IEAGHG Fault Permeability & Overburden Studies

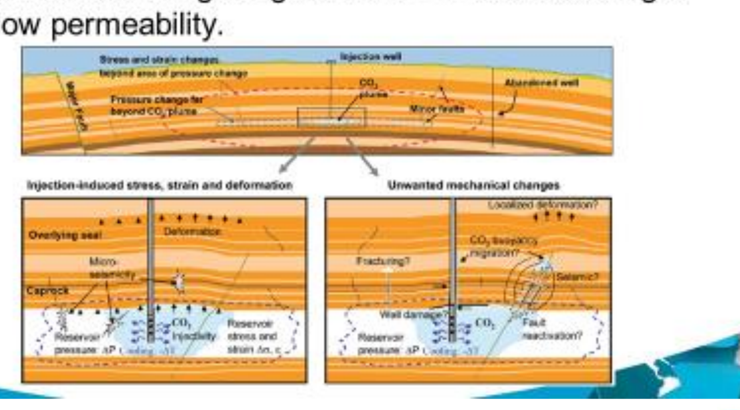
Fault Permeability - Project Outline

contractor: GNS SCIENCE

- Overview of the complexities that control fault permeability in the context of CO_2 storage
- Back ground guide on fault permeability in formations suitable for CO_2 storage.
- Examines variables that control fault permeability.
- Reviews examples of fluid migration along faults including naturally occurring seeps plus demonstration sites.
- Knowledge Gaps and recommendations

Fault Properties

- Natural seeps, mineralised fault zones, thermal & salinity anomalies, gas flux anomalies – indicate fluid migration.
- Compartmentalisation of reservoirs & related pressure anomalies– eg Snøhvit, large volumes of accumulated hydrocarbons over geological time – indicate sealing or very low permeability.



Fault Permeability - Factors

- Fault complexities can include segmentation, bends, branched fractures influencing connectivity and bulk permeability.
- Fault zones are highly anisotropic and heterogeneous properties in space and time.
- Permeability can very by 2 orders of magnitude over distances of ~4m.
- In situ permeability measurements are supported by numerical models which show highly non-linear behaviour.
- Fault permeability can be highly sensitive to any change in the effective stress and may be increased by rising reservoir pressures during CO_2 injection.

Factors affecting hydraulic conductivity

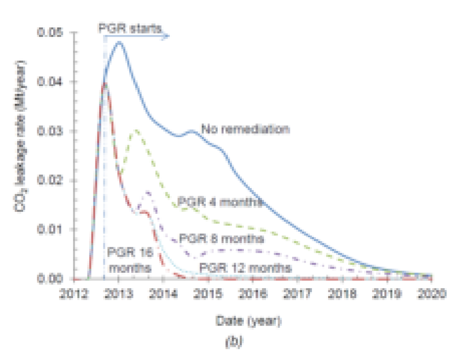
- The composition and rheology of the host rock and its phyllosilicate clay mineral content
- The maximum temperature and depth of burial during faulting
- The stress regime at the time(s) of faulting, during any subsequent deformation event as well as the present day.

Geomechanical modelling

- 1) slip tendency,
- 2) fracture stability,
- 3) dilation tendency.
- Numerous borehole studies support this approach but there is a lack of published material to support the hypothesis on a reservoir or regional scale.

