Reservoir compartmentalisation in HTHP reservoir: beyond fault seal analysis

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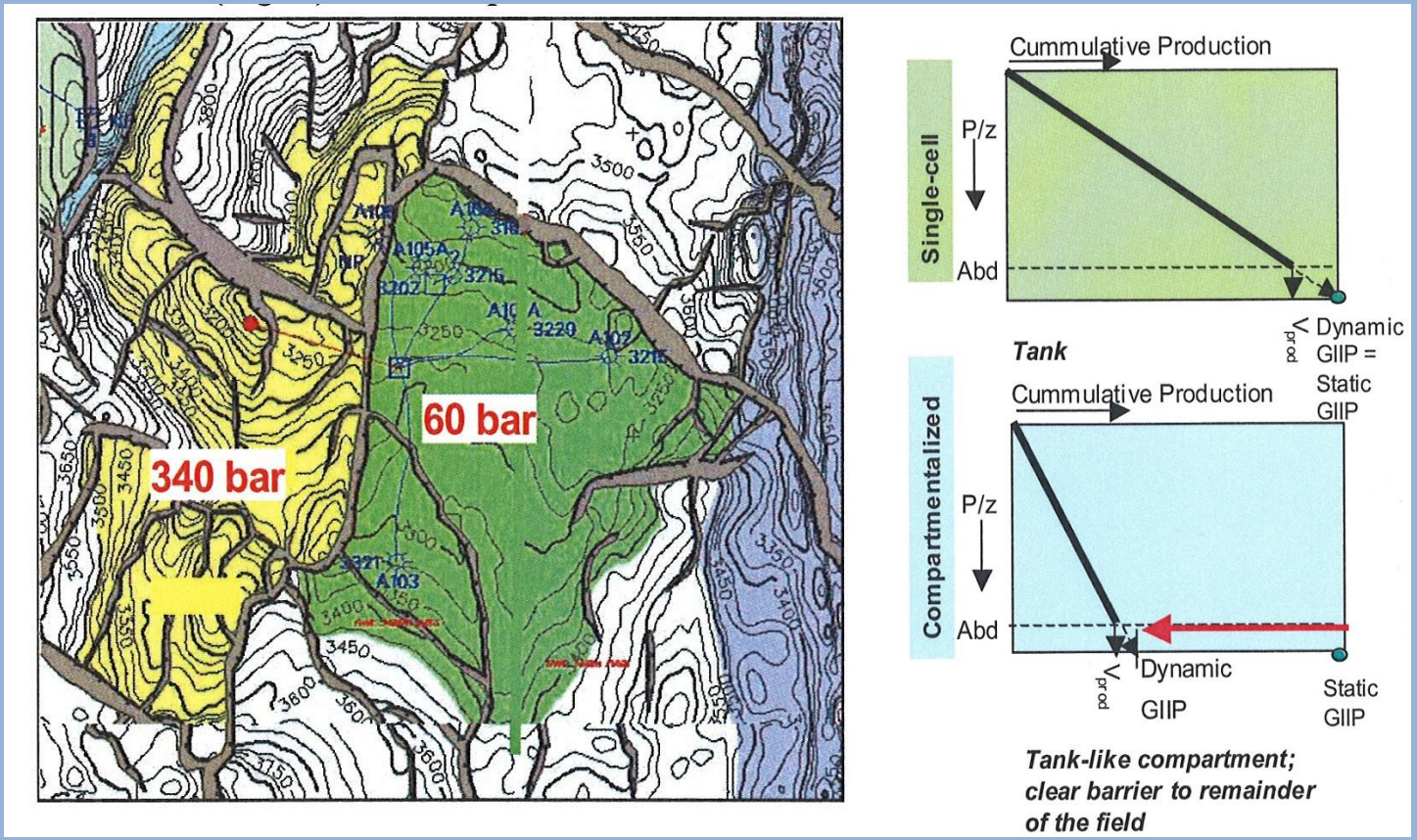
Outline

- Impact of faults on petroleum production
- Incorporating of fault properties into production simulation models
- Examples of successful and unsuccessful fault seal analyses
- Other causes of reservoir compartmentalisation
- Conclusions

Impact of faults on gas production



(From van der Molen et al., 2003)

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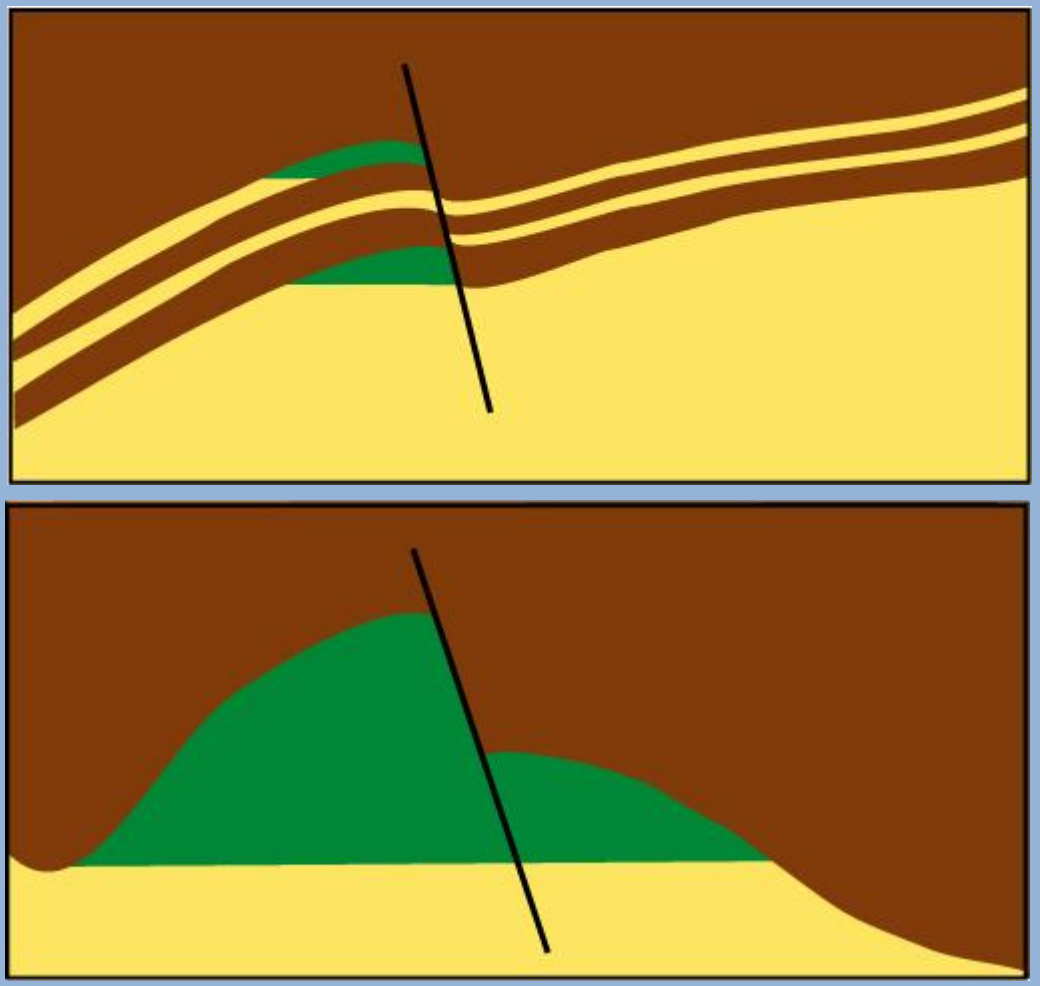
Fault Seal Types in Siliciclastics

