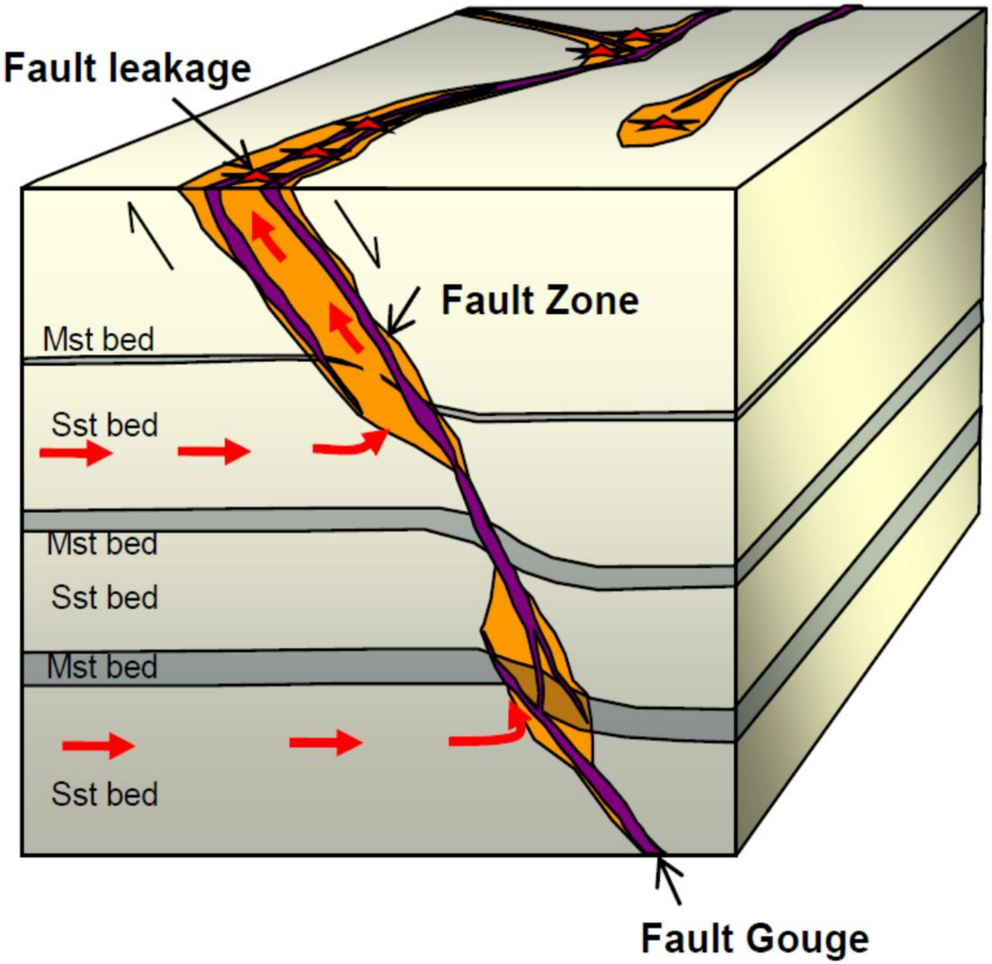
Role of Faults in a CO_2 Reservoir

Fault-zone permeability is controlled by many interdependent factors:

- Fault zone architecture (connectivity, aperture).
- Fault rock type
- The mechanical strength and permeability of the reservoir lithology
- Relationship between faults and the in-situ stress field.
- Pressure and gradients
- Fluid composition
- Extent of pre-existing mineralization

