Storage 2- Containment: Keeping CO_2 in the Subsurface

JOHN KALDI
Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) at University of Adelaide, Australia

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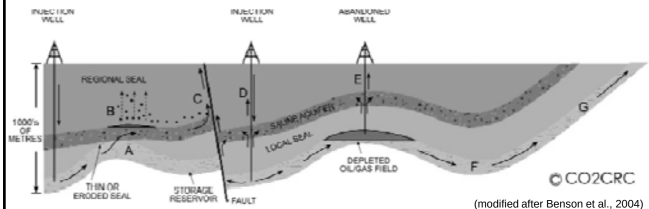
CO2CRC

Potential CO_2 escape mechanisms



(modified after Benson et al., 2004)

A: CO_2 escapes through thin or eroded section of seal,
B: CO_2 buoyancy pressure exceeds capillary pressure and passes through the seal,
C: CO_2 migrates from reservoir and up transmissive fault,
D: CO_2 escapes up wellbore via poorly completed injection well and into shallower formation,
E: CO_2 escapes up wellbore and into shallower formation via poorly plugged old abandoned well,
F: Hydrodynamic flow transports dissolved CO_2 out of closure,
G: CO_2 migrates updip beyond influence of regional seal

Containment of CO_2: caprocks and faults

- **Caprock properties controlling confinement**
  - Petrophysical
  - Geometric
  - Geomechanical
  - Geochemical
  - Hydrodynamics

  Seal Potential
- **Fault properties controlling confinement**
  - Juxtaposition
  - Fault plane / zone properties
  - Reactivation
- **Qualitative assessment methodology for site screening**

Seal potential

- **Capacity, Geometry and Integrity of caprock**
- **Capacity: maximum CO_2 column that can be retained by caprock**
- **Geometry: thickness and lateral extent of the caprock**
- **Integrity: geomechanical properties of caprock**

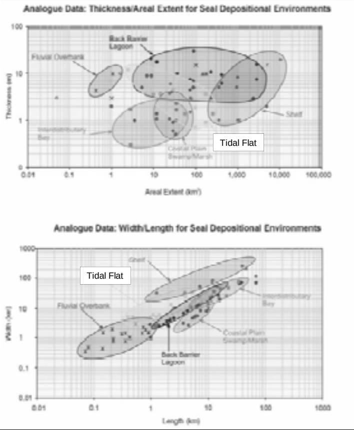
Evaluating seal capacity of caprocks and intraformational barriers for CO_2 containment

- If a capillary ("rock" seal) can support a column of hydrocarbon, then it should support a column of CO_2. (CO_2 column will be smaller than CH_4 column, but bigger than oil column)
- If the seal capacity is calculated as being insufficient to hold the required column, the cap rock may still be viable as low permeabilities may inhibit migration ("rate" seal)
- If upward migration through the seal does occur, it would be at very slow rates (3μm-30mm /1000 years) with low volume
- Break-through rates can take >0.3Ma/ 100m for migration via diffusion (e.g. Muderong Shale)

Seal geometry

- **Structural position, thickness and areal extent of caprocks**
- **Estimated by integrated studies of seismics, core data, well correlations and geological/depositional models**
- **Caprock thickness (z) does not influence capillary entry pressure, but is critical for continuity in faulted regimes (z > fault throw)**

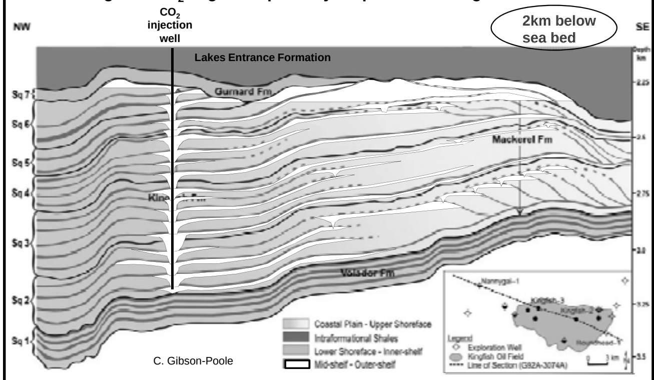
Thickness versus areal extent (upper) and width versus length (lower) of potential seal lithologies from various depositional environments