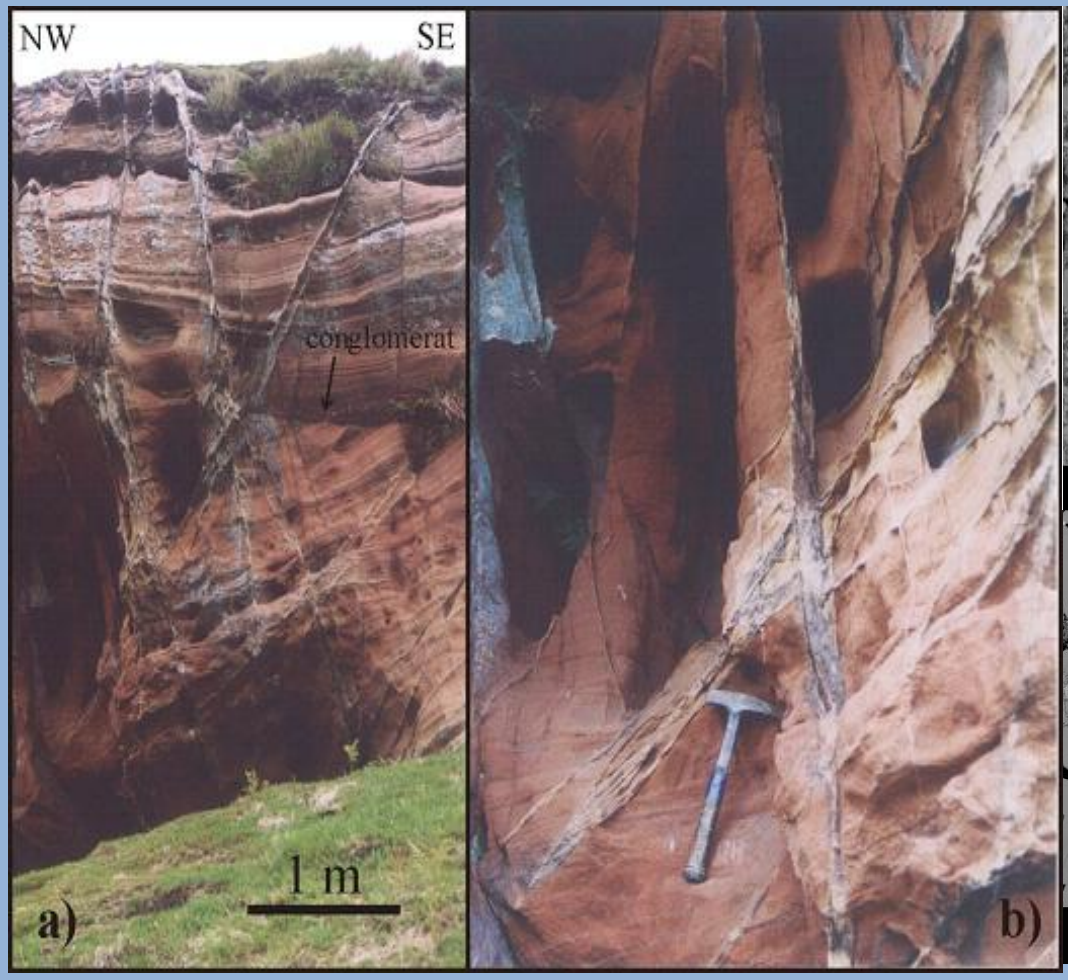


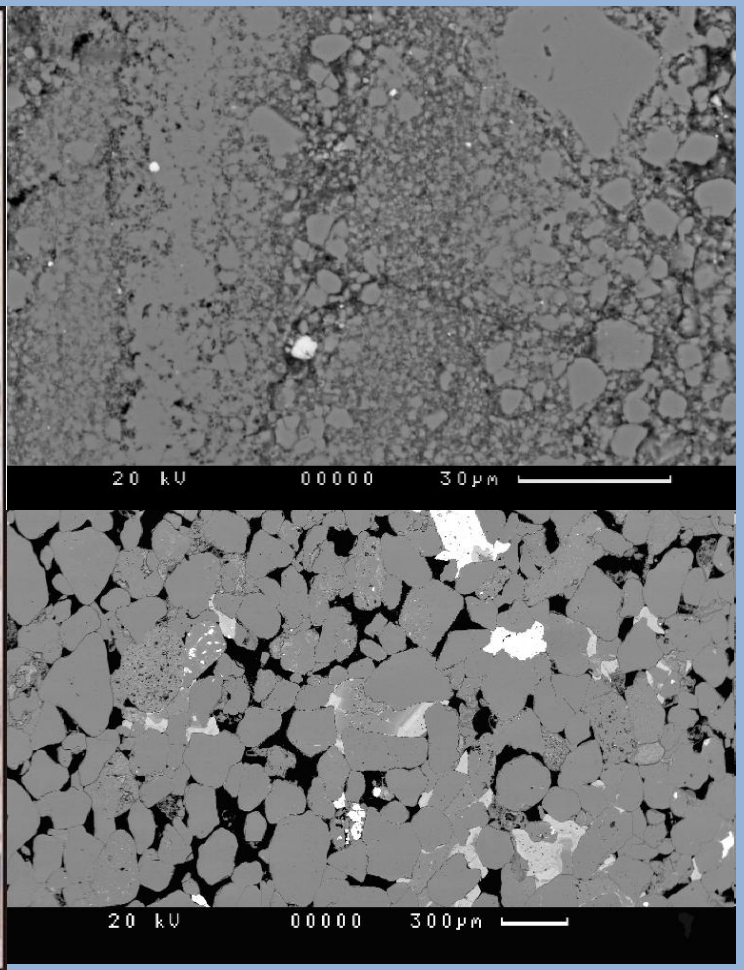
Juxtaposition seal (by far the most common type of barrier to production)

Fault rock seal (fault seal *sensu stricto*)

- This appears to be the case for Rotliegend example

Fault rock seals





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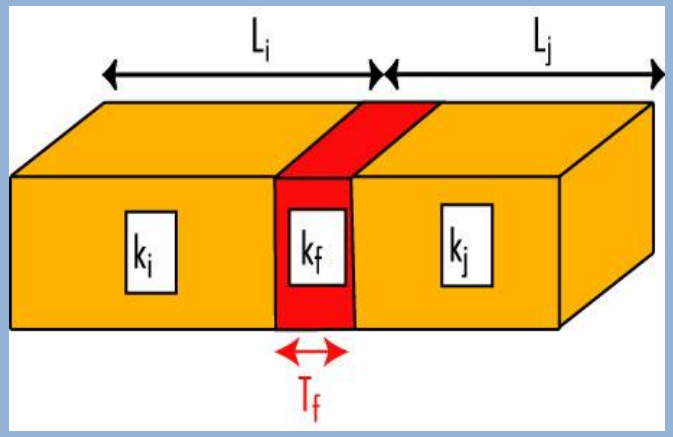
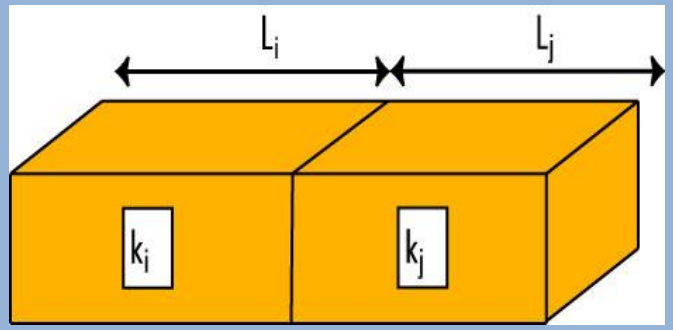
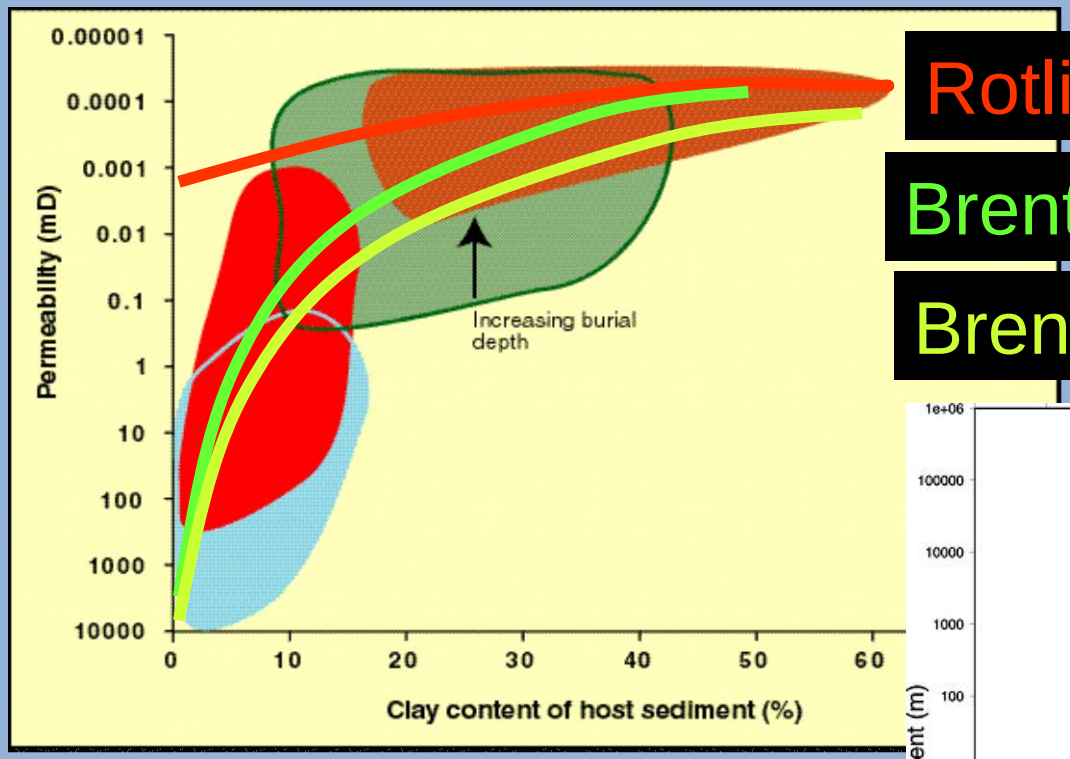
Calculation of transmissibility multipliers

$$TM = \frac{Trans_{ij} = \left(\frac{2}{\frac{L_i - t_f}{k_i} + \frac{2t_f}{k_f} + \frac{L_j - t_f}{k_j}} \right)}{Trans_{ij} = \left(\frac{2}{\frac{L_i}{k_i} + \frac{L_j}{k_j}} \right)}$$





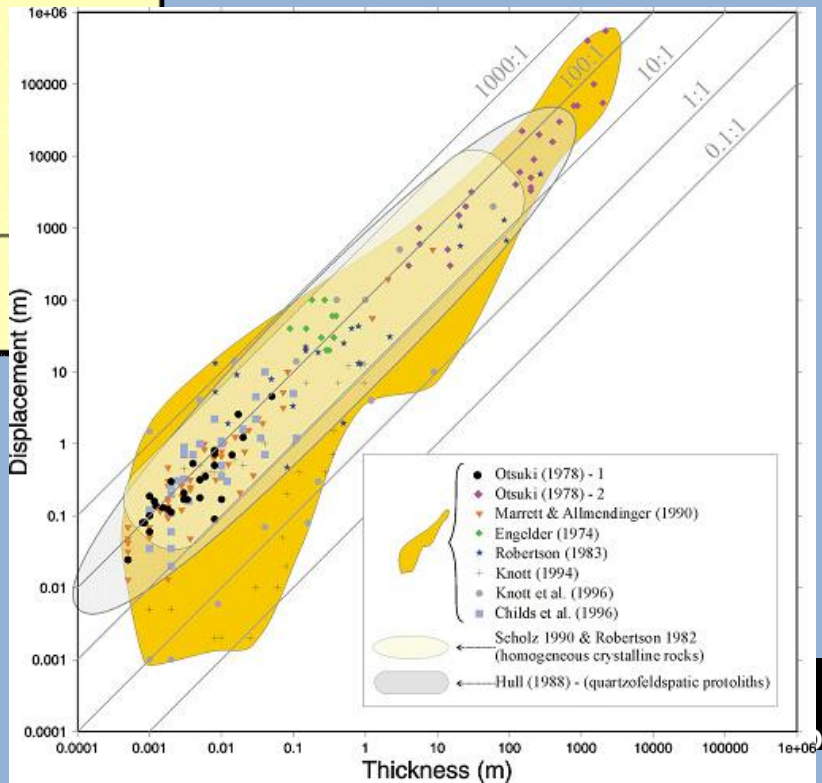
Extensive databases on fault properties are now available



Rotliegend

Brent 3500 m

Brent 2500 m



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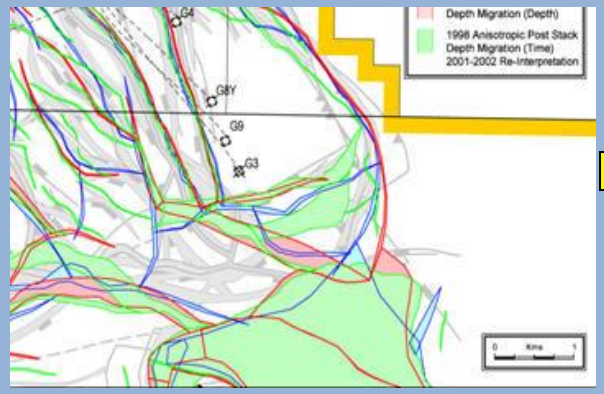
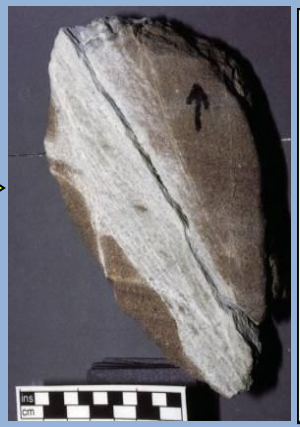
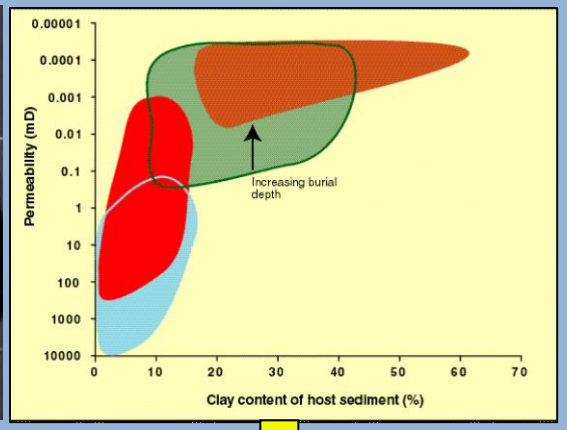
Standard fault seal analysis workflow

