Challenges integrating seismic data with hydro-mechanical models:

Characterising and monitoring subsurface geological repositories

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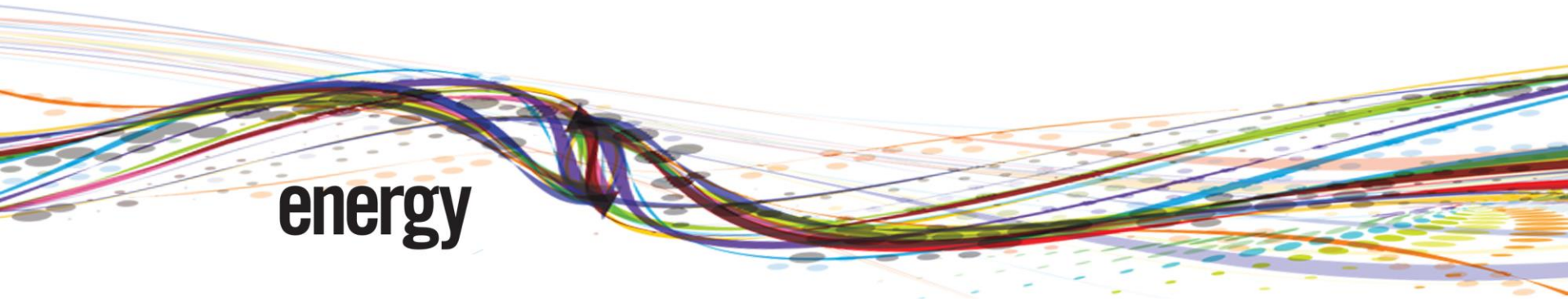
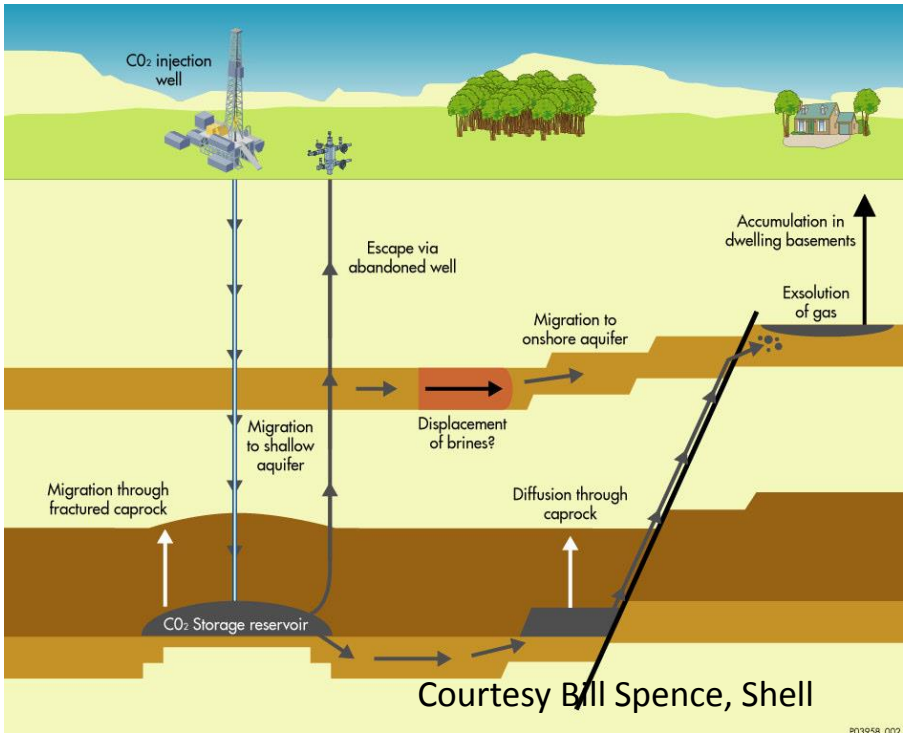
Outline

- Waste repository sites (geophysical context)
- Effective stress concept
- Multi-physics of porous deformable media
- Rock physics transforms
- Seismic monitoring
- Examples
- Monitoring strategies
- Challenges



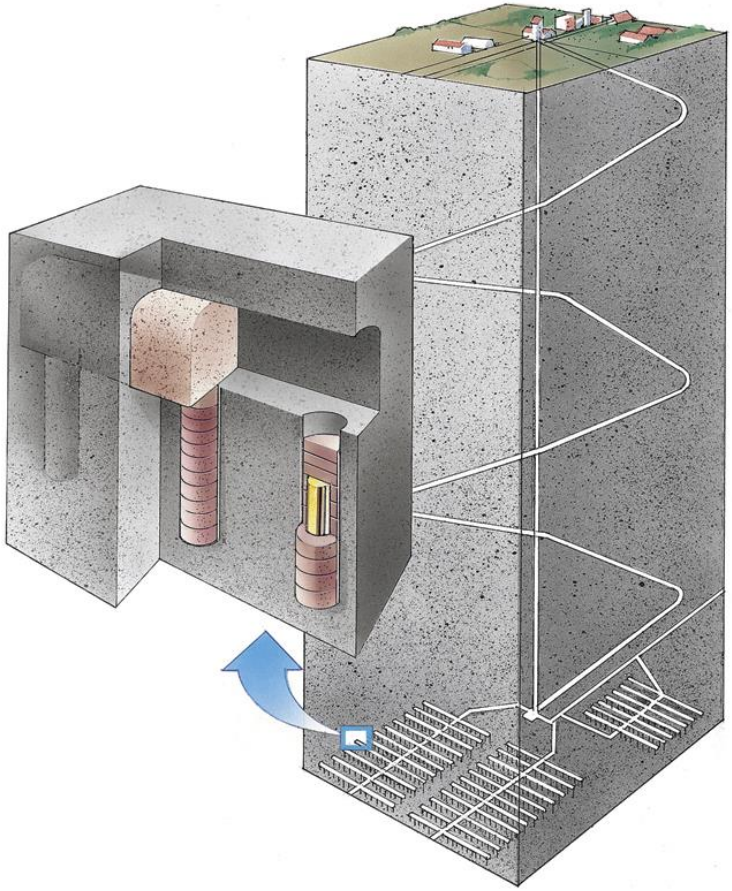
Waste repository sites

Carbon Capture and Storage (CCS)



Courtesy Bill Spence, Shell

Deep Geological Repository (DGR)



From “Nuclear waste – Can it be disposed of safely?” by HR Jones

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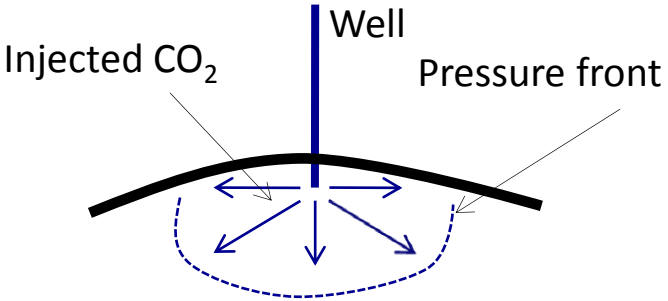
Waste repository CCS

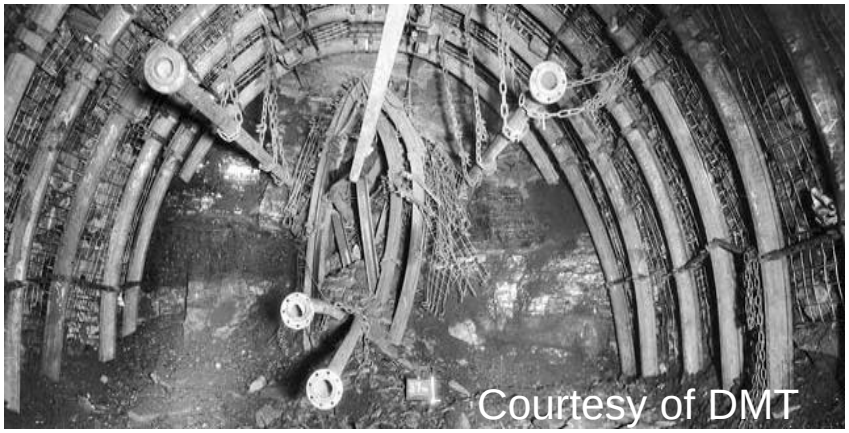
- Injectivity:
  - Storage capacity?
  - Injection rate?
  - Optimal injection strategies?
- Security:
  - Is CO_2 behaviour as predicted?
  - Is CO_2 safely stored?
- Monitoring
  - Can we monitor CO_2 volume?
  - Can we observe CO_2 migration?