E-Mail: david.d.mcnamara@nuigalway.ie

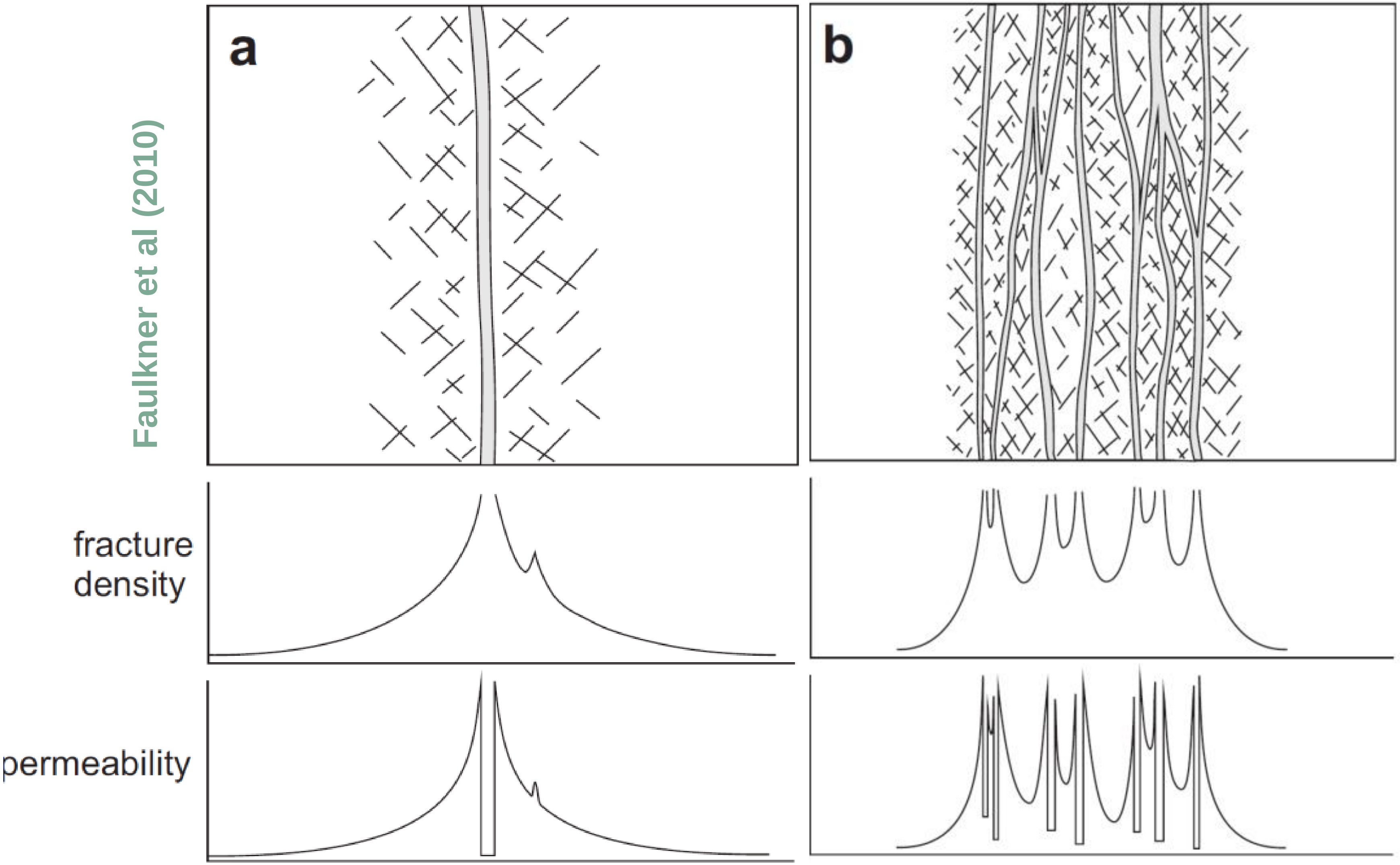
Fault Zone Architecture



- Fault zones are 4-dimensional volumes of deformed rock with highly anisotropic and heterogeneous properties that evolve through time.
- Fault-zone complexity produces property variations along strike and down dip, which even over short distances (e.g. 4 m wide fault zone can show at least three orders of magnitude permeability changes).

E-Mail: david.d.mcnamara@nuigalway.ie

Fault Zone Architecture



E-Mail: david.d.mcnamara@nuigalway.ie

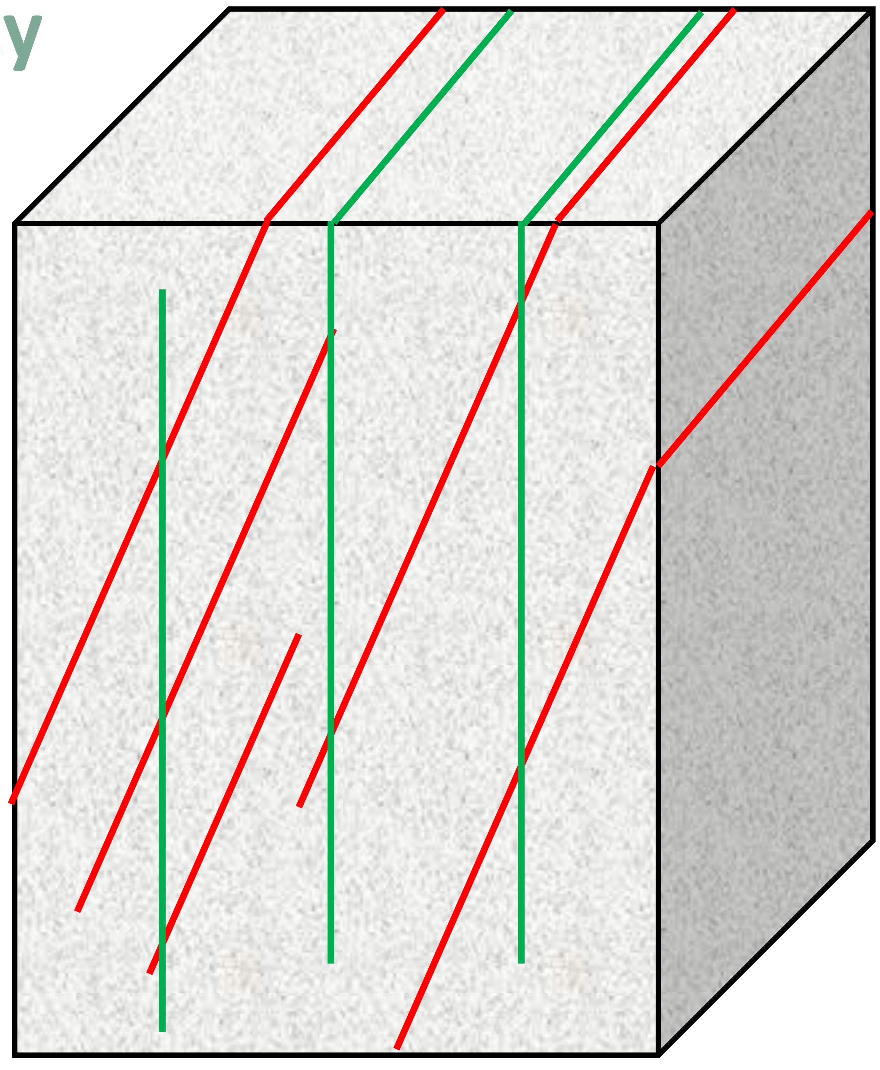
Fault Zone Architecture

Fracture Connectivity

Orientation - More orientations of structures = more connectivity = more fluid flow!

Length - longer fractures connect with greater numbers of other fractures = more fluid flow.

Density – more fractures = more fluid flow.