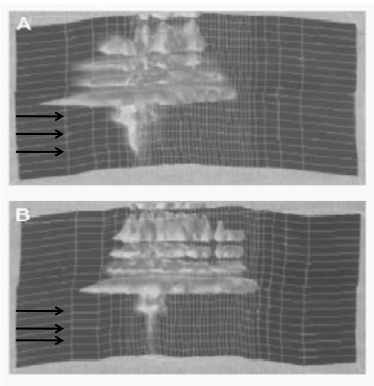
Data from world-wide modern and ancient analogues. Compiled by (Gibson-Poole et al., 2009 after Root, 2007)

Intraformational seals (baffles)

increase length of CO_2 migration pathways & potential for Sgr and dissolution



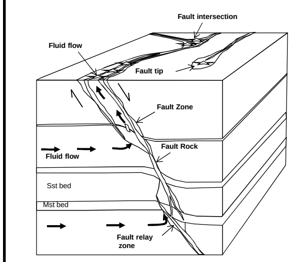
Intraformational seals: Sleipner



Numerical flow simulation of CO_2 injection at Sleipner Field, which has been history matched with time lapse 3D seismic reflection data. Two perpendicular cross-sections of a simulation result are shown (A & B). Intra-formational seals act as barriers to vertical $scCO_2$ migration

(van der Meer et al., 2000).

The role of faults in CO_2 containment



- Schematic diagram showing zones of fractures (orange polygons) associated with a fault (yellow polygons).

Question

- Do faults seal or leak?

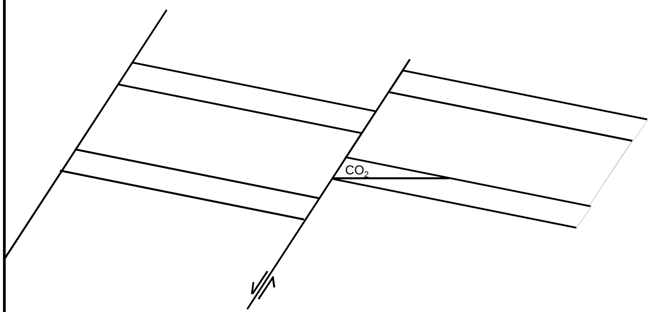
Answer

- Yes!

The role of faults in CO_2 containment

- Faults do not necessarily act as conduits; empirical evidence that many thousands of hydrocarbon accumulations are trapped by sealing faults
- In such cases, either the fault itself is acting as a seal or the juxtaposition of rocks across the fault results in sealing
- Fault movement (reactivation) results in fluid migration along the fault

Shale-sand juxtaposition traps CO_2



Juxtaposition:

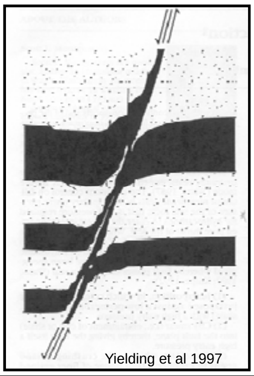
- Not the only mechanism for fault sealing
- Sand on sand may also be sealing via grain sliding, cataclasis, diagenesis, clay smear / shale gouge
- Need to consider fault zone deformation processes (FZDP) along with juxtaposition

Principle fault zone deformation processes

- Grain Sliding:- Grain slippage along fault plane due to minor fault movement or high pore pressure
- Cataclasis:- Grain breakage and crushing to cause fine grained gouge along fault
- Diagenesis:- Preferential cementation (or dissolution) along permeable fault plane
- Shale Gouge / Clay Smear:- high shale/sand ratio causes clay to be incorporated into fault plane

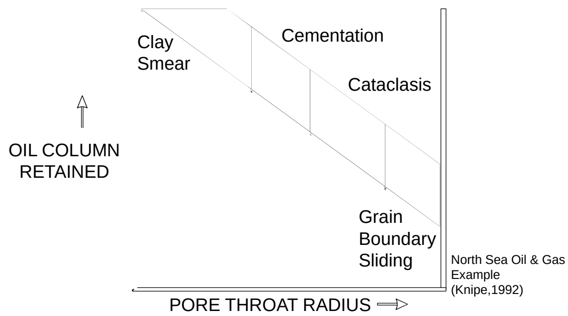
• Understanding of deformation processes needed to predict the fault rock properties along the fault plane (risk of seal vs "leak")

Clay Smear (Shale Gouge)



Yielding et al 1997

Which fault zone deformation processes result in best seals?