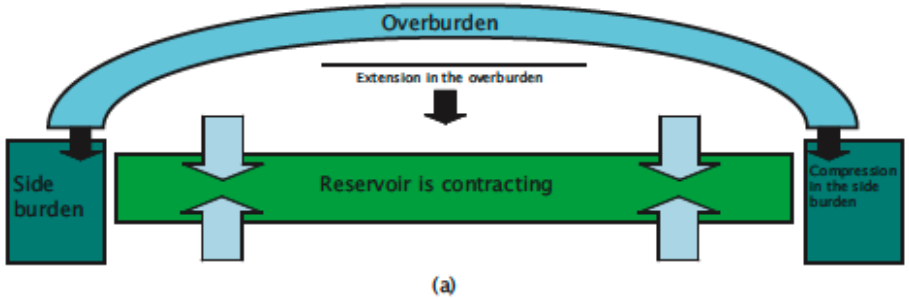
Waste repository DGR

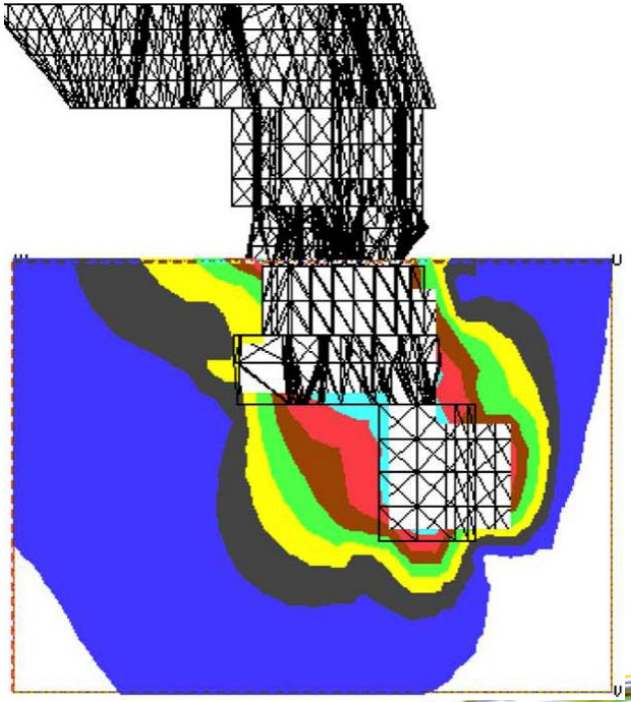
- Siting:
  - Is site suitable and accessible?
  - Any unforeseen features not seen observed in siting survey?
- Security:
  - Is repository site behaving as predicted?
  - Is waste safely stored?
- Monitoring
  - Can we monitor geomechanical problems?

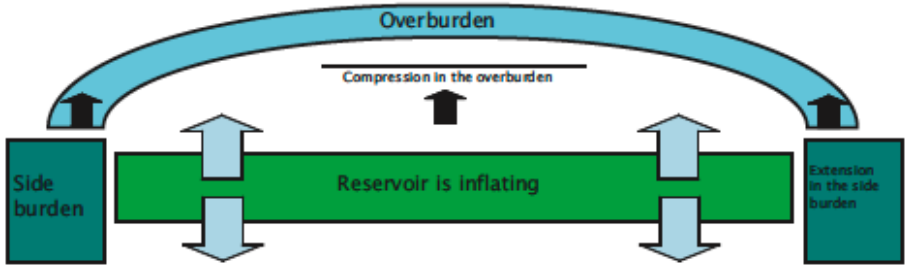
Effective stress











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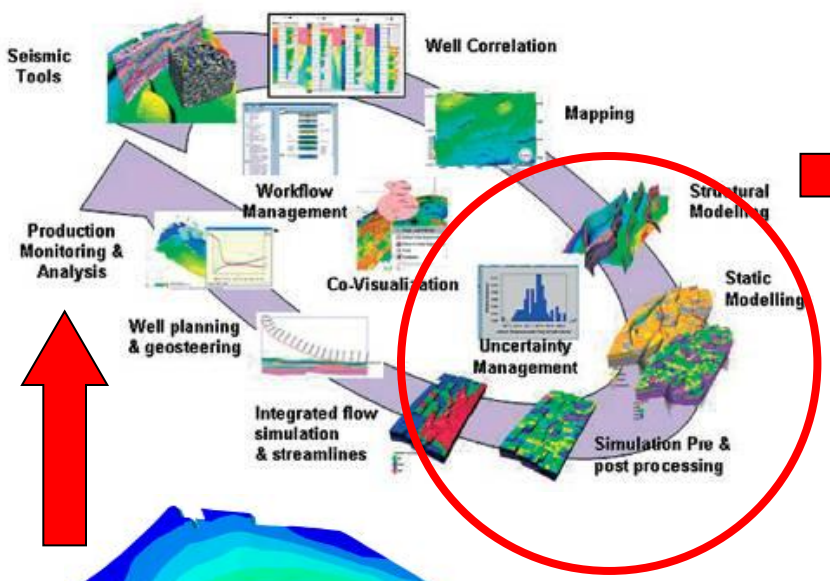
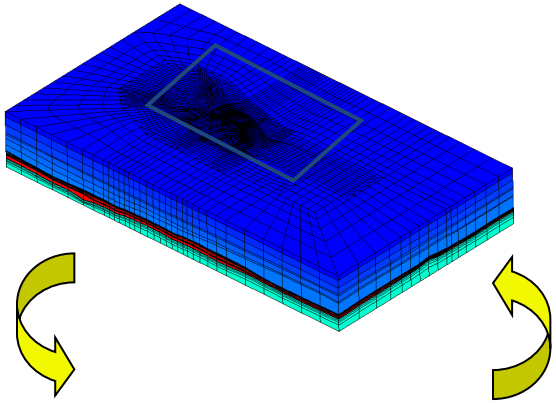
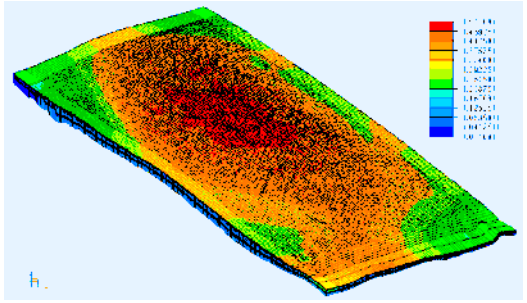
Multi-physics of porous deformable media