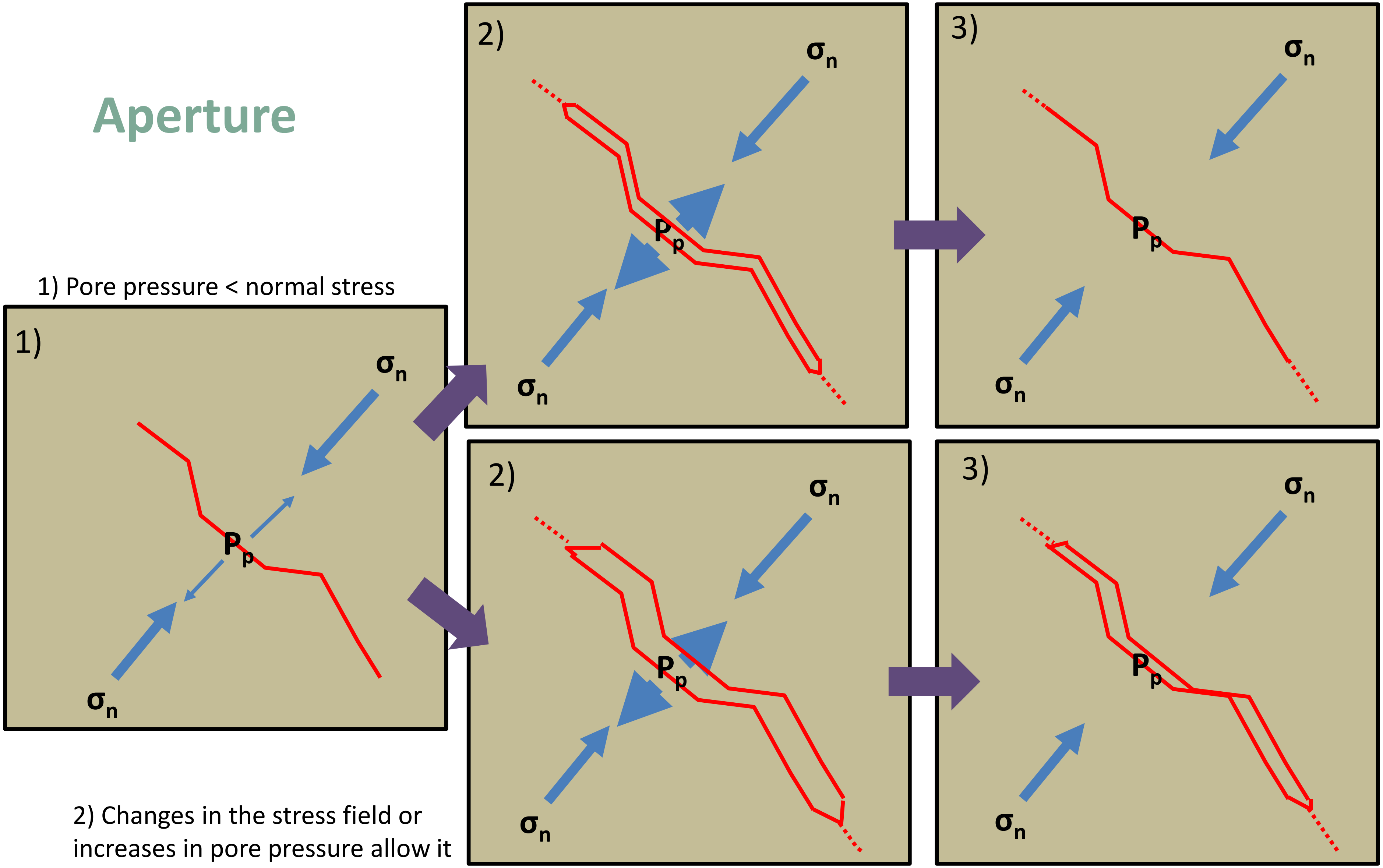
Fault Zone Architecture

- **The aperture of a fracture is the separation between its two walls (width).**
- **The more open a fracture is the more fluid can move along it.**
- **Deeper in the crust we expect fractures to be closed because of rapidly increasing confining pressure with depth.**
- **Fractures at depth only express aperture when pore pressure exceeds the normal stress acting on the fracture surface keeping it closed.**
- **When this happens the fracture will open, propagate, the pore pressure will drop and the fracture will close again.**