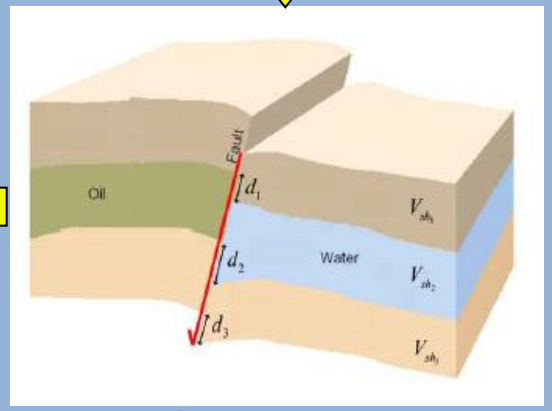


Map faults

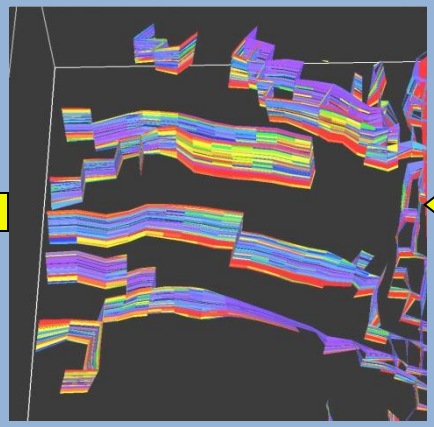




Estimate fault rock properties



Estimate clay content



Calculate fault transmissibility multiplier

Simulation model

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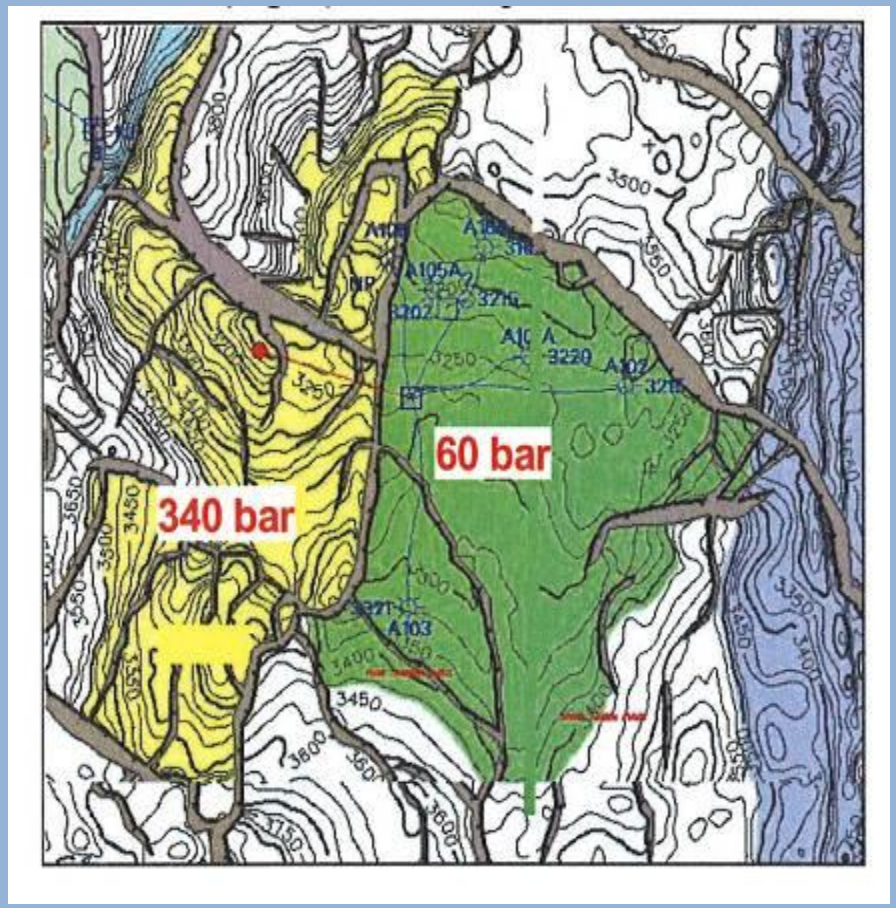
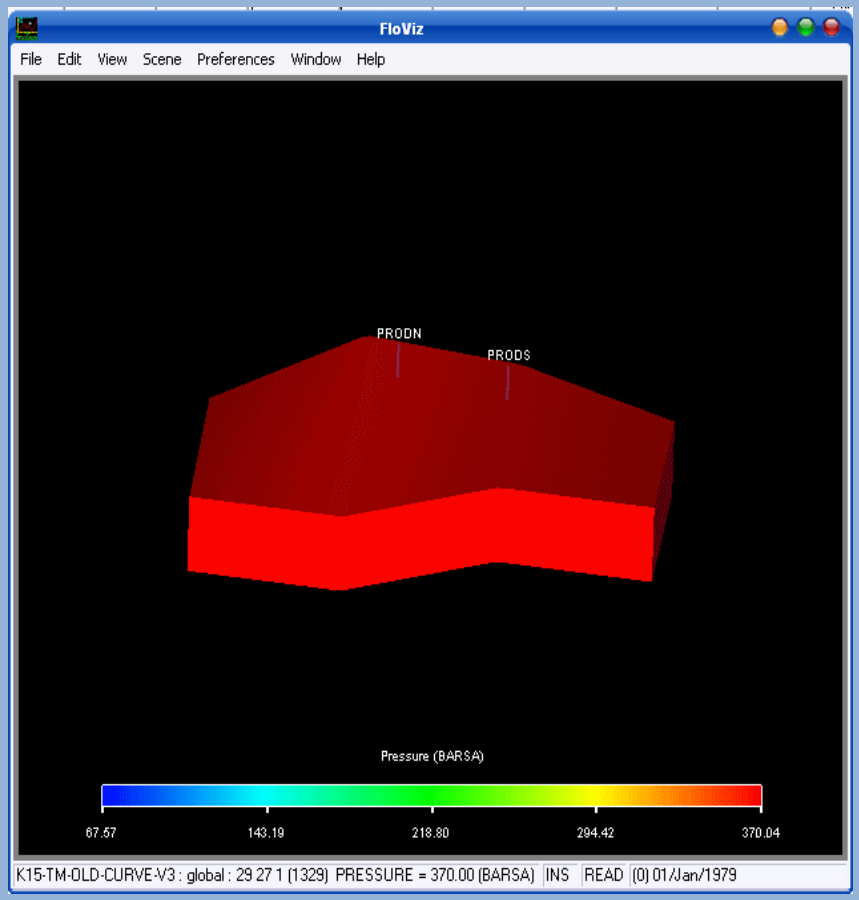
Simulation model using single-phase fault permeabilities





van der Molen et al., (2003)

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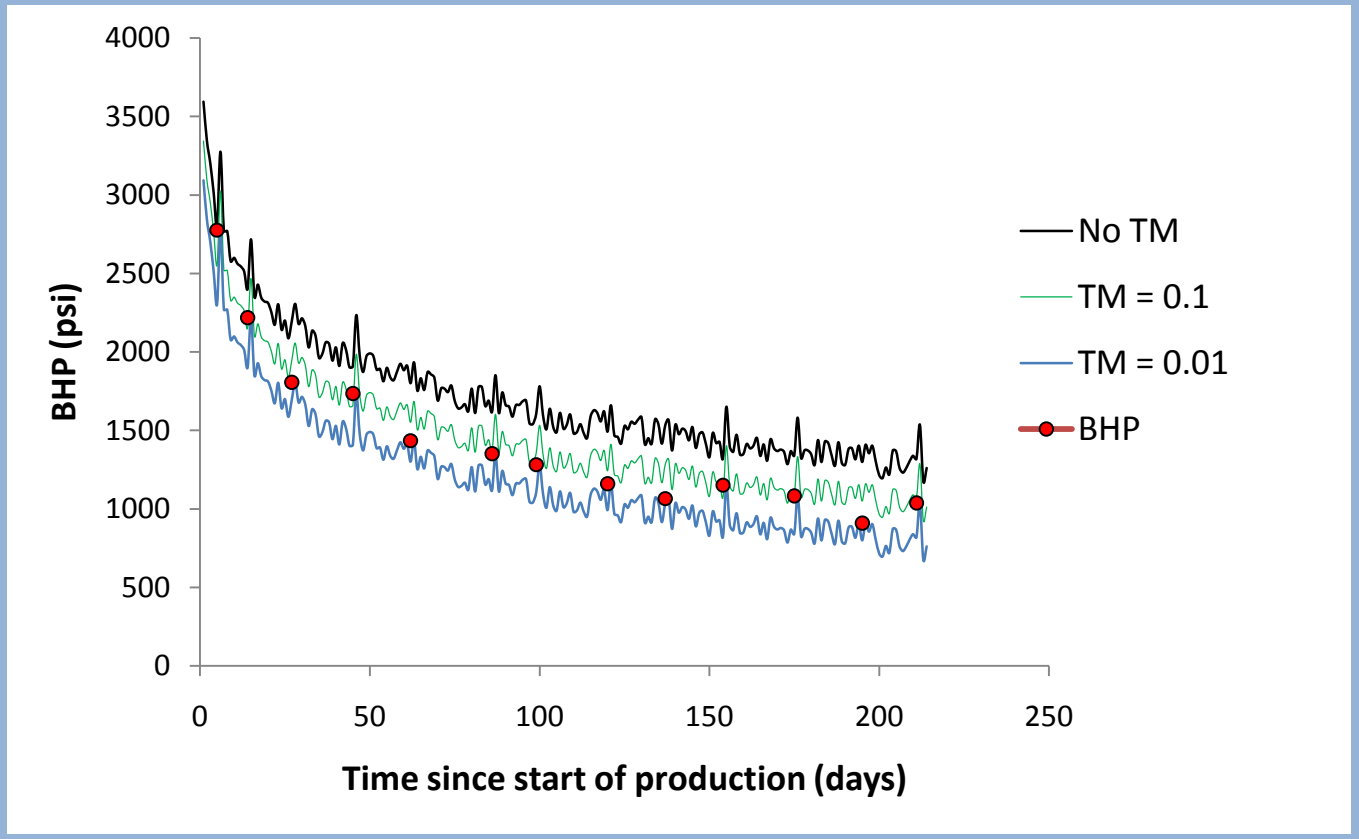
History match from HTHP reservoir