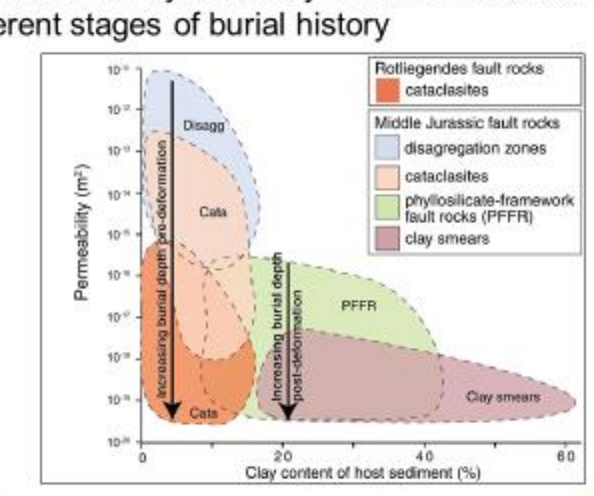
Mitigation of Fault Leakage

- Back-production of injected CO_2
- Hydraulic barriers – model example CO_2 CARE FP7
- Biofilms,
- Microbially induced calcite precipitation – field tested,
- Reactive grout eg using an aq soln of $Na_2O.3SiO_2$



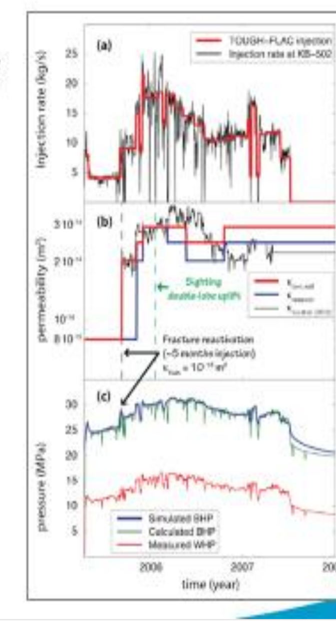
Fault Permeability - Factors

- Lithology composition and burial history is also influential
- Faults can be hydraulically conductive & sealing at different stages of burial history



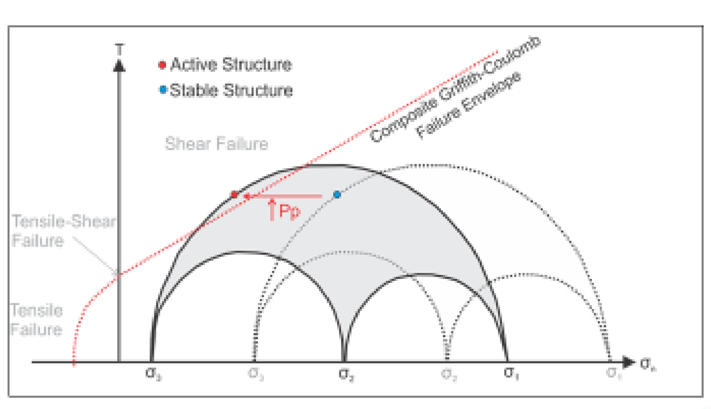
Case study – Krechba Gas Field

- Field evidence of stress induced dilation



Stress Regime

- A shift towards increasing shear stress (τ), caused by increasing pore pressure, will eventually lead to shear failure.



Conclusions

- Fault-zone complexities produce variations, even over relatively short distances permeabilities can vary by as much as two orders of magnitude.
- A range of fault and fracture properties, both hydraulically conductive and sealing, can be present in a single region. Understanding the burial history of a fault is also important when considering its hydrogeological properties.
- Fracture permeability generally decreases with depth. Open fractures are most likely to modify bulk conductivity in low permeability caprock and can increase permeability by as much as 3 orders of magnitude.
- High pore fluid pressures and/or preferential stress alignments are not a prerequisite for enhanced hydraulic conductivity.

Conclusions

- Prediction of hydraulically conductive faults and fractures preferentially oriented with respect to the stress field is complicated by fracture healing whereby mineralisation of void space results in the stress independence of the fracture.
- The results of detailed fault studies and in situ permeability measurements are supported by numerical models which show highly non-linear behaviour and flow localization
- Transient high permeability may develop due to high fluid pressures at depth resulting in episodic fluid flow.
- Fault permeability can be highly sensitive to any change in the effect stress acting normal to a fracture plane and in some cases may be increased by rising reservoir pressures.