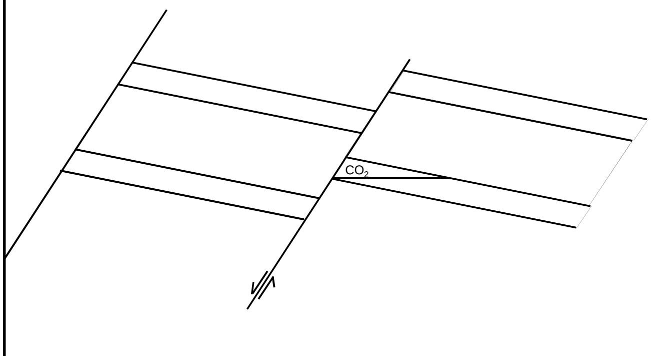


Reactivation of faults

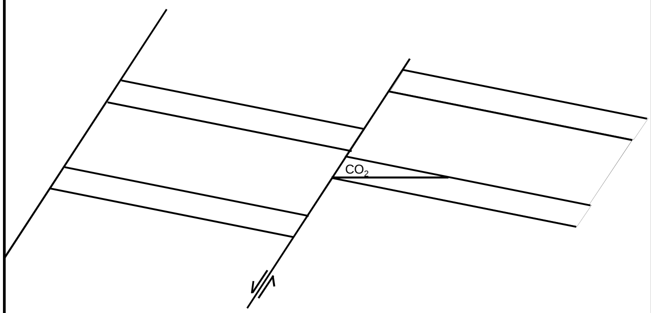
"Reactivation of faults results in creation of structural permeability networks permitting hydraulic flow".

(Sibson, 1996)

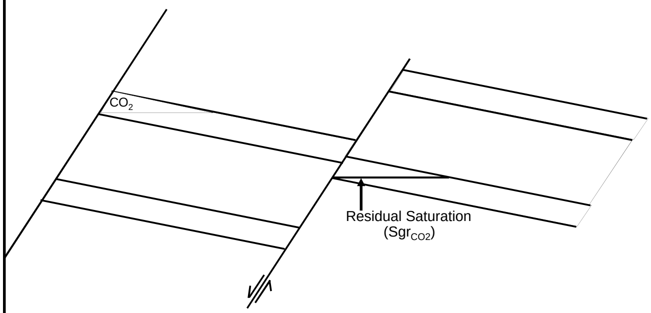
Juxtaposition + Reactivation



Juxtaposition + Reactivation



Juxtaposition + Reactivation



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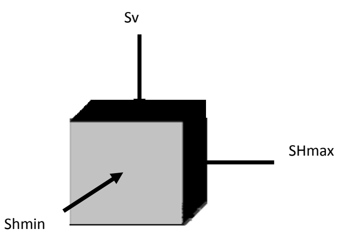
The stress tensor



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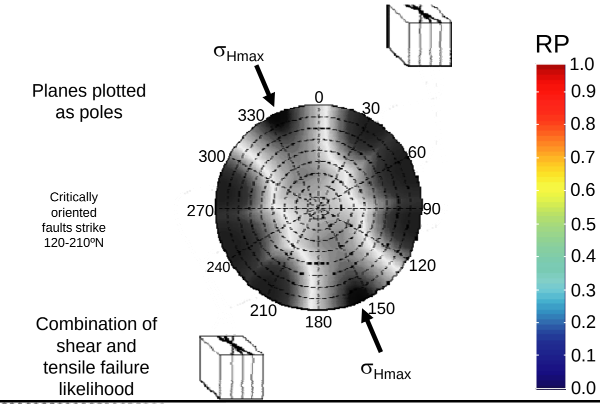
Structural permeability stereonet