Fault TMs altered on a trial and error basis until a history match is achieved

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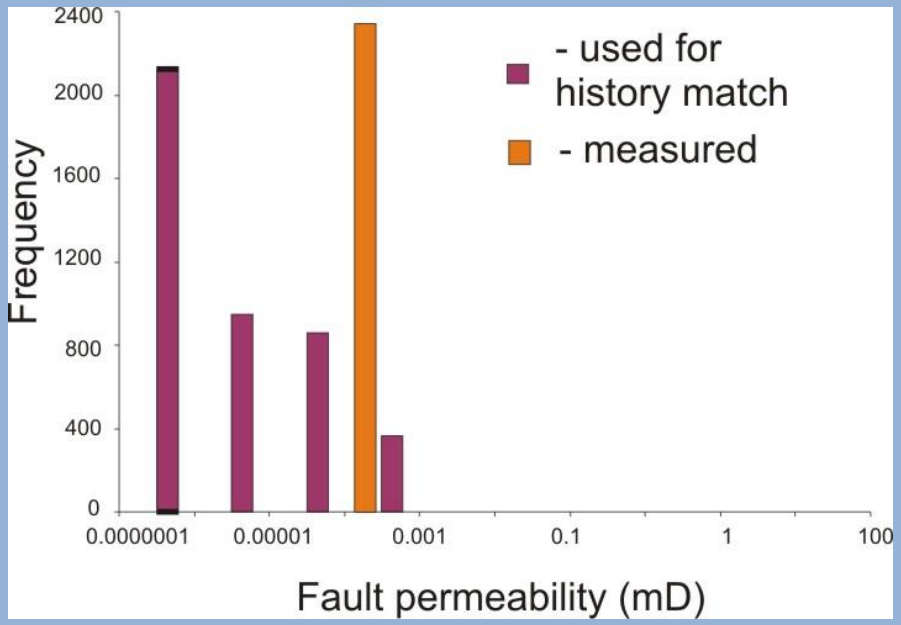
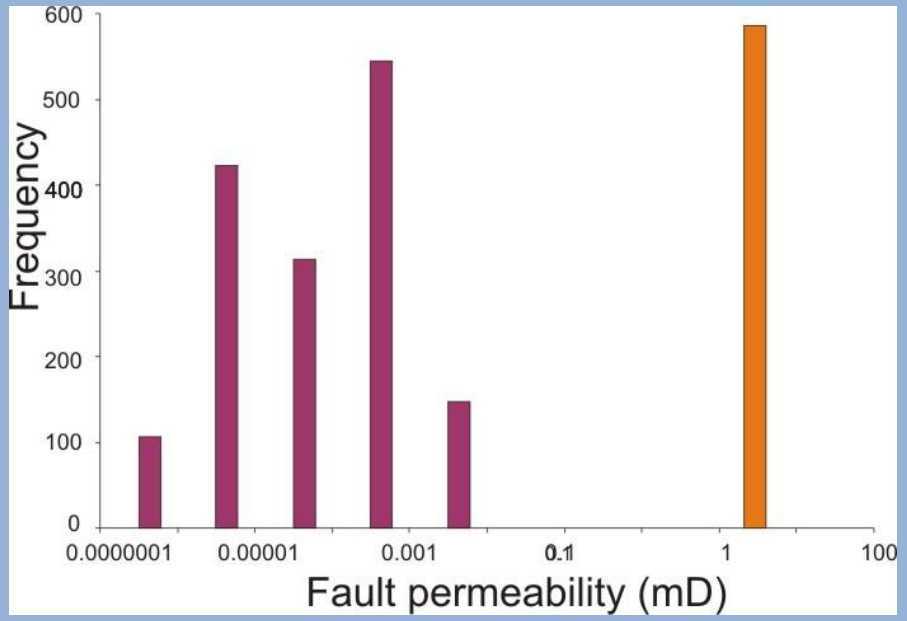
Fault rock permeability needed for history match

Rotliegend



Jurassic



Fault TMs required to achieve history match are often equivalent to permeabilities that are far lower than are measured

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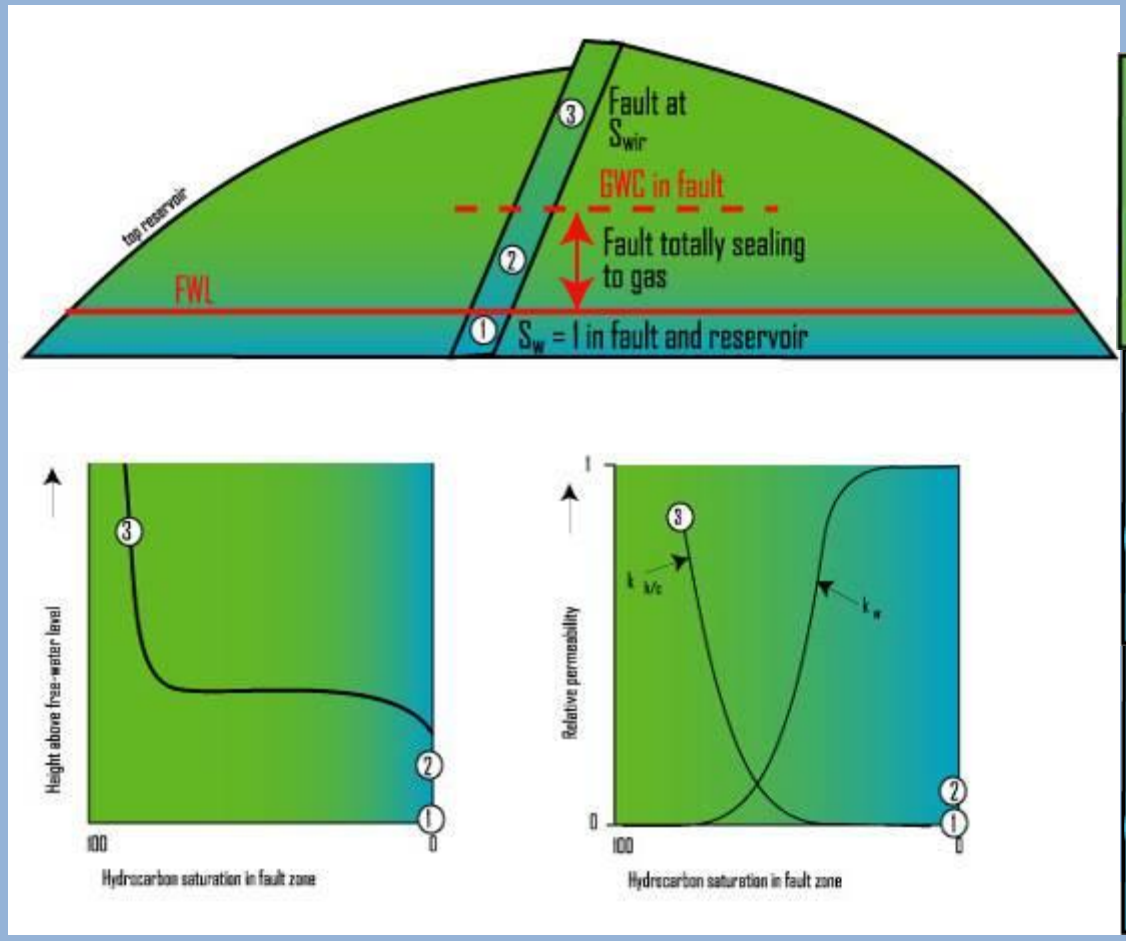
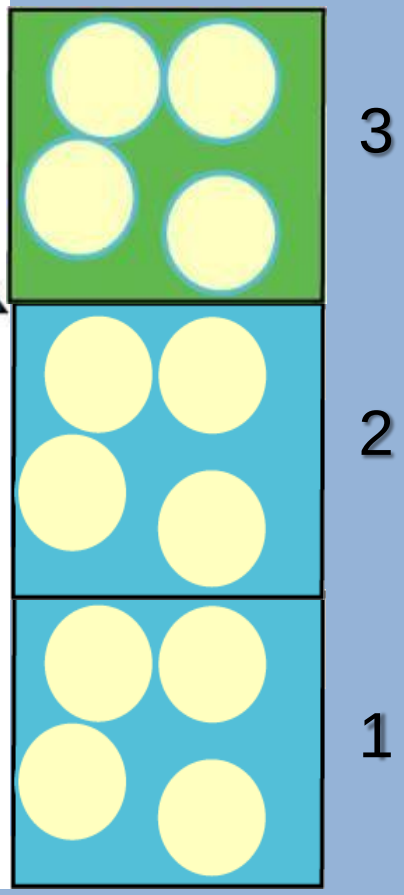
So why are fault permeabilities needed for history matches often far lower than measured in core?

Relative permeability of faults





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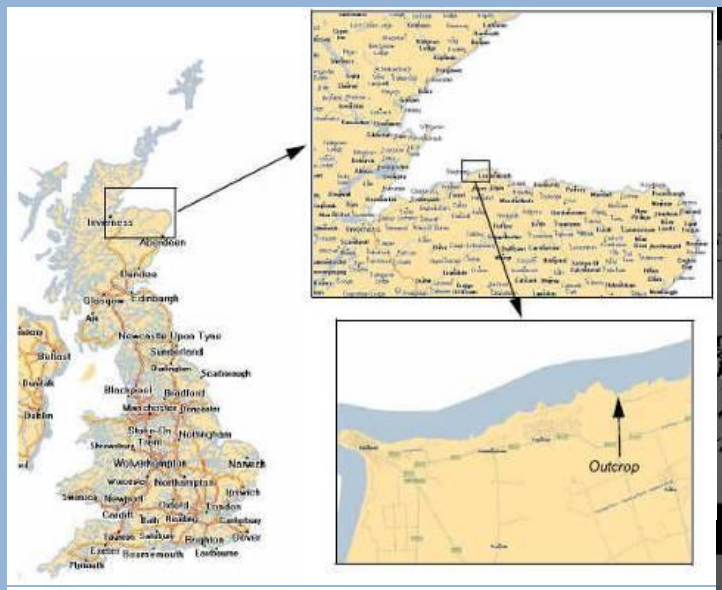
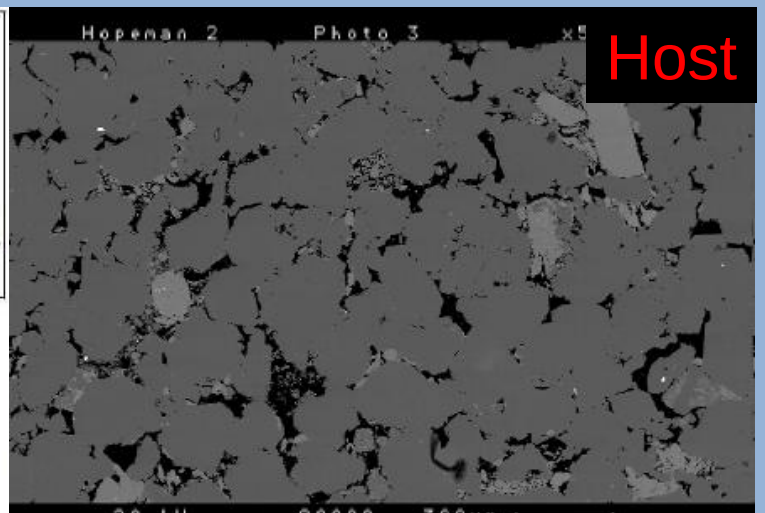
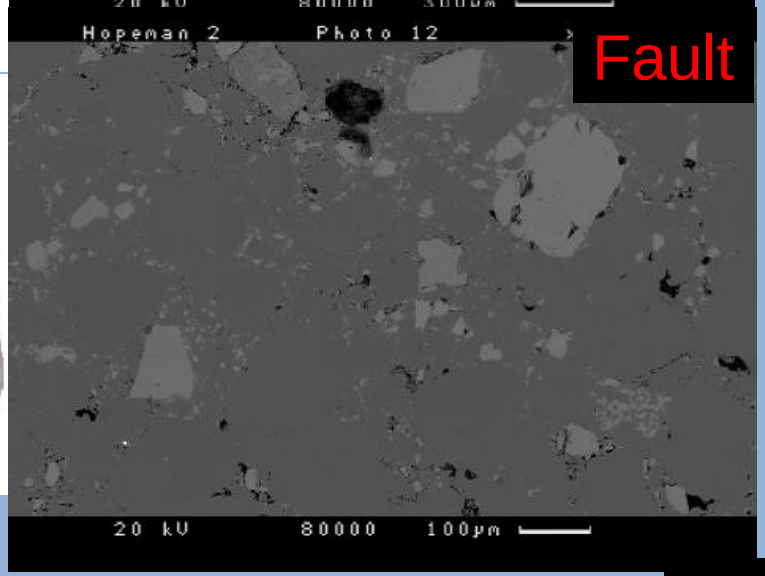
Lossiemouth Fault: Hopeman sandstone