Key Take-Home Messages

- Faults can either act as barriers to fluids, or as conduits for migration. Consequently, the properties of faults that dissect or form a boundary with potential CO_2 reservoirs, need to be determined.
- There is widespread experience of working with faults and fractures and provided there is sufficient characterisation of their properties they should not restrict storage development.
- If fault zones are present they need to be carefully characterised to ensure the development of an effective containment assessment and to inform the development of operational constraints and monitoring plans.
- A number of mitigation measures have been proposed to counter potential leakage.

Overburden – Project Outline

contractor: BGS

Overburden: defined as the entire geological succession above the target reservoir formation with the lowermost stratum forming the primary seal.

Focused on how to include the overburden is storage risk assessments:

- What are potential fluid flow pathways in the overburden?
- What are potential fluid flow rates?
- How is the overburden currently characterised?
- What impact do these findings have on conducting storage risk assessments?

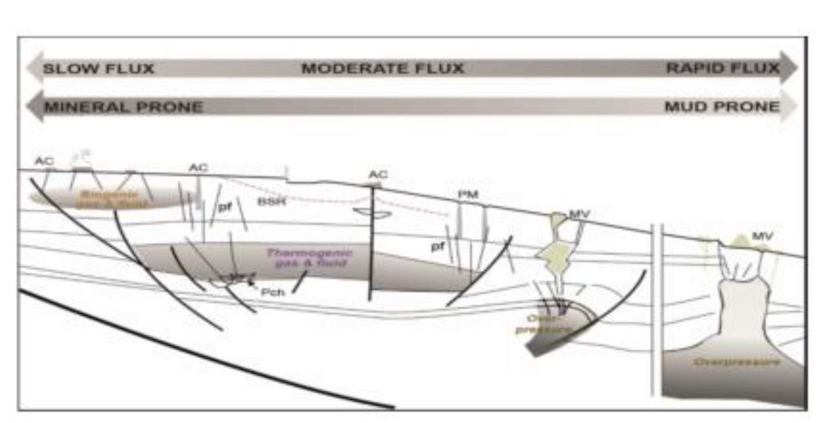
Case studies looked at in depth:

- Review of the overburden at 5 current or planned CCS sites;
- Review of monitoring techniques and migration rates and 6 natural seepage sites;
- Study of migration rates at 7 controlled release experimental sites.

Rates of Migration

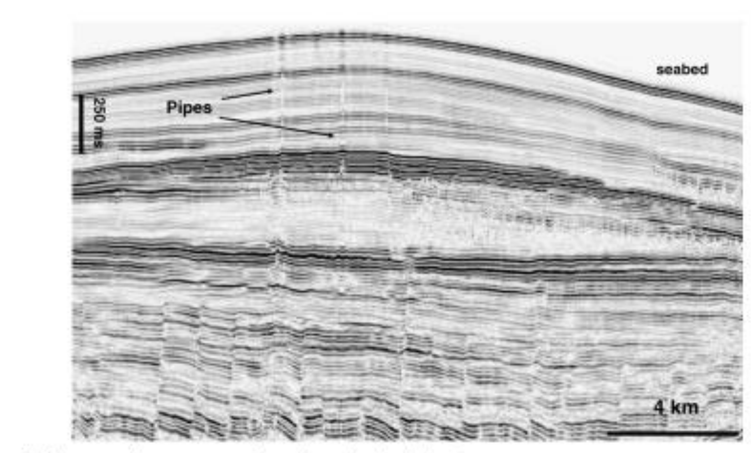
- **Evidence of rates of migration:**
  - Measurement and modelling of CO_2 flux from faults
  - Methane flux at natural seepage sites
  - Studies on well integrity
- **Difficult to constrain without permenant monitoring**
  - Fluid flow often spacially and temporally variable
  - Can be modified by tide/ocean swell and earthquakes
  - Few datasets from actual wellbore leakages