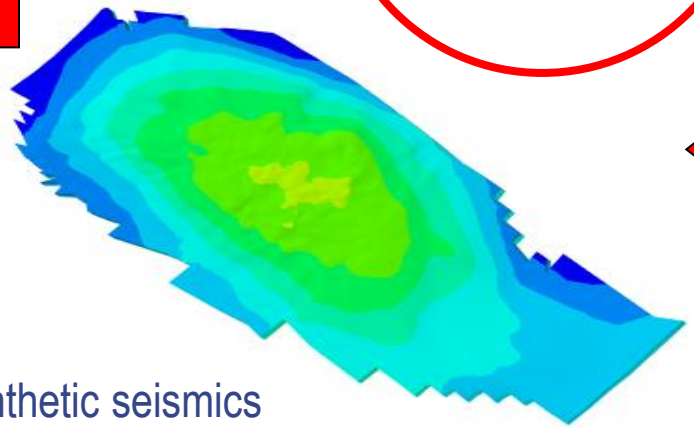




MPI interface



Hydro-mechanical models



Synthetic seismics

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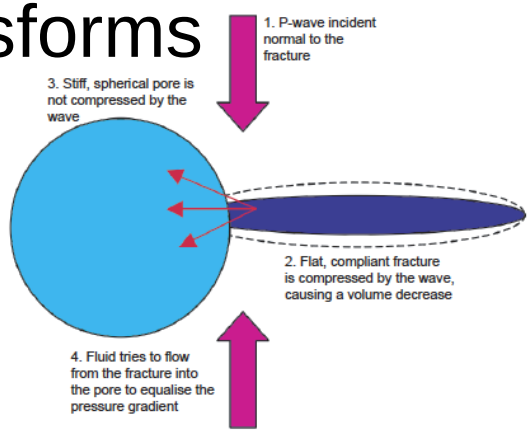
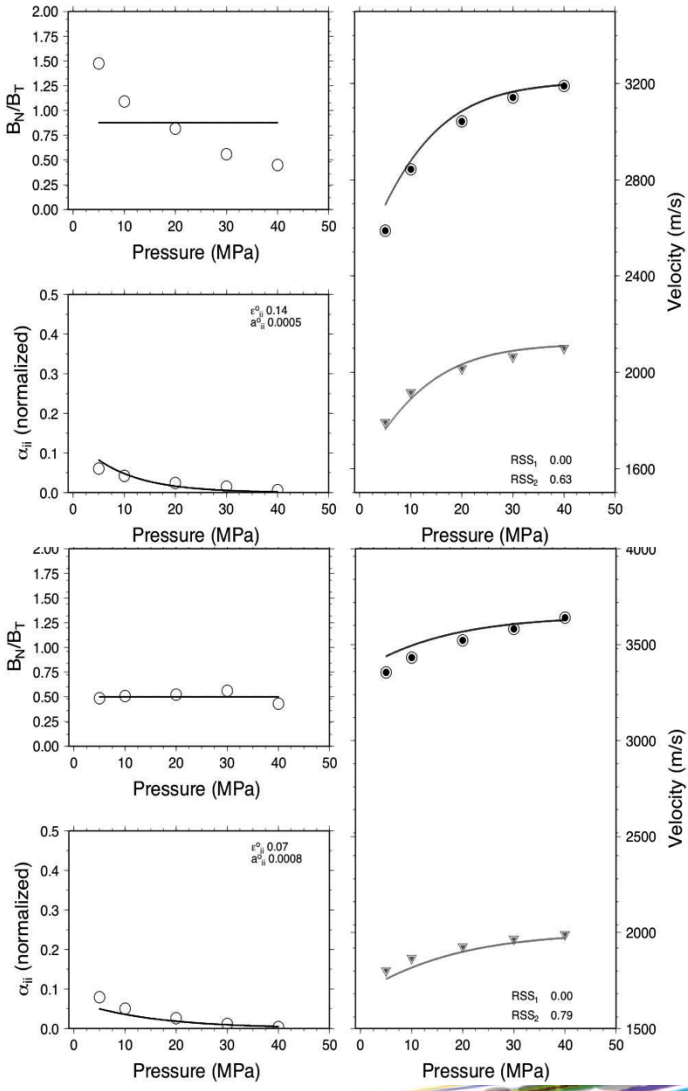
Rock physics transforms



rock physics model

- intrinsic anisotropy → Implement geomathematical model (see Kendall et al., 2007)
- static to dynamic conversion → Not implement yet, but exploring options such as Guyer et al. (1995)
- nonlinear stress dependence → Implement microstructural analytic nonlinear mode (see Verdon et al., 2008)
- fluid effects
  - low frequency → Gassmann's equation (see Brown & Korringa, 1975)
  - frequency effects → Squirtflow model (see Chapman et al., 2002)
- effects of fractures → Implement fracture induced excess compliance and anisotropy (see Hall, 2000, for review)

Stress dependent velocities



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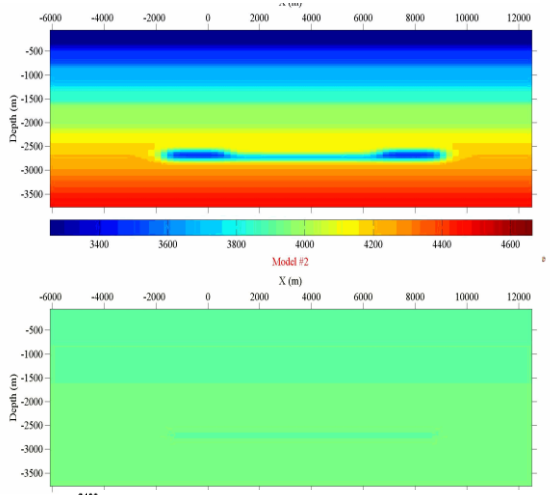
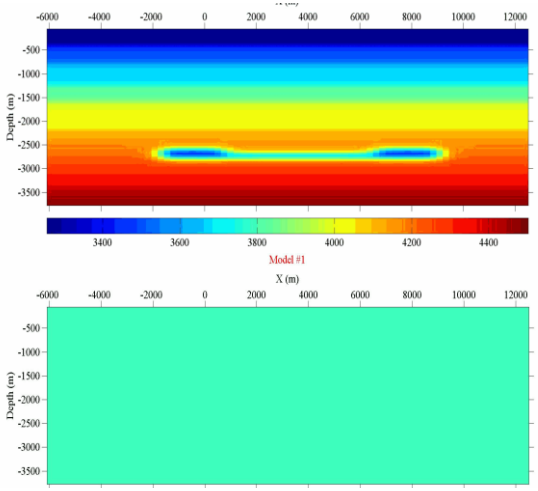
Rock physics