Host



Fault

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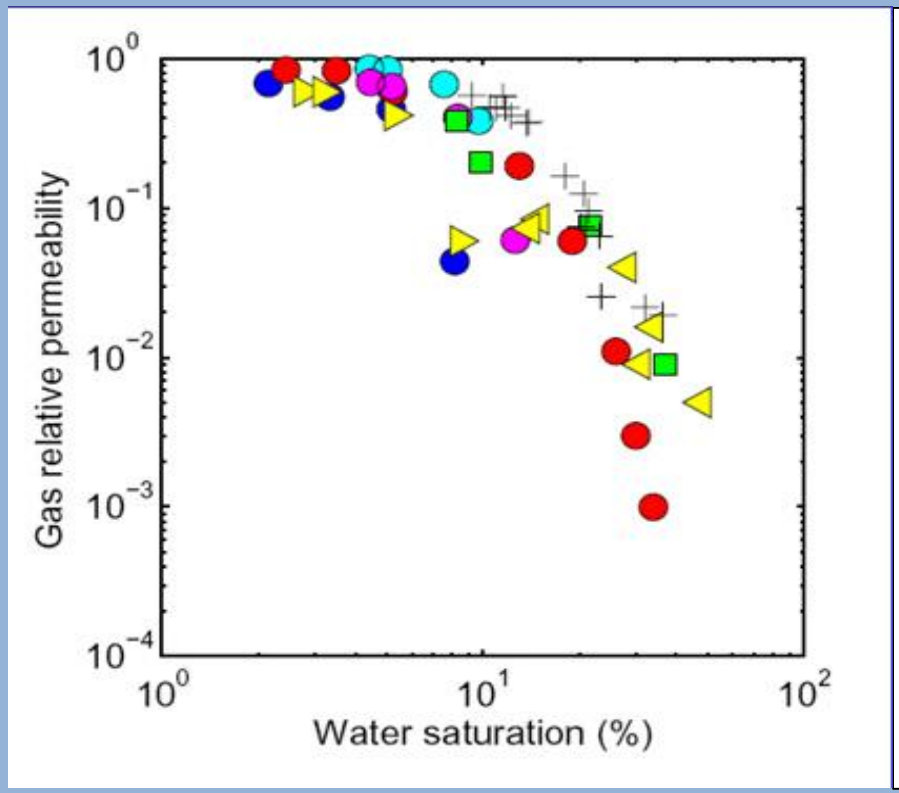
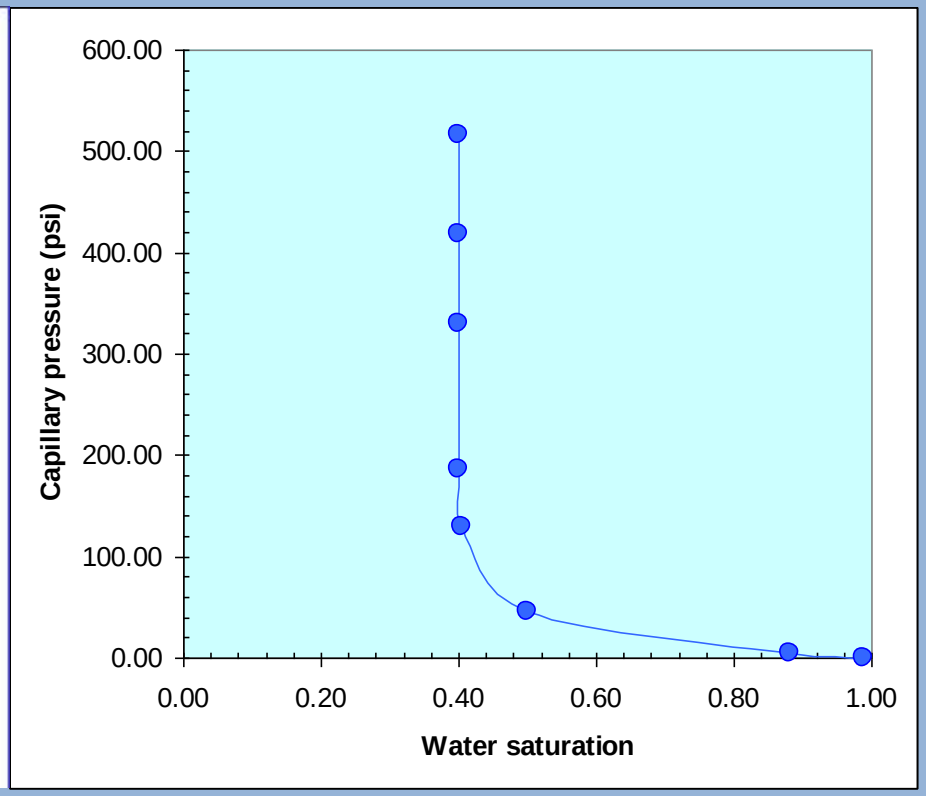
Gas relative permeability – Hopeman fault





Al-Hinai et al, 2008

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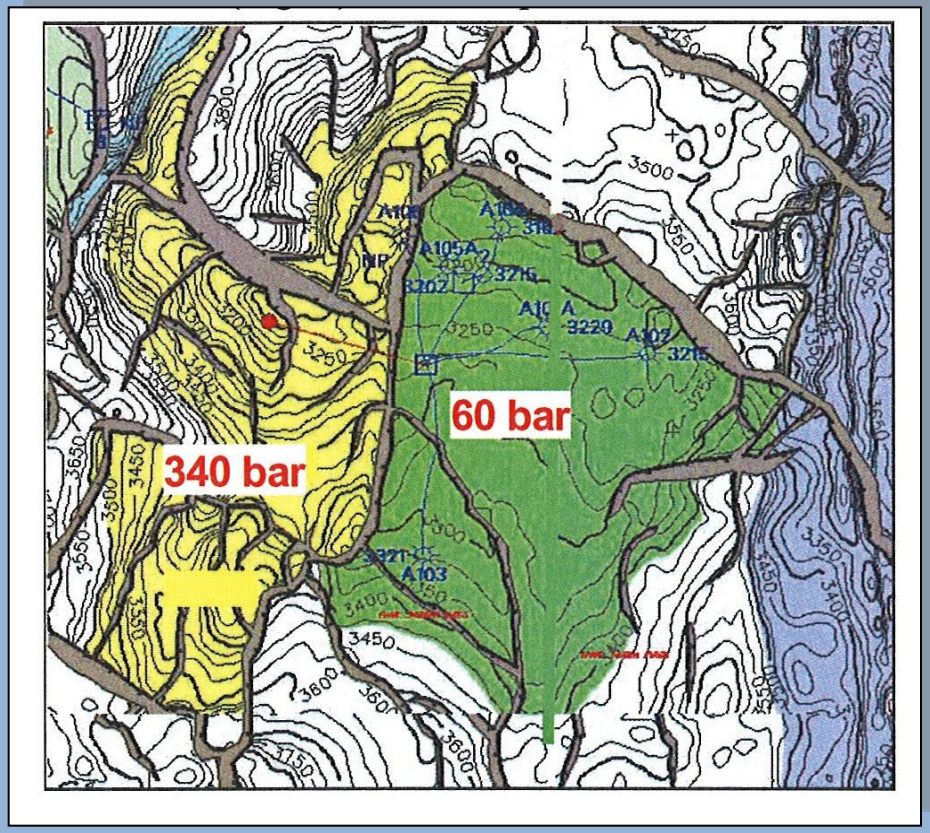
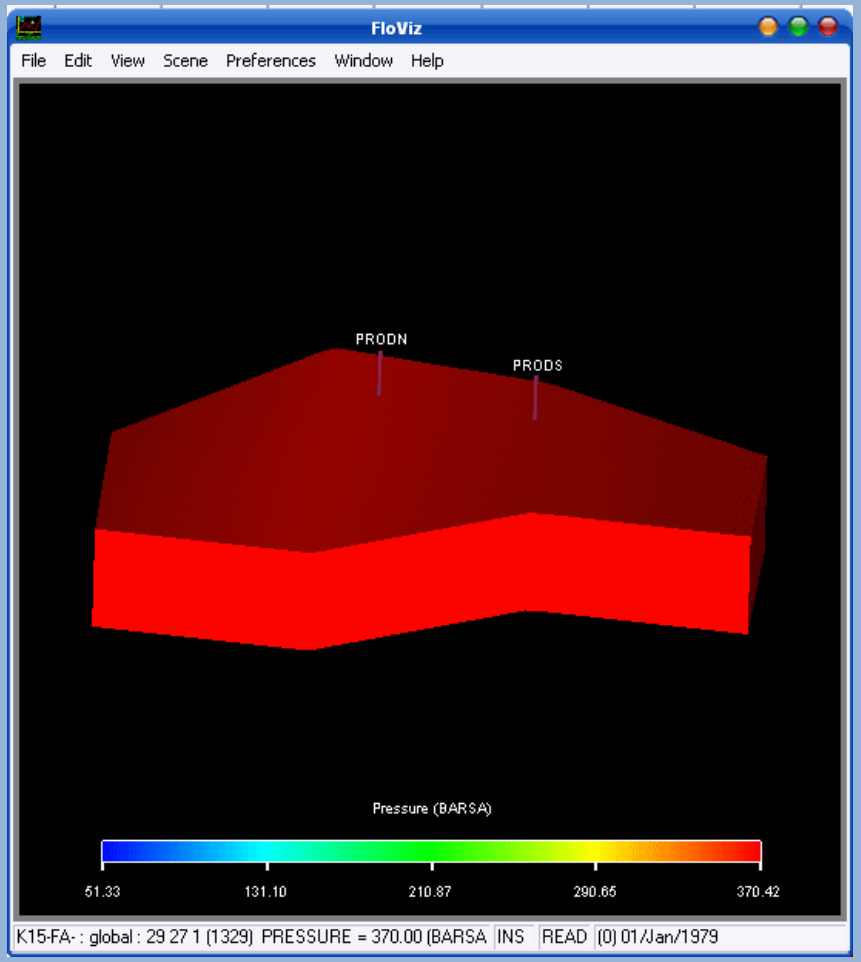
Fault-related barriers to gas production