Fault Zone Architecture

Aperture

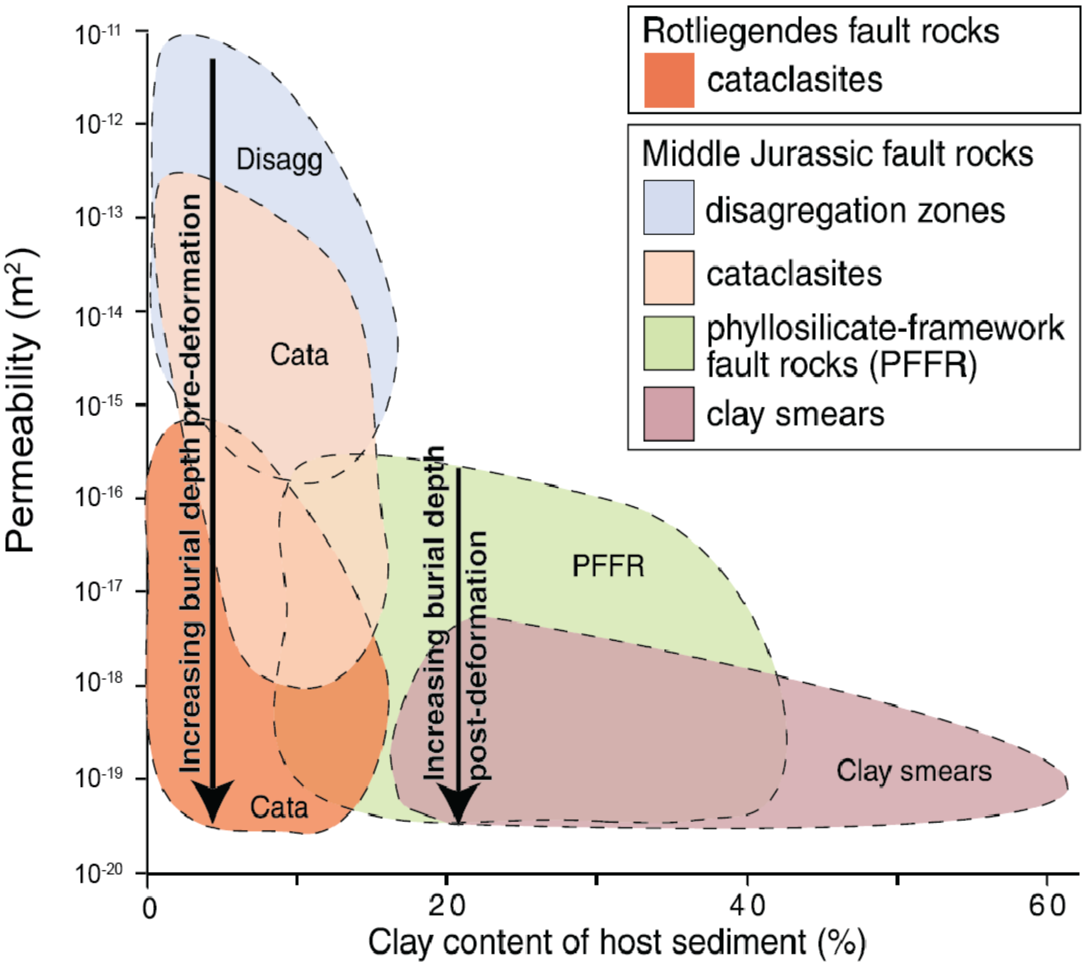
1) Pore pressure < normal stress



2) Changes in the stress field or increases in pore pressure allow it to exceed the normal stress – fracture opens

3) Fracture grows, pore pressure drops, and depending on how the fracture moved either closes or maintains open space.