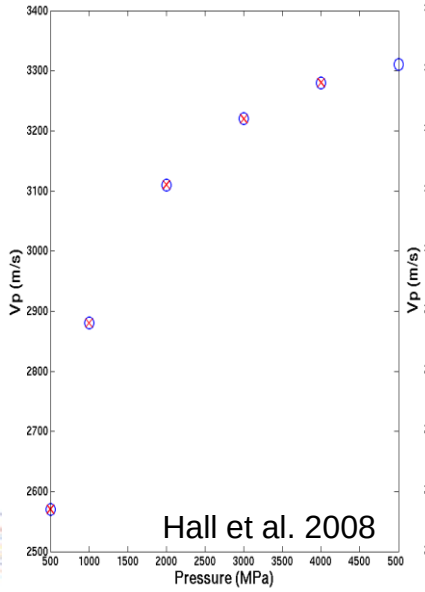
- Models
- Calibration

Reservoir model with high fault transmissibility

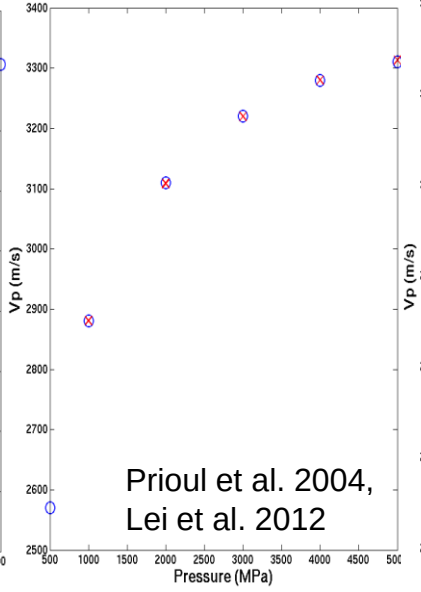


Reservoir model with low fault transmissibility

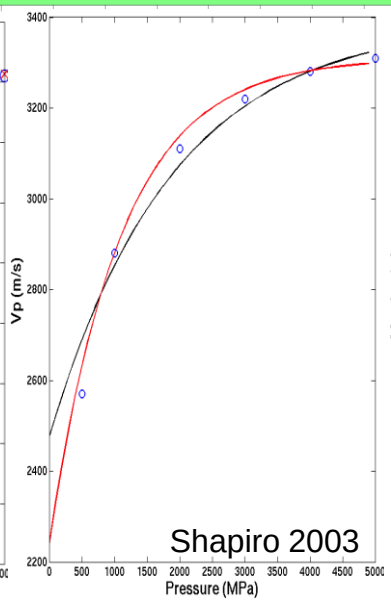




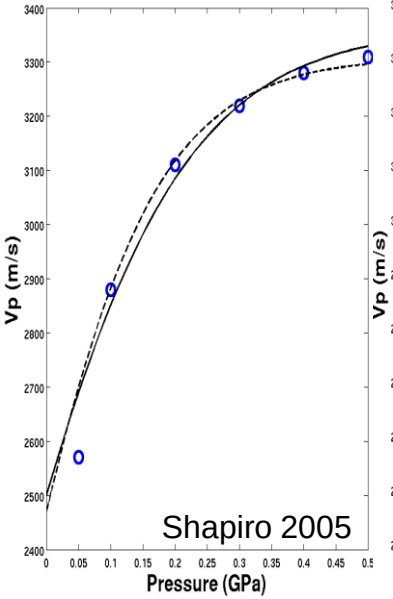
Hall et al. 2008



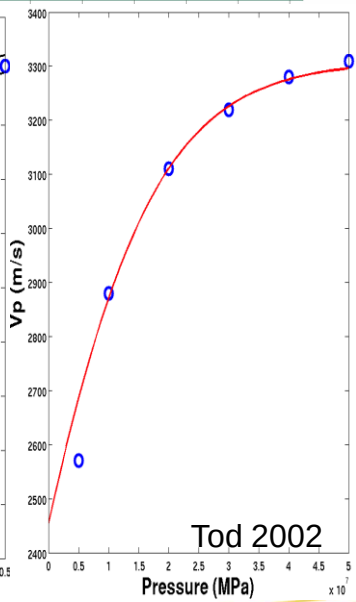
Prioul et al. 2004,
Lei et al. 2012



Shapiro 2003



Shapiro 2005



Tod 2002

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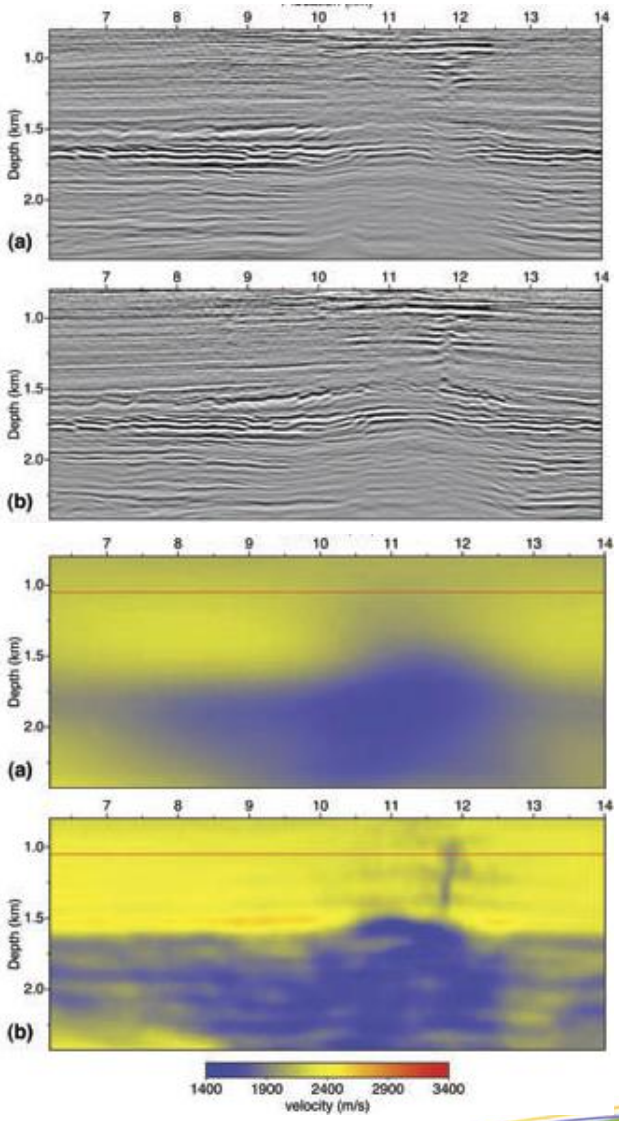
Geophysical imaging

- Seismic methods (elastic)
  - Time-lapse
  - Microseismic
- Electromagnetic (conductivity)
- Gravity (density)
- Geodesy
  - InSAR
  - GPS

Seismic imaging



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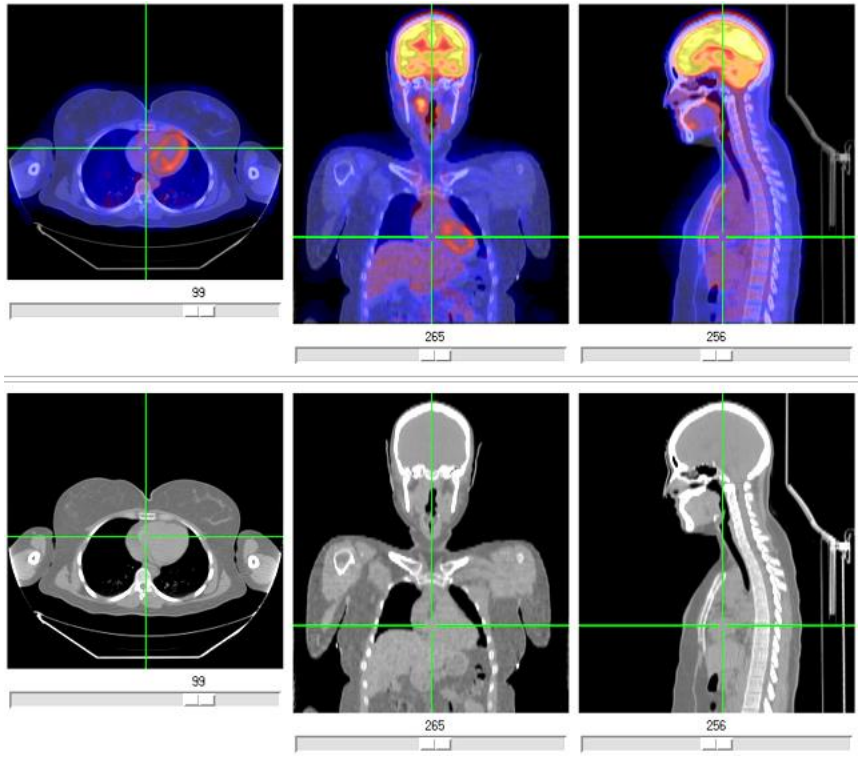
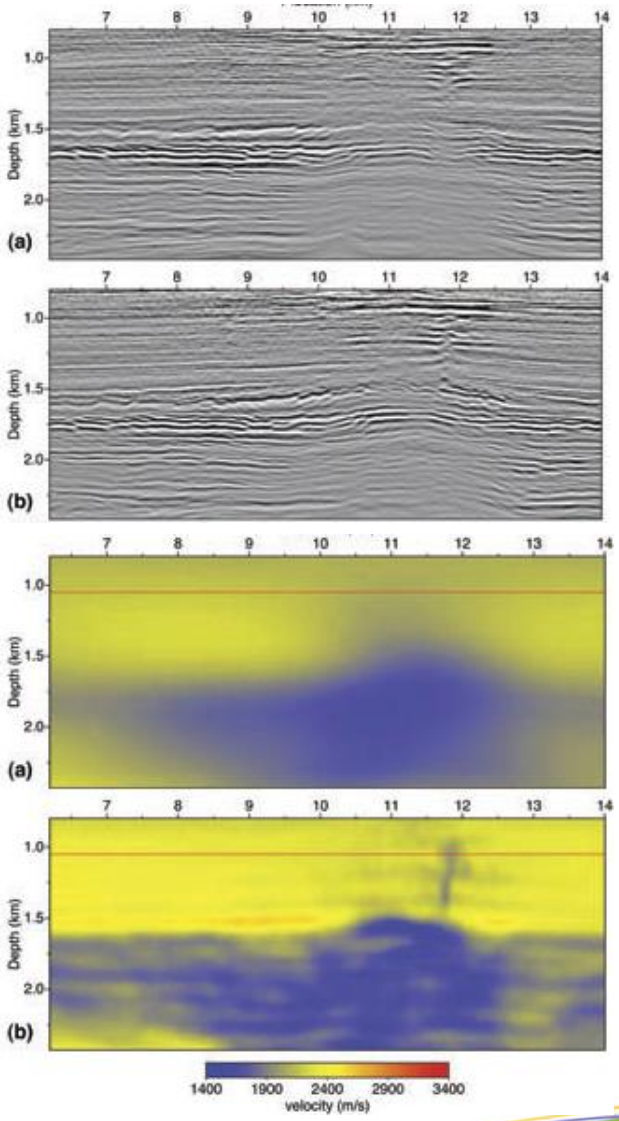
Geophysical imaging