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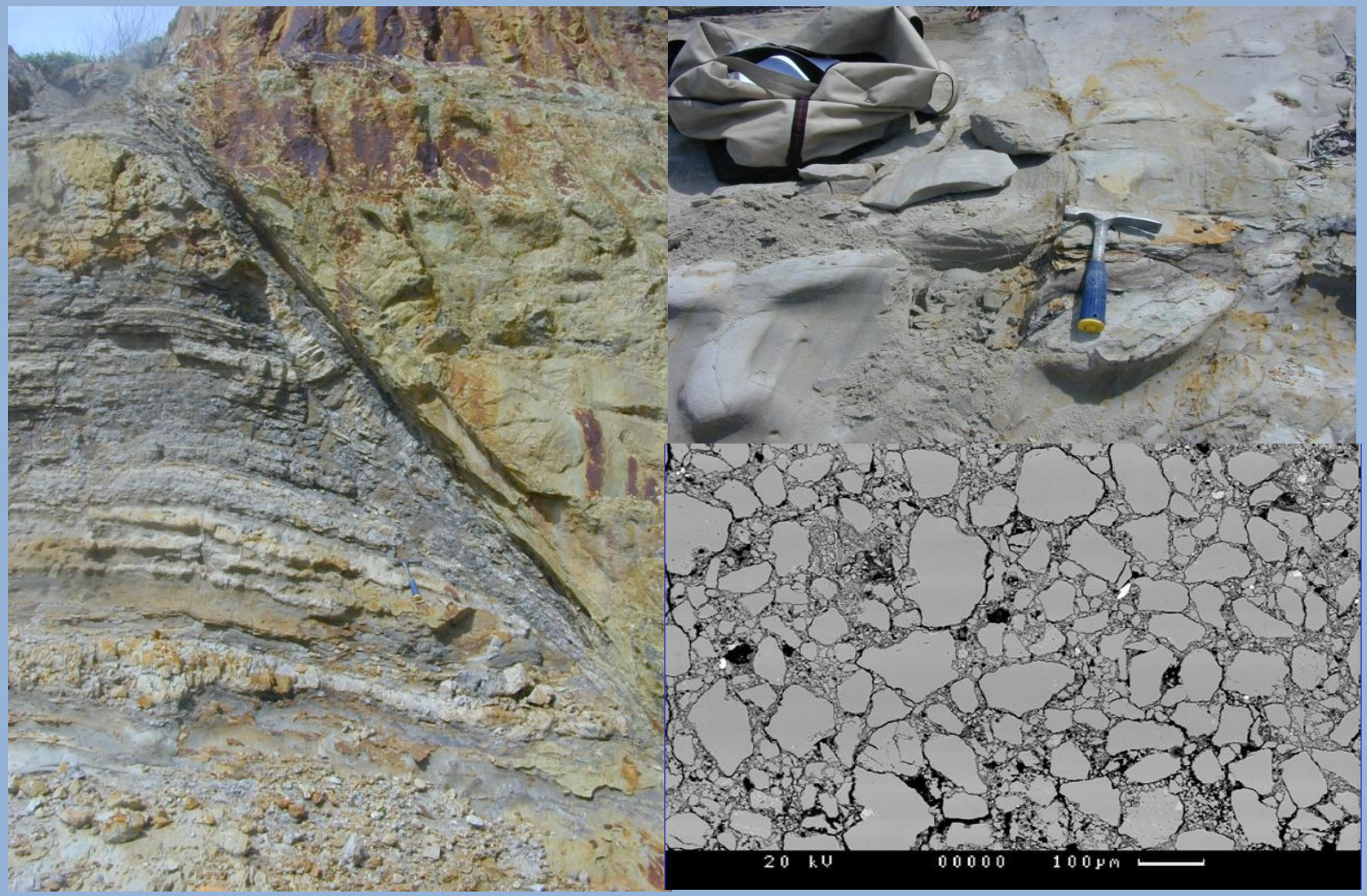
Miri cataclasite



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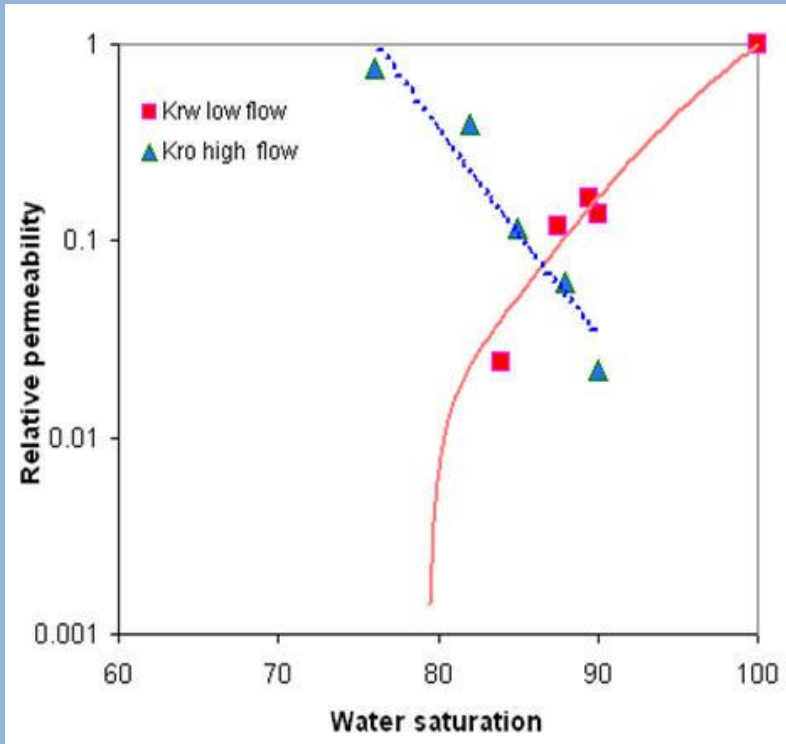
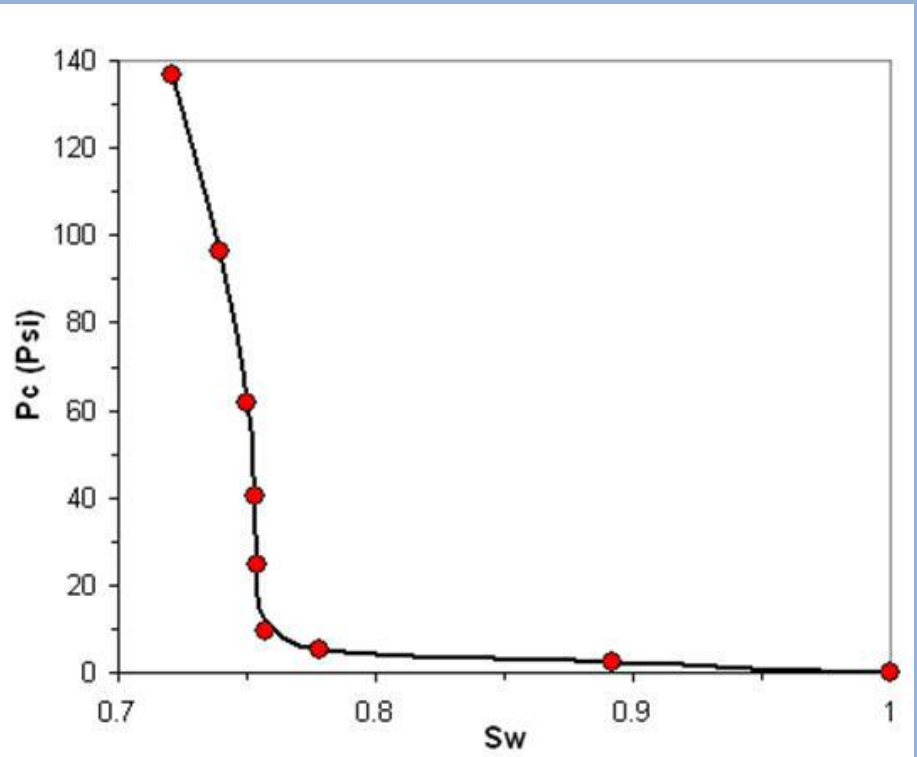
Oil-water relative permeability – Miri cataclasite/pffr





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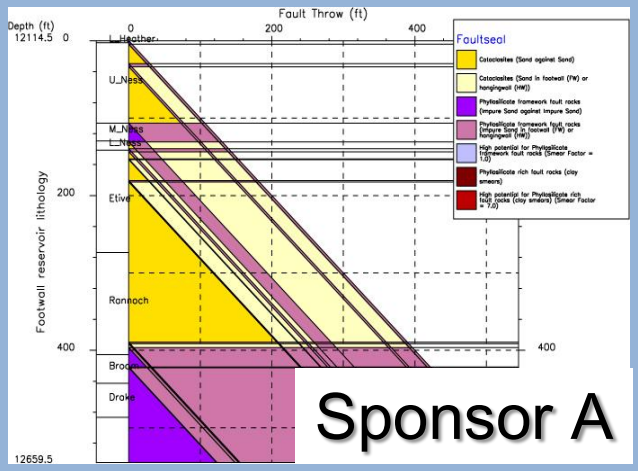
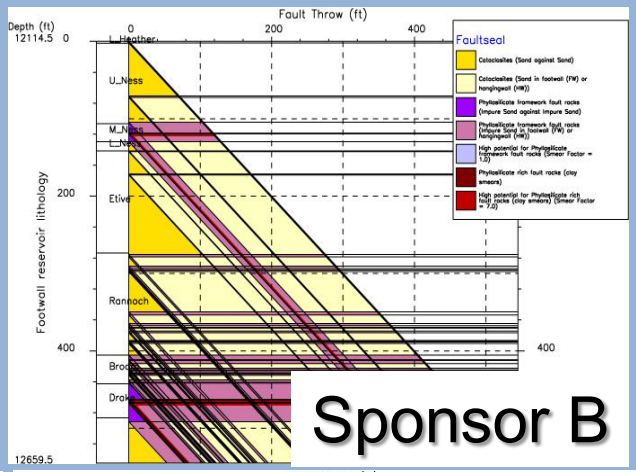
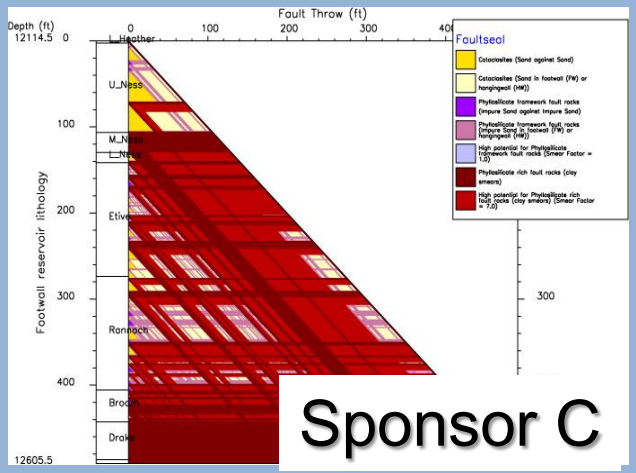
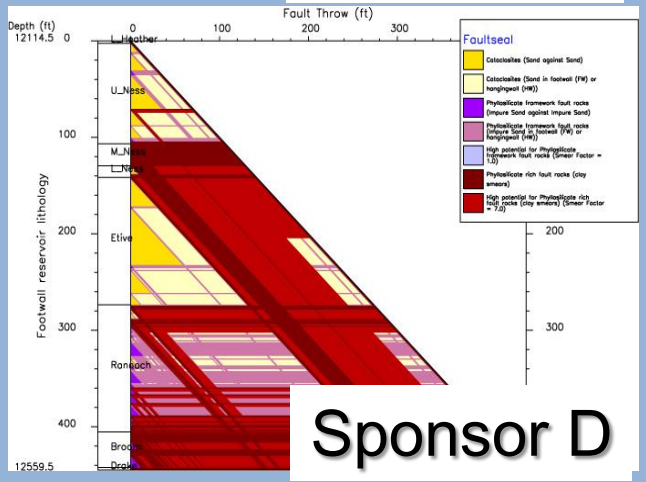
Variation in clay content between different interpretations of log data