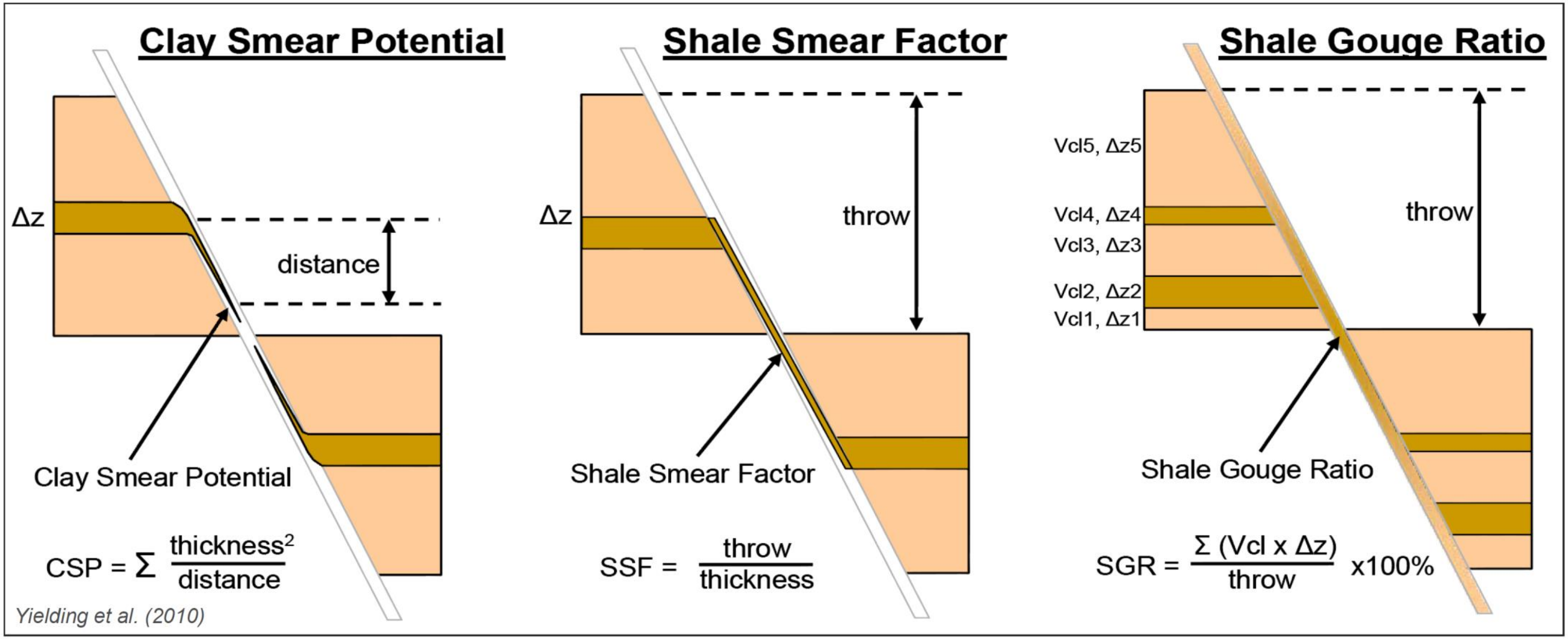
Fault Zone Rock Types



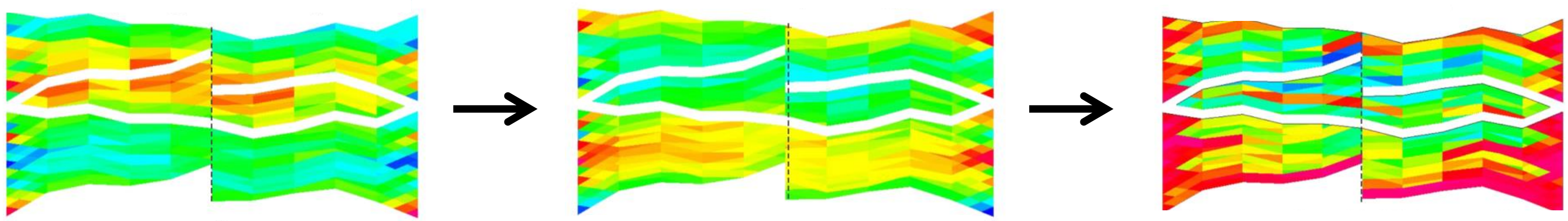
Fisher and Knipe (2001)

- Fault core (rock) low permeability clay-rich rock.
- Fault damage zone can have elevated permeability.
- Fault zones impact on fluid flow dependent on many factors including, host rock type, stress conditions, fault zone architecture and depth of burial.
- Individual faults can enhance fault-parallel flow and retard fault-normal flow.

Fault Permeability



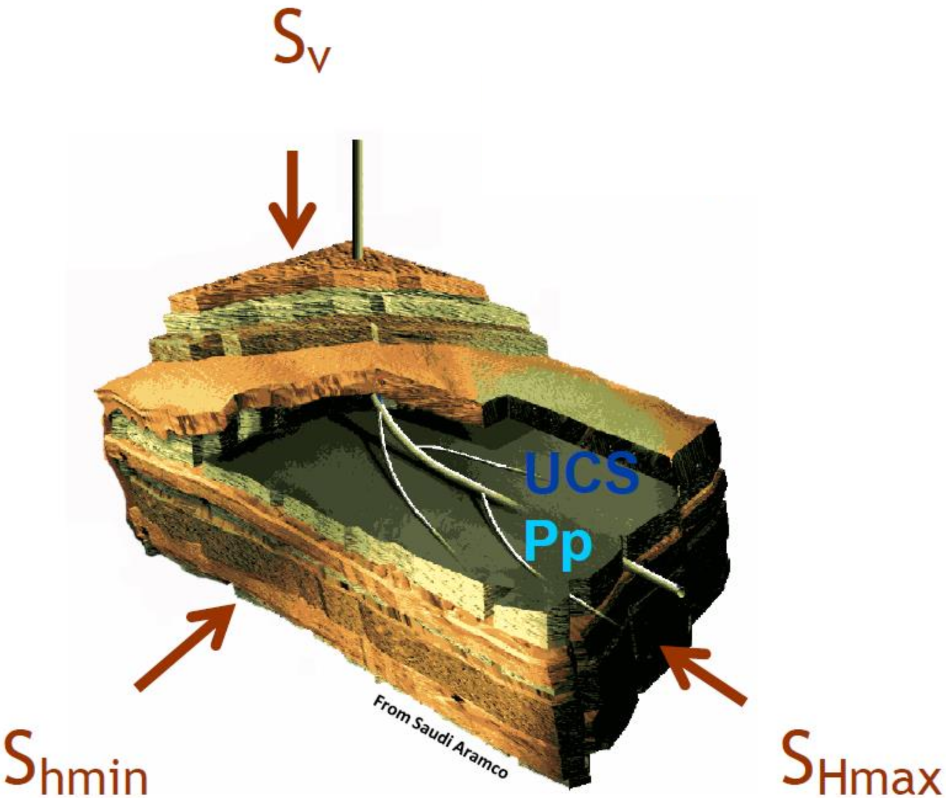
Shale Smear Algorithms and Fluid Flow



Shale Gouge Ratio → **Permeability (*Kf*)** → **Transmissibility multiplier**

E-Mail: david.d.mcnamara@nuigalway.ie

Geomechanical Models – Fluid Flow



Geomechanical models of faults allow identification of their likelihood to slip and dilate allowing fluid escape.

Requires knowledge of:

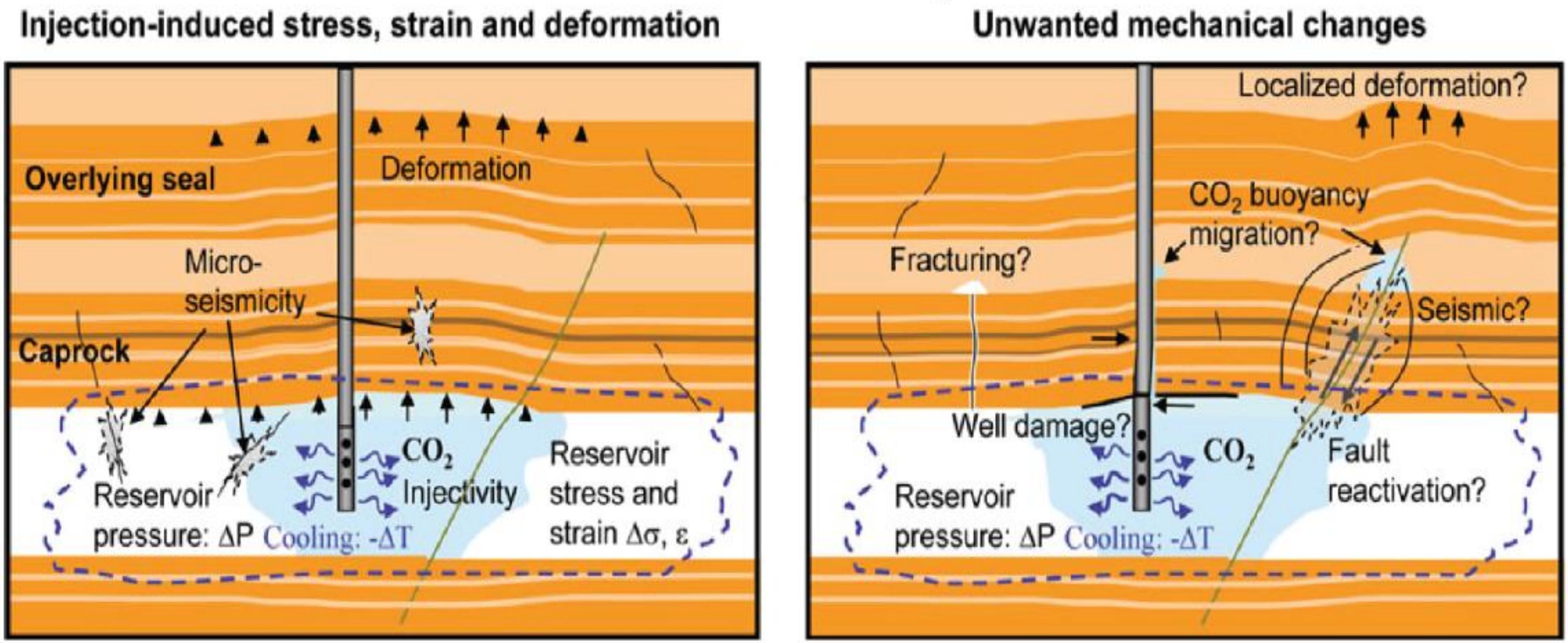
- ❖ Structural architecture of subsurface
- ❖ In-situ stress orientations
- ❖ In-situ stress magnitudes
- ❖ Pore pressure monitoring data (both pre, during, and post activity)
- ❖ Rock strength properties (UCS, tensile strength).

E-Mail: david.d.mcnamara@nuigalway.ie

CO_2 Reservoir Scale Geomechanical Models

Schematic model CO_2 storage project

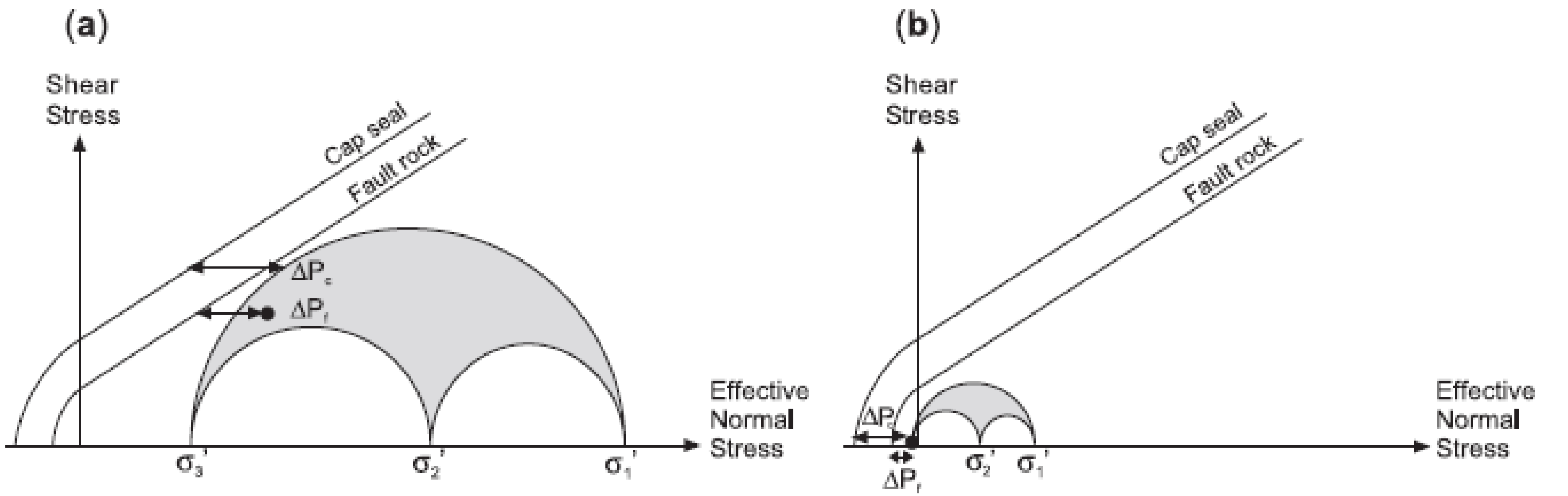
Rutqvist 2012



- Geomechanical models can be matched with reservoir performance.
- Flow simulation modelling suggests that low-permeability fault rock may compartmentalise reservoirs giving rise to increased pressures and promoting upward flow of CO_2.