Medical imaging



Seismic imaging



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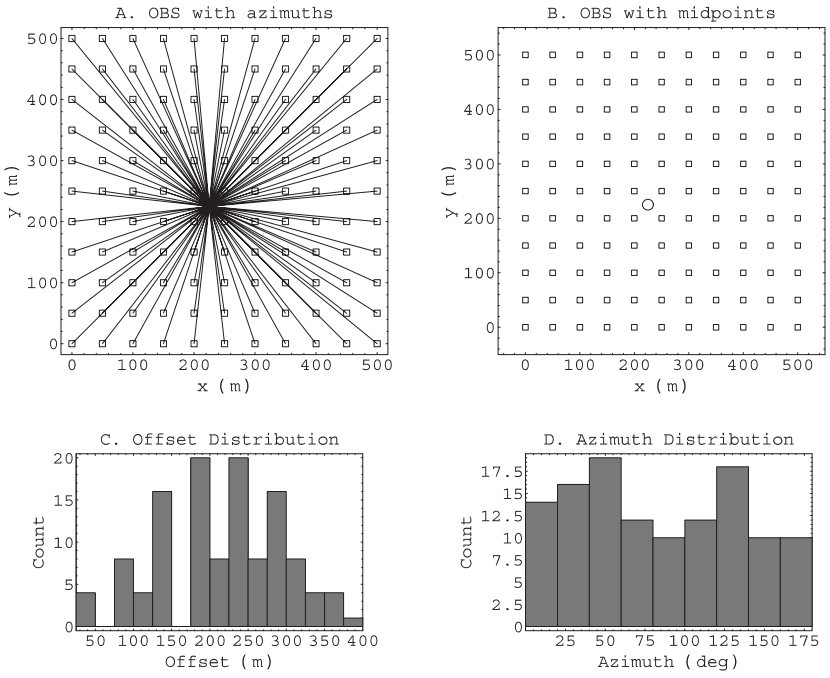
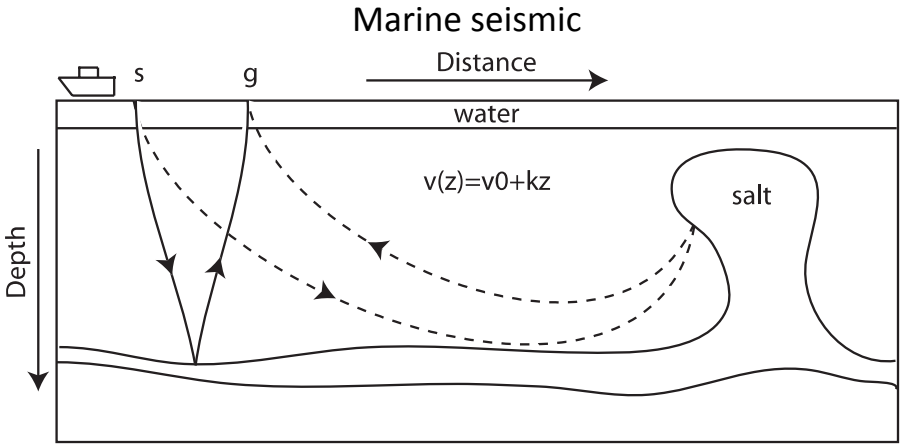
Seismic monitoring

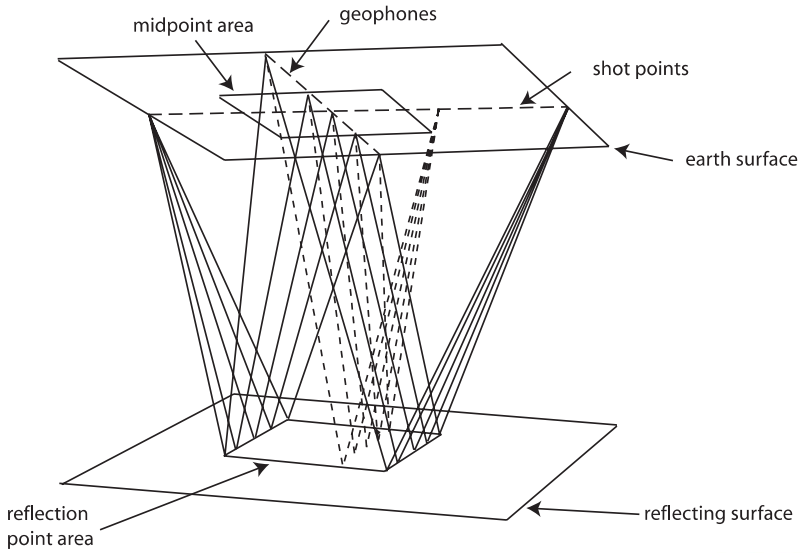
Acquisition (instrument) geometry



Marine seismic



Land seismic



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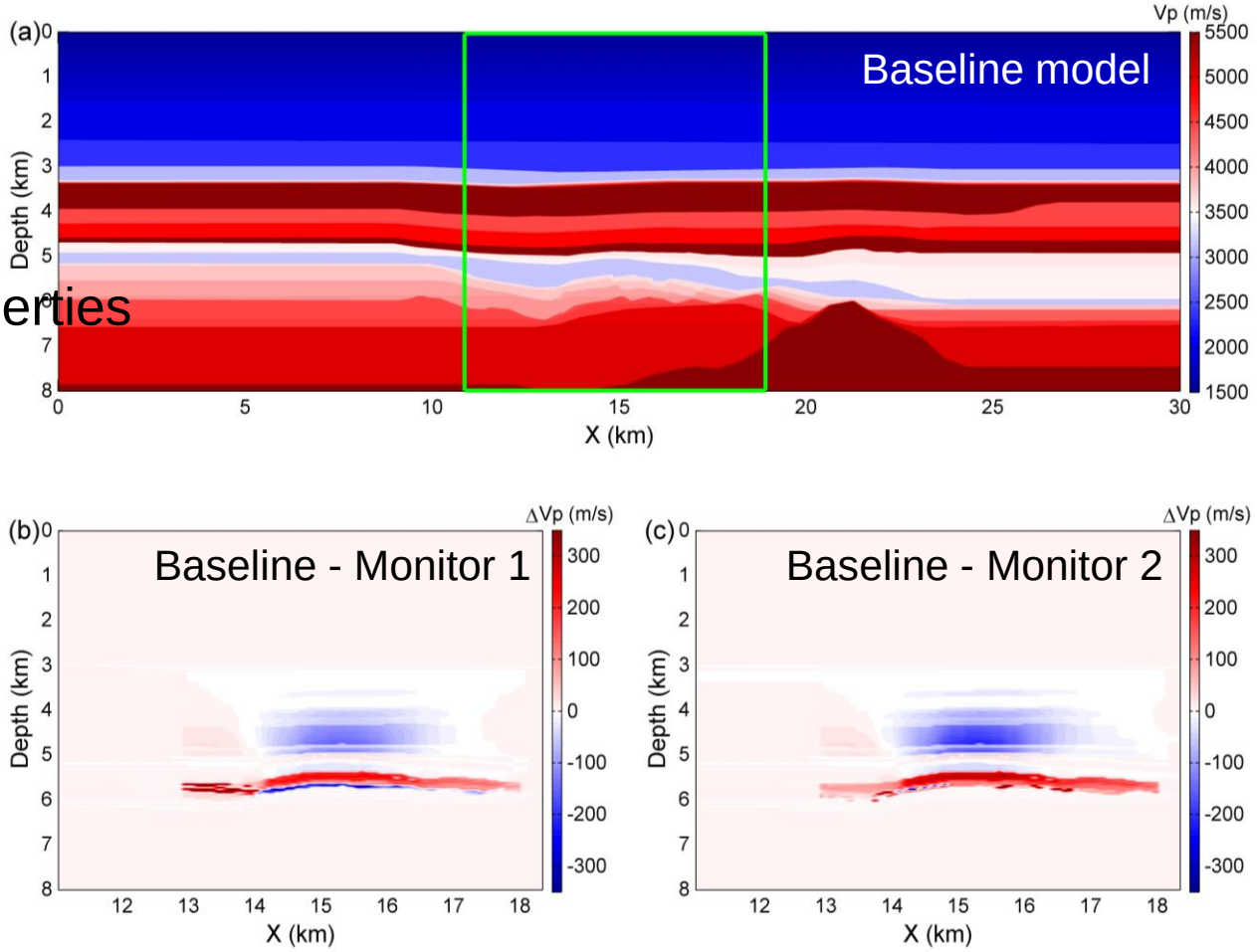
Time-lapse or 4D seismic