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From Fisher et al. 2003

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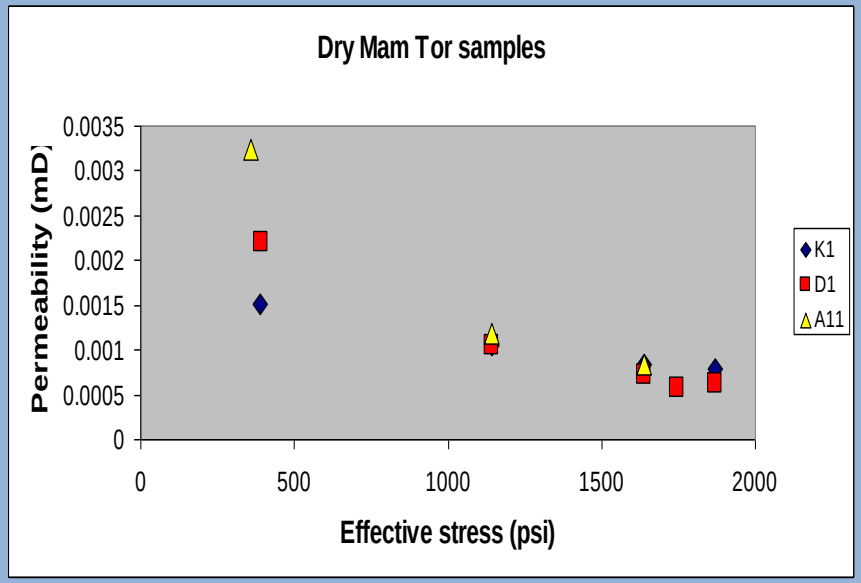
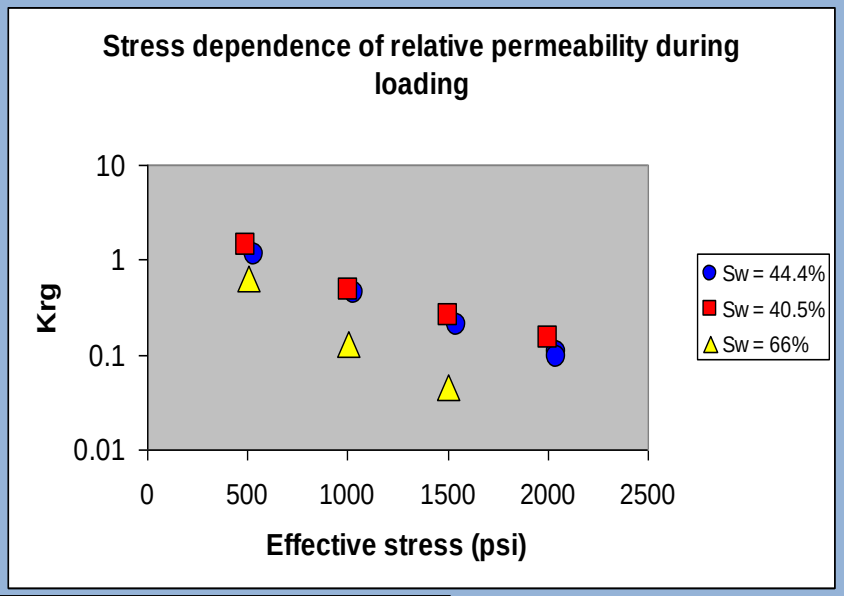
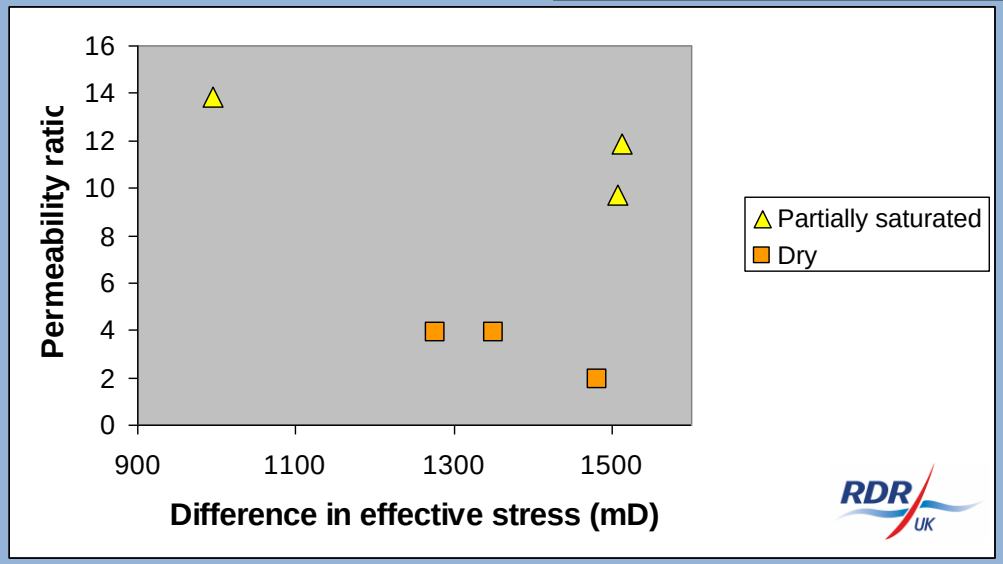
Stress sensitivity of fault rock properties

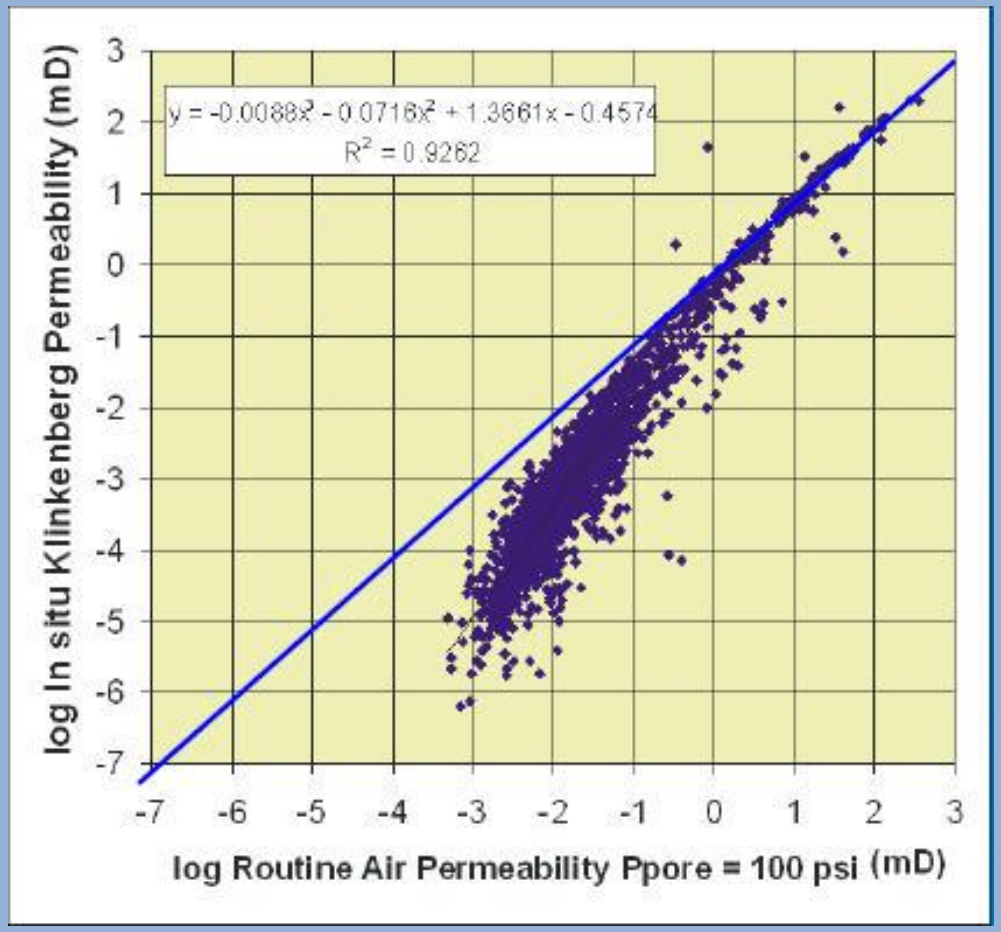
Stress dependence of permeability and relative permeability