Geological Fluid Flow Features



Fluid flow features can include pockmarks, chimneys or pipes, mud volcanoes, sand mounds, gas hydrates, sediment injections

Chimneys / pipes

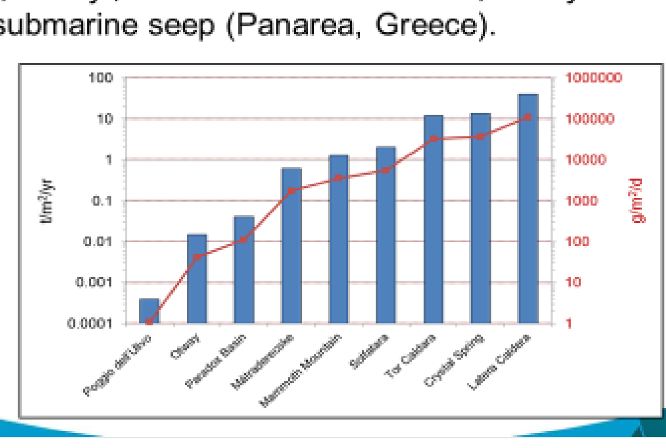


Fluid escape features rooted in polygonally faulted unit

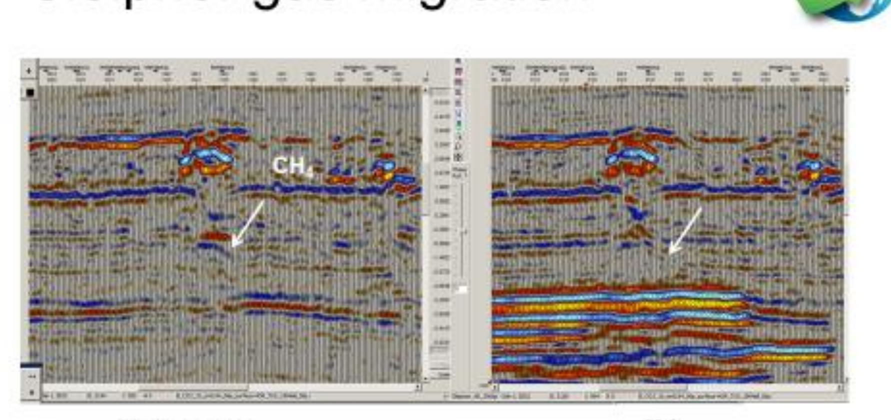
CO_2 Storage Case Studies

Natural CO_2 Seeps

- Maximum CO_2 flow rates for natural analogues of CO_2 seeps associated with faults are generally >0.1 t/m²/yr. For these flow rates volumes of CO_2 leakage could reach 15,000 t/yr, which is similar to the 25,000 t/yr estimated for a submarine seep (Panarea, Greece).