- Change in:
  - Saturation
  - Pressure/stress
  - Mechanical properties



P-wave velocity change for true earth model

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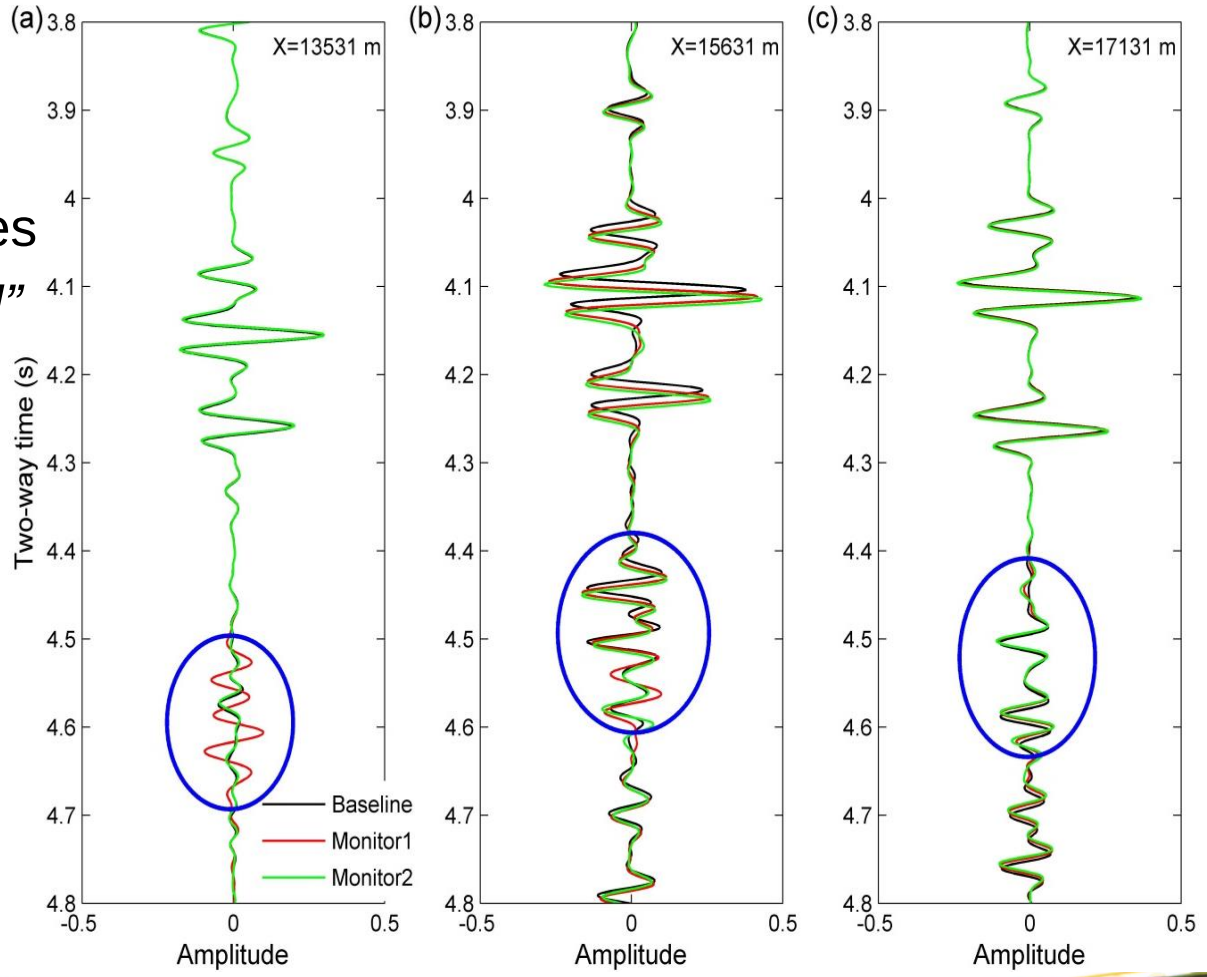
Time-lapse or 4D seismic

- What is measured:
  - Time differences
  - Amplitude differences
  - *“Devil is in the detail”*



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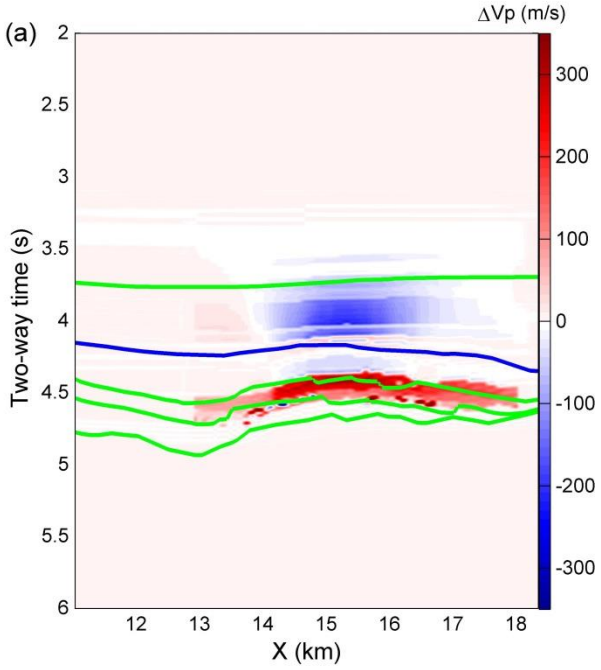
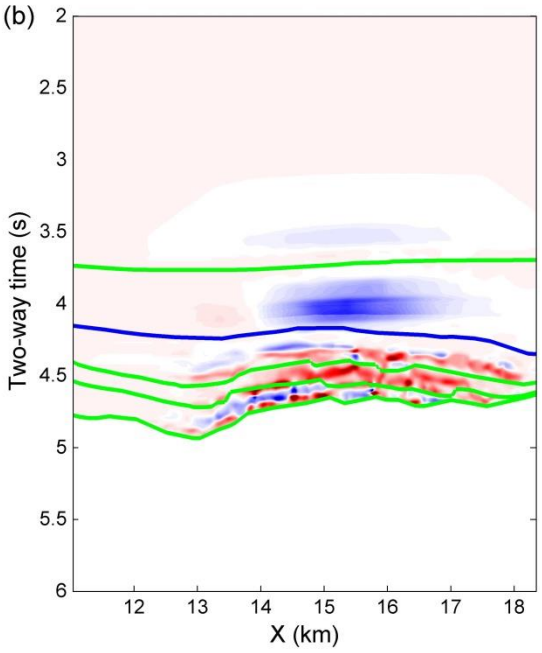
Time-lapse or 4D seismic

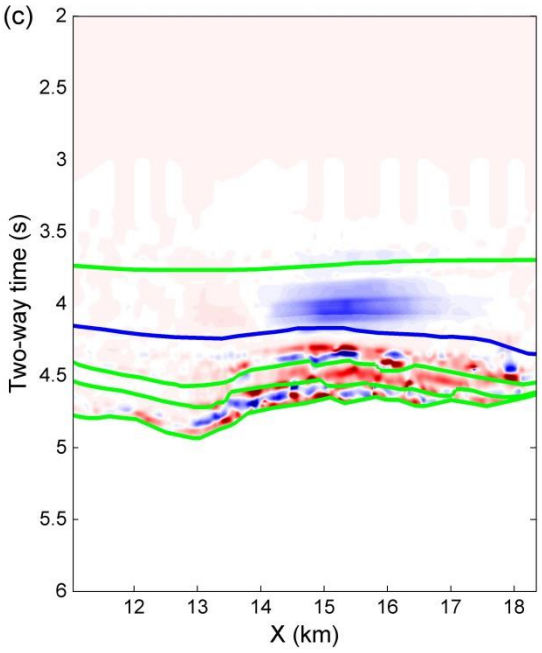
- Extract time-lapse velocity changes



P-wave velocity change for true earth model



Estimated P-wave velocity change using full-offset seismic data



Estimated P-wave velocity change using near-offset seismic data

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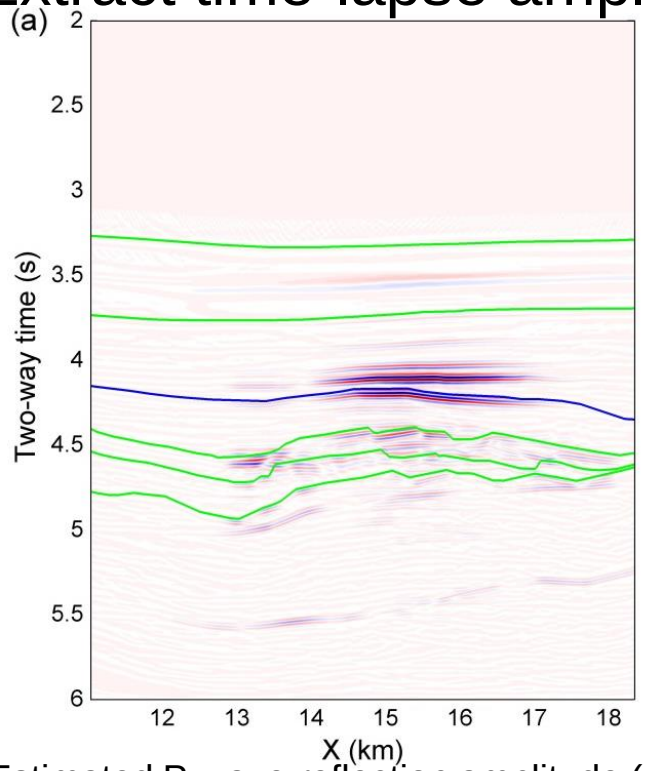
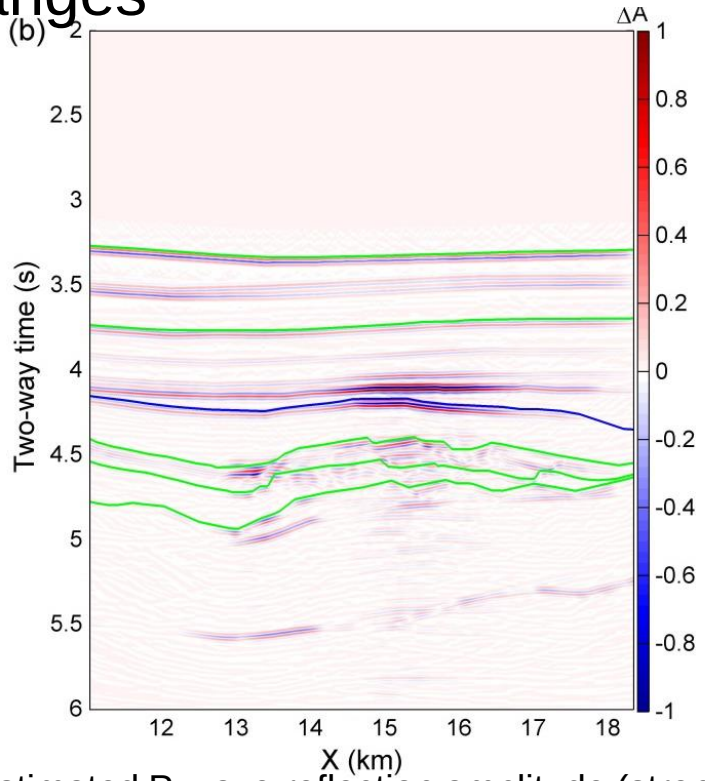
Time-lapse or 4D seismic