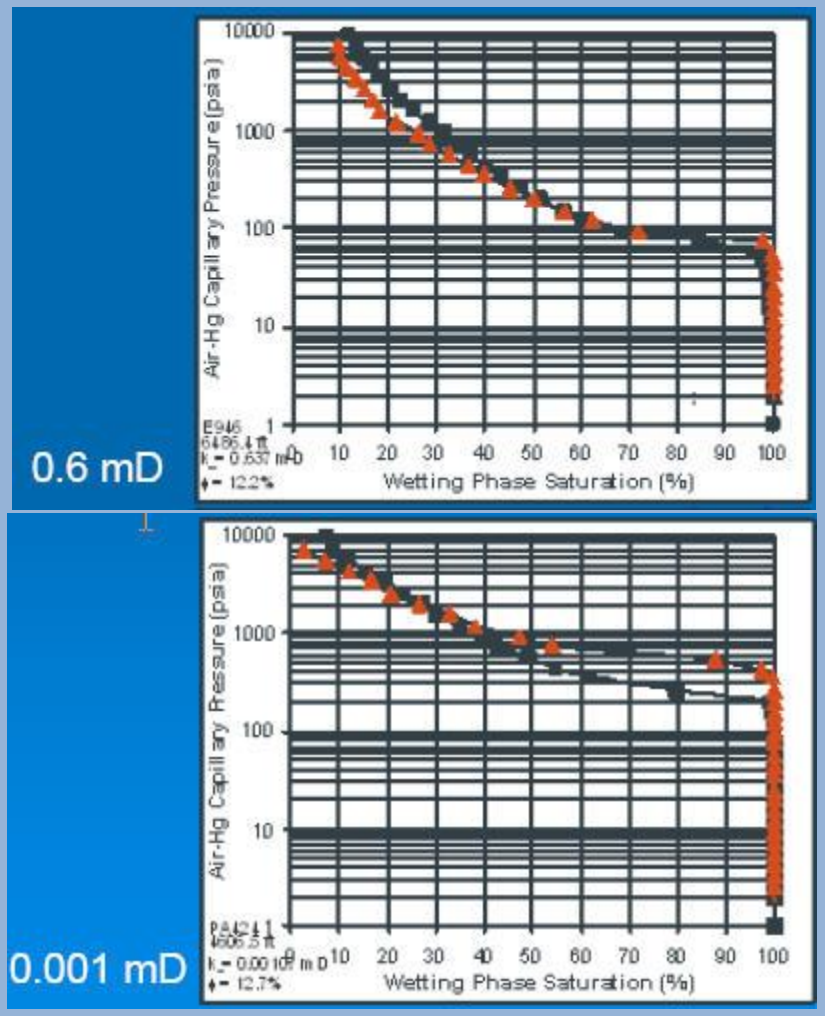
Stress dependence of absolute permeability



- Stress dependence of absolute permeability of tight gas sands
- No stress dependence above 10 mD
- Suggests published databases of permeability of low permeability fault rocks should be treated with caution
- Doesn't help explain Middle Jurassic history matches

From Cluff et al., (2009) Tight Gas SPE Forum

Stress dependence of Hg injection data



- Stress dependence of absolute permeability of tight gas sands
- No stress dependence above 1 mD
- Suggests published databases of Hg-injection data from low permeability fault rocks should be treated with caution
- Doesn't help explain Middle Jurassic history matches

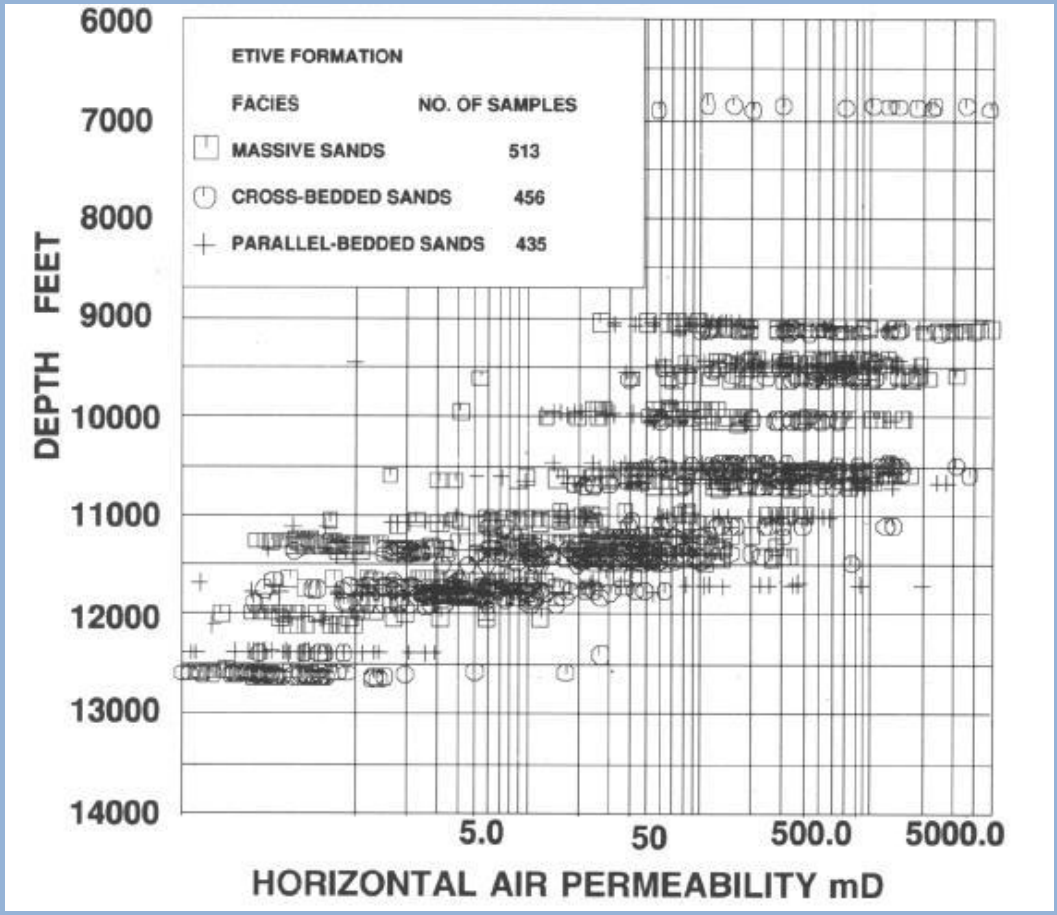
From Cluff et al., (2009) Tight Gas SPE Forum

So why are such low fault permeabilities needed to history match some reservoir models?

It's not the faults fault

- Other possibilities include:-
  - Lack of sediment connectivity
  - Misrepresentation of three phase flow properties in simulation models
  - Overestimation of sediment permeability

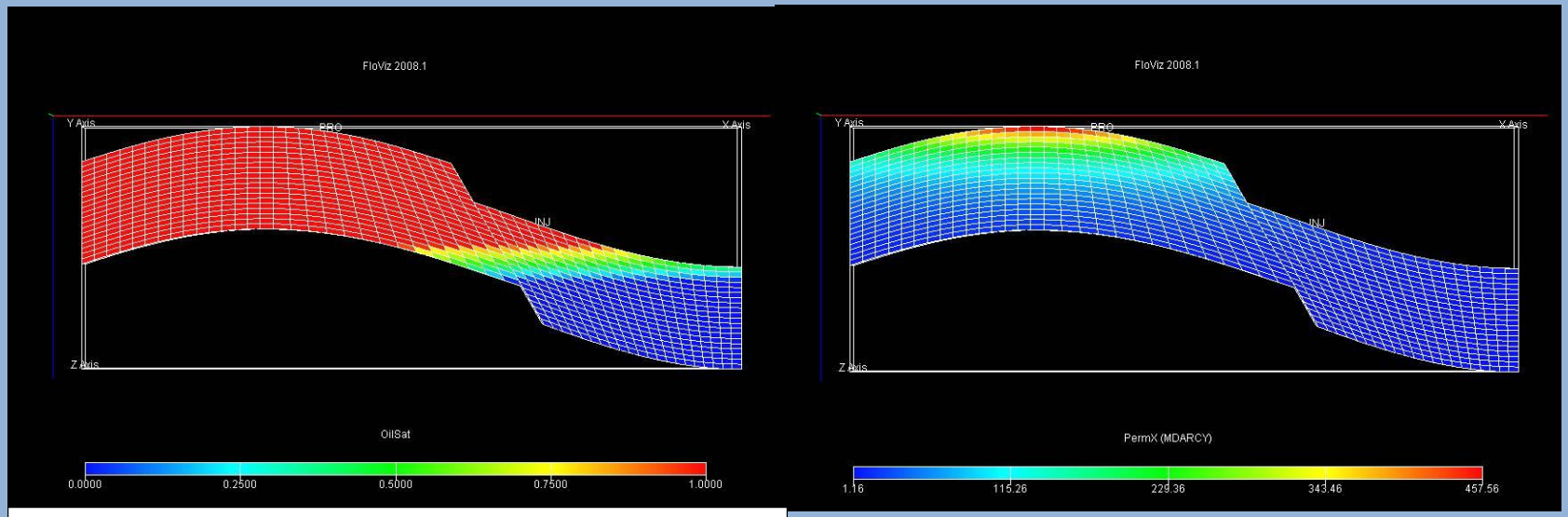
Reservoir quality in HTHP reservoirs

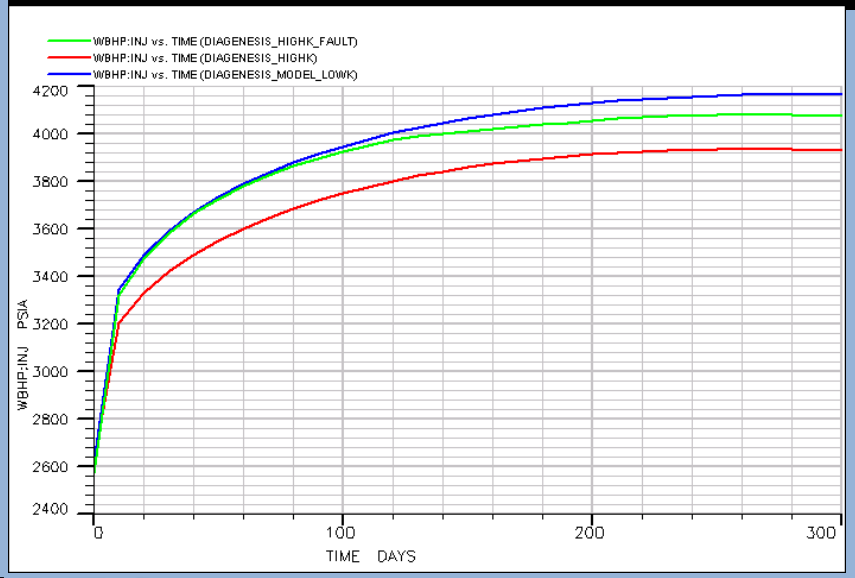


- Rapid decrease in permeability below 12000' due to quartz cementation and illite precipitation etc.
- Larger uncertainties in core analysis due to stress dependency, failure to reach capillary equilibrium, damage of illite etc.

(from Giles et al. 1992)

Diagenetic compartmentalisation





1 mD difference in the permeability of the reservoir can have the same impact as a partially sealing fault

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Conclusions

- To gain history match of many HTHP reservoirs far lower fault transmissibility multipliers are used than can be justified based on published fault rock permeability data
- Taking into account problems with existing databases on fault rock properties does not provide good explanation for why such low TM values are needed for history match
- Overestimation of sediment connectivity or failure to properly model 3-phase flow may be an issue
- Diagenetic alteration maybe responsible for poor communication between injectors and producers
  - Potentially reservoir permeability is slightly overestimated
  - Transition zone forms a permeability jail: consistent with lack of aquifer support in many HTHP reservoirs

Acknowledgements

- BG, BP, Chervron, ExxonMobil, Petrobras, Total, Shell, Statoil for sponsoring research
- Roxar for providing Tempest™ license
- Schlumberger for providing Eclipse™ license

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