E-Mail: david.d.mcnamara@nuigalway.ie

Geomechanics and Critical Risk



a) Critical Risk – Fault Reactivation in Shear

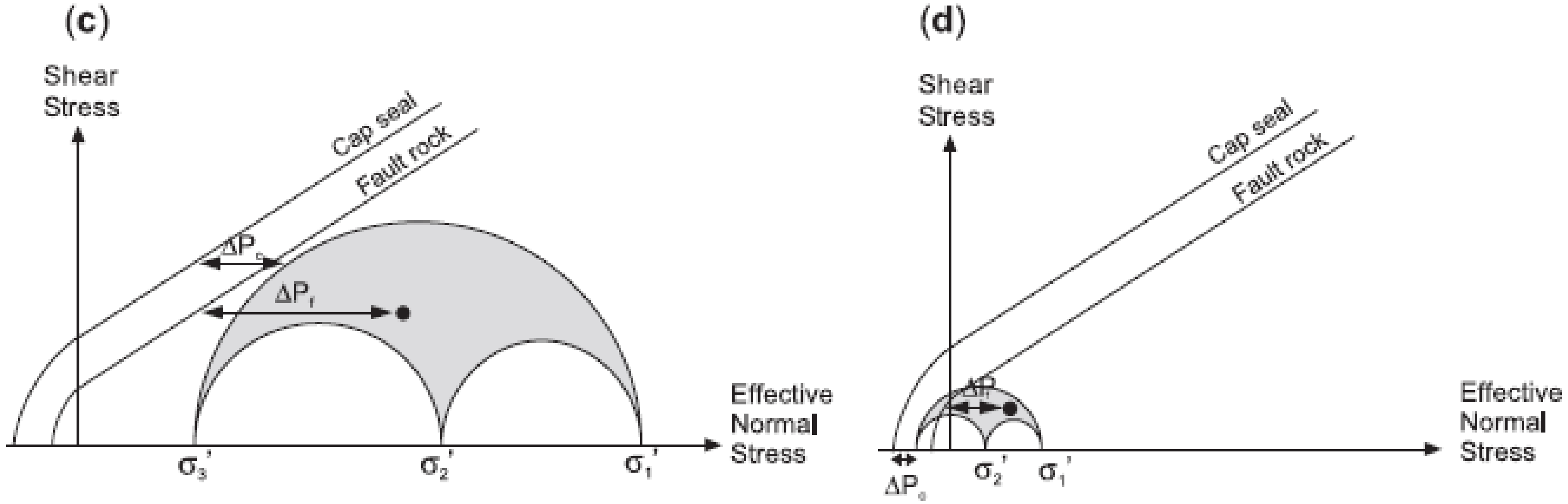
A fault suitably oriented for shear reactivation in the reservoir is a higher risk to the resource than cap rock failure.

b) Critical Risk – Fault Reactivation in Tension

A fault suitably oriented for tensile reactivation in the reservoir is a higher risk to the resource than cap rock failure.

E-Mail: david.d.mcnamara@nuigalway.ie

Geomechanics and Critical Risk



c) Critical Risk – Shear Failure in the Cap rock

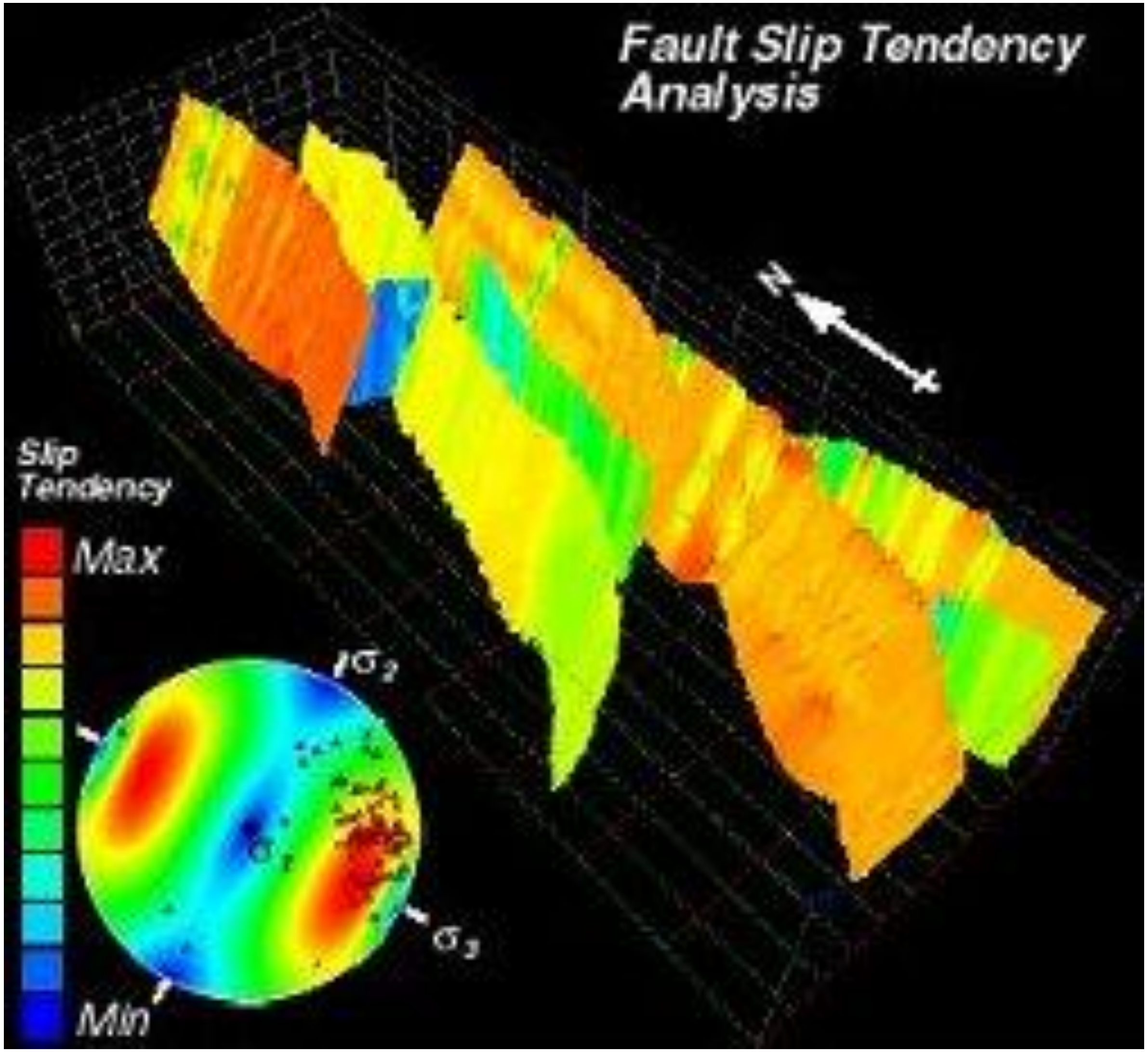
Fault not suitably oriented for reactivation in the reservoir and so shear failure of the cap rock is a higher risk to the resource.