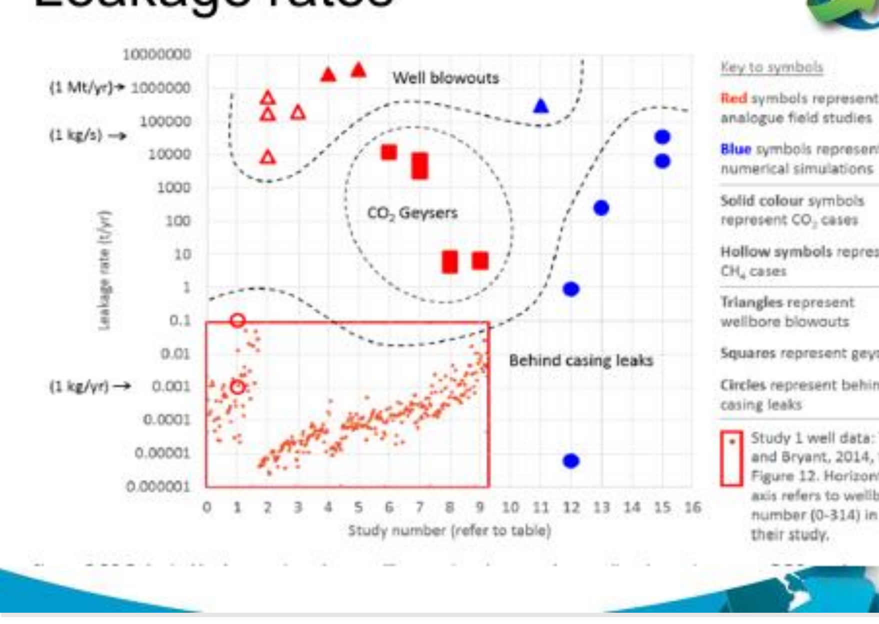


Sleipner gas migration

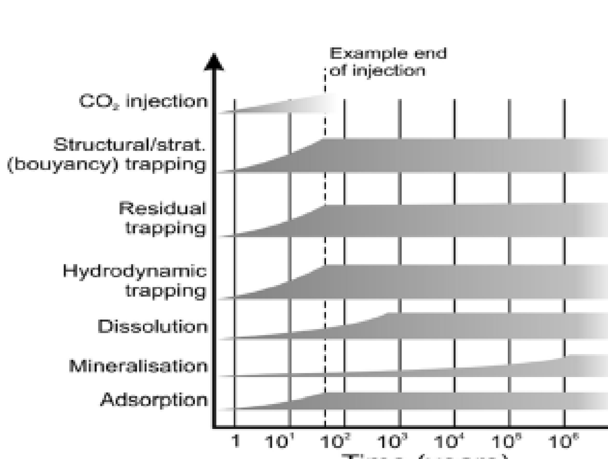


No evidence detected of changes in the pathway above the plume

Leakage rates

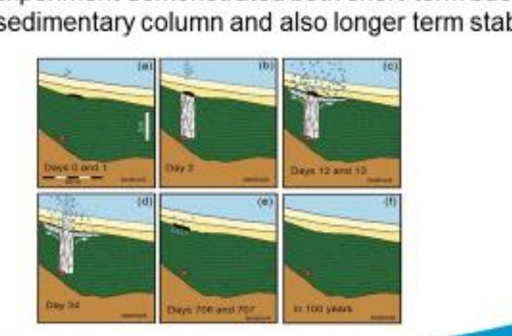


Trapping Mechanisms



Research Projects

- The EU funded STEMM-CCS project: will use seismic and electromagnetic techniques alongside a drilling and logging program to look at in-situ properties of large deep-rooted chimneys.
- UK NERC funded CHIMNEY project: a geophysical experiment is planned to characterise the internal structure of a chimney using broadband seismic anisotropy experiments.
- The QICS experiment demonstrated both short-term buoyancy-driven flow in the sedimentary column and also longer term stabilisation.



Conclusions

- The largest challenge in modelling fluid migration in the overburden is characterising a large and complex area and the identification of appropriate parameters.
- Lack of in-situ sampling of chimneys makes estimations of potential fluid migration rates difficult.
- The conductivity of glacio-tectonic structures is poorly understood. There is the possibility that hydrofractures may be reactivated if over-pressured but quantifying the pressures required is not currently achievable.
- Long-term observations of wellbores will be required to validate predictive models as currently only relatively short-term experimental data is readily available.
- There is some evidence that the formation of hydrates as CO_2 migrates from the reservoir may act as a secondary trapping mechanism

Key Take-Home Messages

- Characterisation methods are currently identifying structures within the overburden but further in-situ analysis on potential migration rates (and hence the potential risks posed by such structures) is required .
- Monitoring should be designed to detect leakages occurring over small surface areas with high temporal variability.
- A range of sealing and non-sealing processes occur in the overburden the nature of which are not yet fully constrained e.g. whether a fault will form a barrier or flow pathway.
- Understanding natural fluid migration in the overburden aids risk assessment especially attribution of fluids.

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