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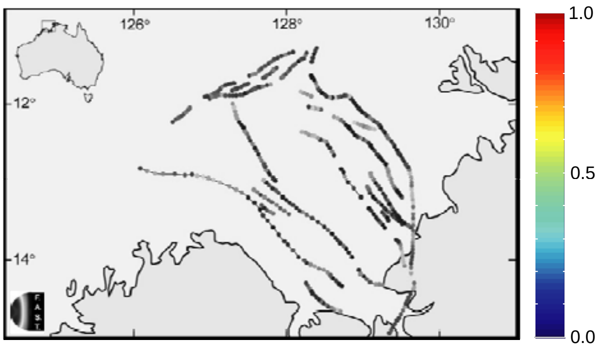
Relative risk of reactivation



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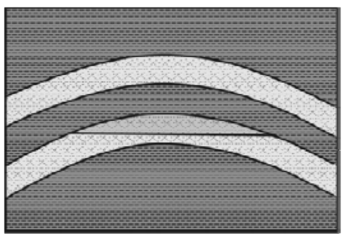
Risk assessment of caprock seal

A caprock seals if it has adequate seal capacity, to retain the required CO_2 column, continuously covers the trap and is not cut by open fractures.*



*fractures here taken to be those below seismic resolution: if fractures (faults) cutting the seal are recognised on seismic data, the trap is considered a fault trap

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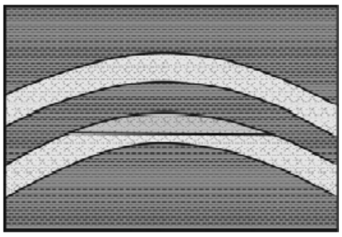
Risk assessment of caprock seal

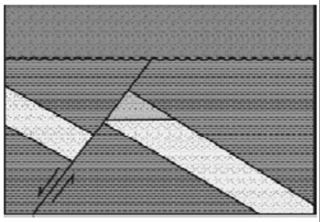
Pcap = i*j*k

Probabilities (0-1)
i: cap rock capacity
j: cap rock geometry
k: cap rock integrity



Risk assessment of fault seal

A fault seals if it juxtaposes sealing rocks against reservoir rocks or fault zone properties cause adequate seal capacity, and the fault has not been reactivated post CO_2 injection.



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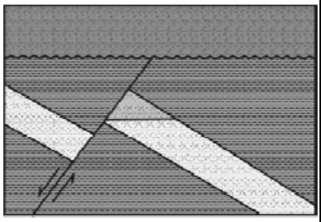
Risk assessment of fault seal

Pfault = {1-[(1-a)*(1-b)]}*(1-c)

Probabilities (0-1)
a: juxtaposition (x-fault lithologies)
b: fault zone properties
c: post-injection reactivation



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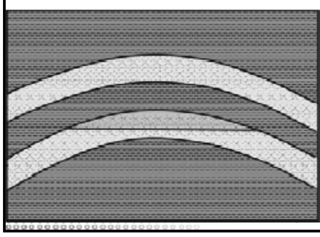
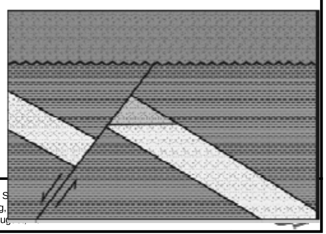
Risk assessment of caprock & fault seal

A fault bounded trap is confining if both the caprock and the fault are sealing.

Ptrap = (Pcap * Pfault)

Ptrap = (i*j*k) * {1-[(1-a)*(1-b)]}*(1-c)





Caprocks & faults for containment: summary

- **Assessment of caprocks & faults highly site-specific**
- **Caprock seal potential a function of capacity, geometry and integrity**
- **Fault seal controlled by juxtaposition relationships, fault zone properties, risk of reactivation**
- **Key knowledge gaps include:**
  - Wettability and IFT for water-rock-scCO_2 systems
  - Hydrodynamic effects on caprocks during large scale storage
  - Coupled geochemical / geomechanical models
  - Upscaling lab scale properties to regional scale
  - Effects & prediction of subseismic faults

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