d) Critical Risk – Tensile Failure in the Cap rock

Fault not suitably oriented for reactivation in the reservoir and so tensile failure of the cap rock is a higher risk to the resource.

E-Mail: david.d.mcnamara@nuigalway.ie

Predicting Potential Fault Migration Pathways

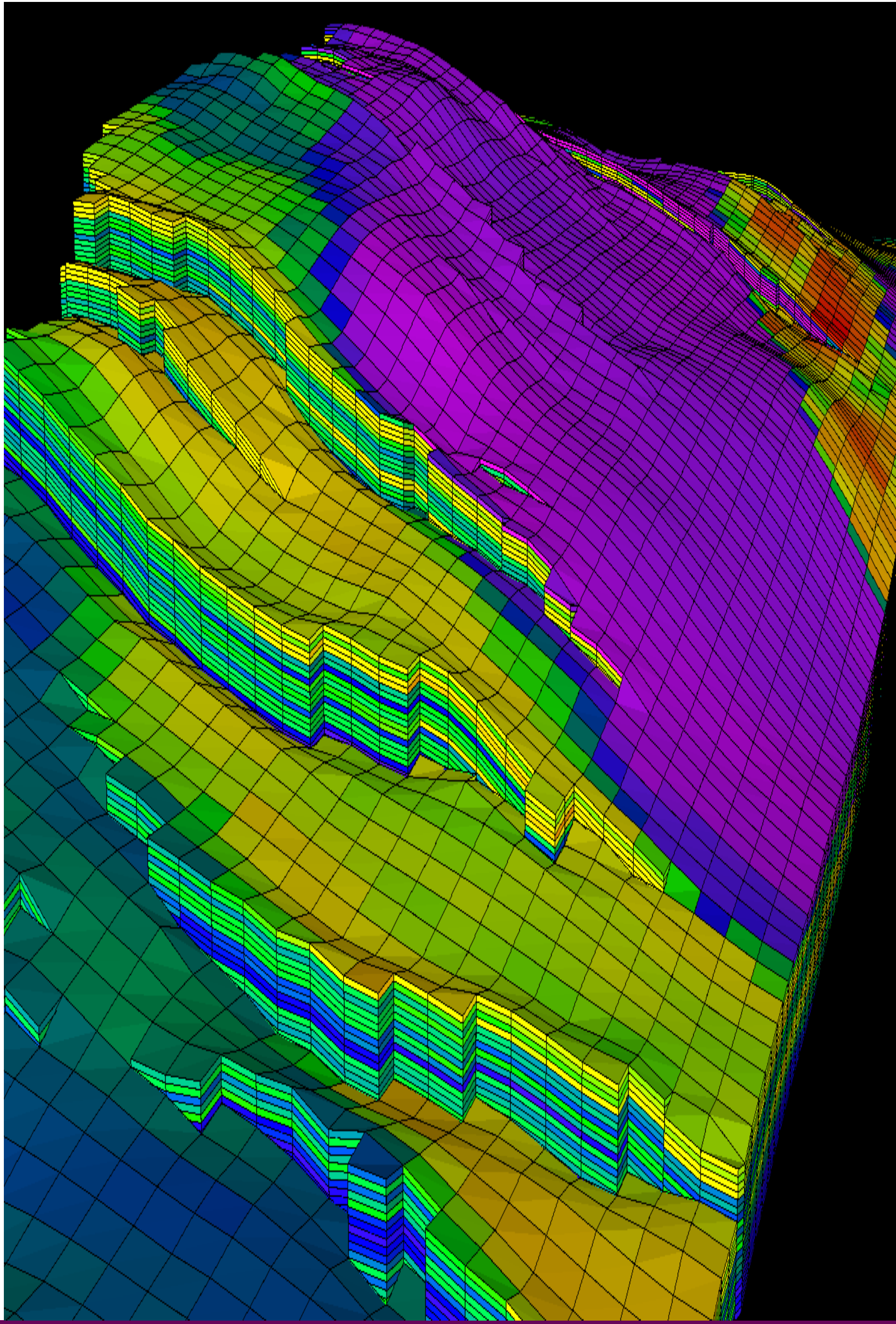


Combining data on the stress field and 3D fault orientation you can use geomechanics to determine which faults in a reservoir are likely to slip and possible rupture your seal rock.

E-Mail: david.d.mcnamara@nuigalway.ie

Conclusions

- Faults are complex. They can compartmentalise reservoirs and promote migration of CO_2.
- Fault permeability is stress, rock type, and fault geometry dependent.
- Along-fault flow can be highly heterogeneous and difficult to predict.
- Leakage along faults at natural seeps can be up to 15000 t/yr.
- In situ flow data are essential for testing permeability predictions and fluid flow models.



E-Mail: david.d.mcnamara@nuigalway.ie

Thank You

E-Mail: david.d.mcnamara@nuigalway.ie