- Extract time-lapse amplitude changes



Estimated P-wave reflection amplitude (strength) changes using full-offset seismic data

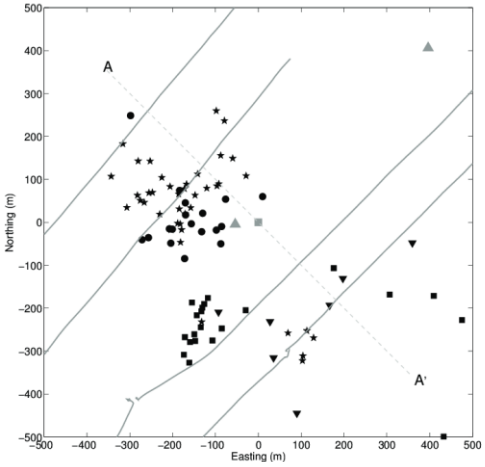


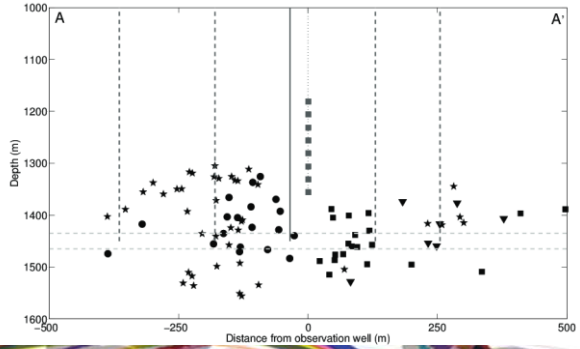
Estimated P-wave reflection amplitude (strength) changes using near-offset seismic data

Microseismicity:

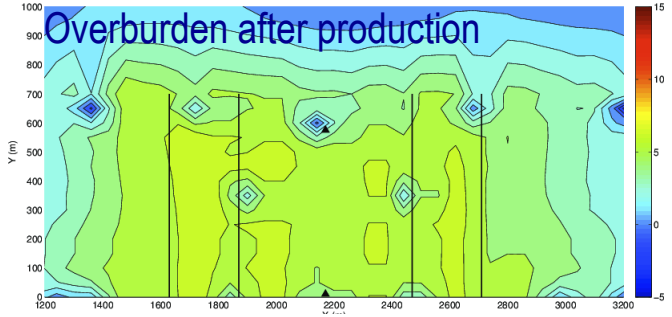
- Weyburn CCS pilot
- Geomechanics and microseismicity

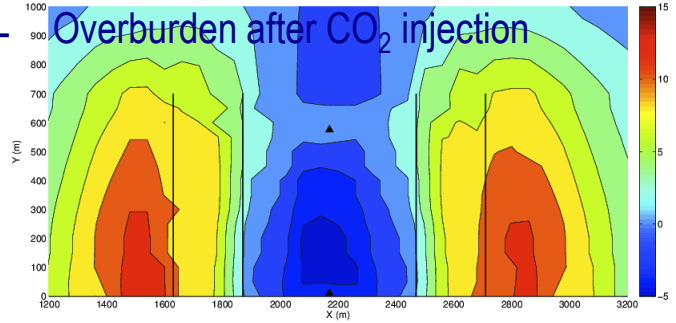
Microseismic locations

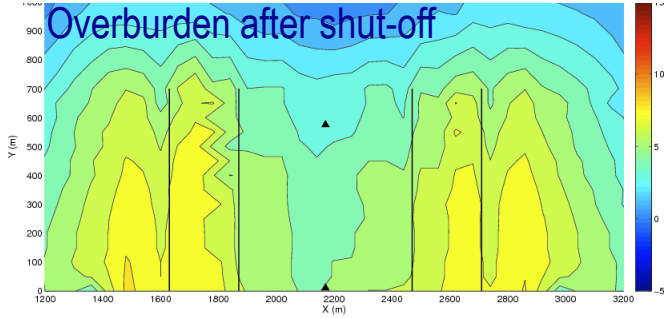




Overburden fracture potential







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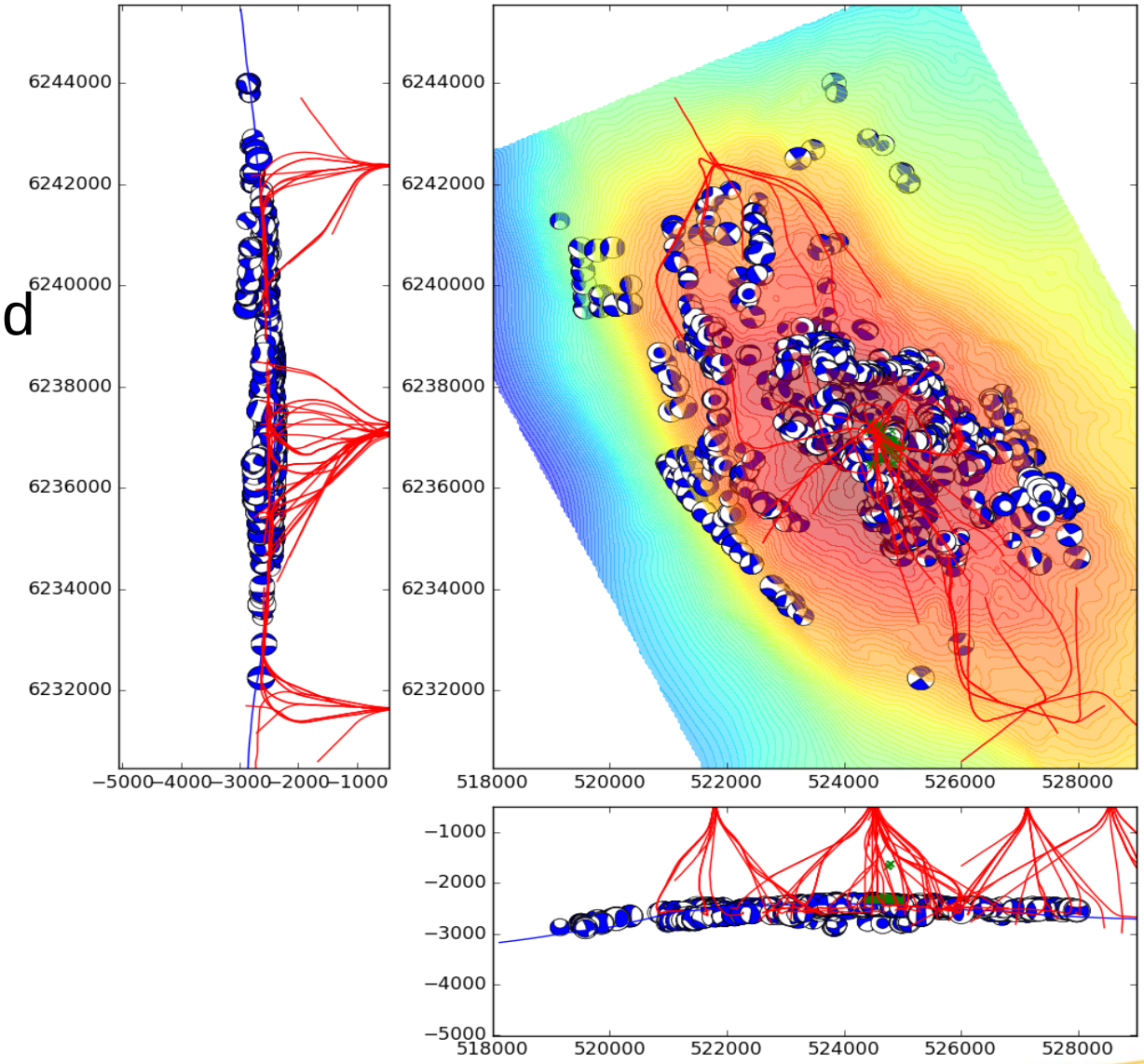
Microseismicity:

- Valhall reservoir
- Geomechanics and microseismicity



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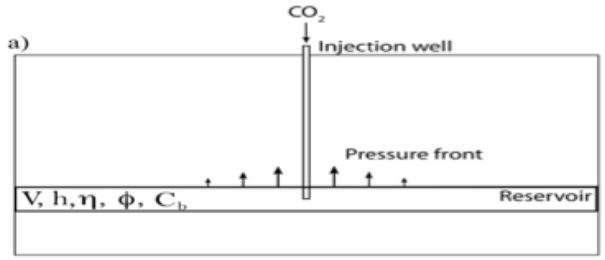
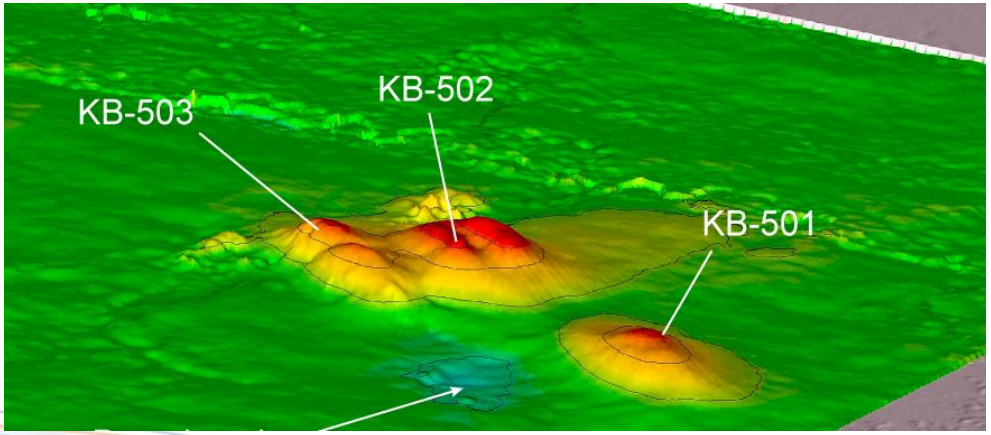
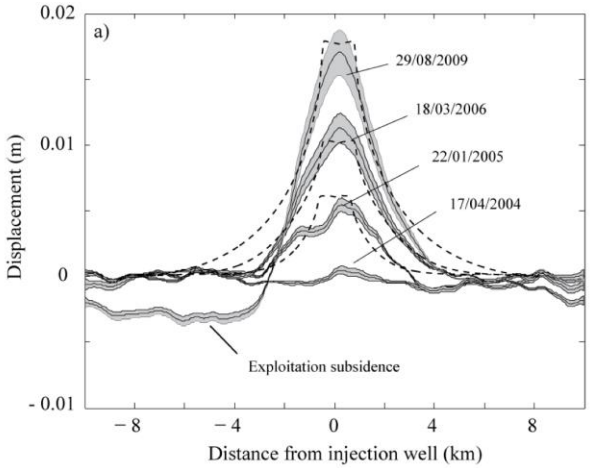
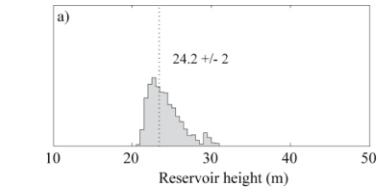
Geodesy (InSAR)

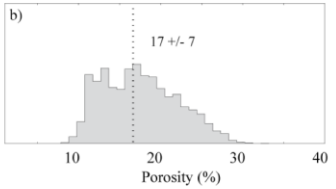
- Geomechanics and geodesy
- In Salah, Algeria CCS pilot

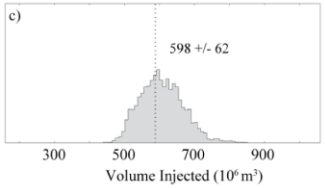


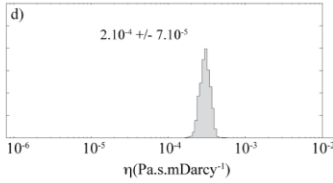


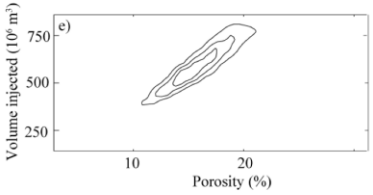












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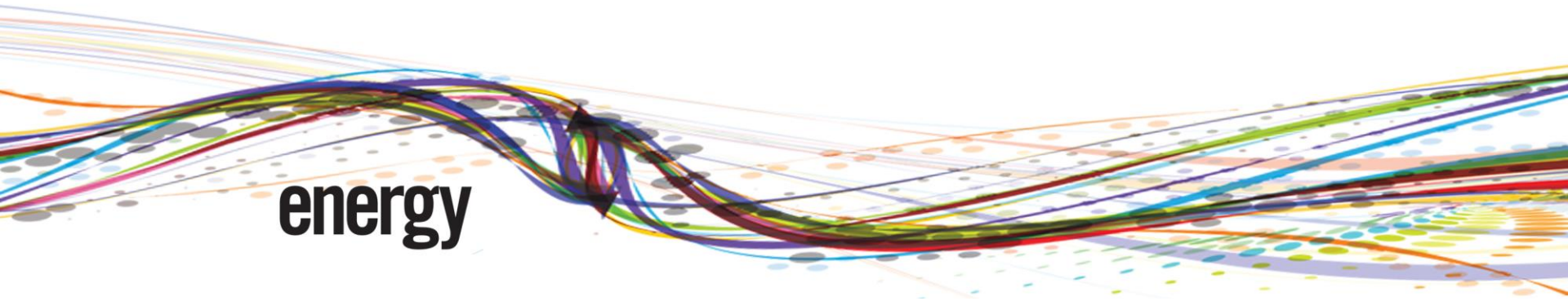
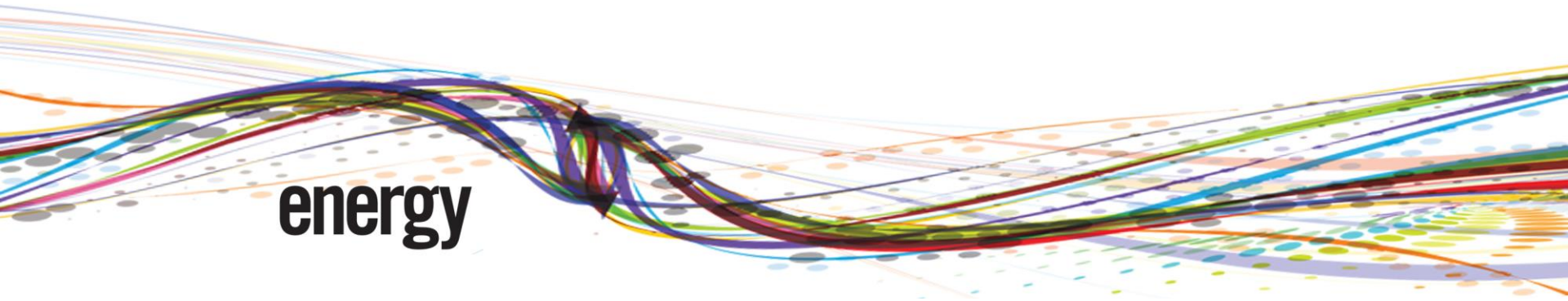
Instrumentation

- Conventional geophysical instrumentation:
  - ~ High quality
  - ~ Cost effective
  - ~ Work well for typical problems
- For waste repositories:
  - Need to be reliable over longer time spans (years to decades)
  - Need to be significantly more cost effective
  - May need to perform under hostile conditions (high temperatures, high pressures, highly corrosive environments)



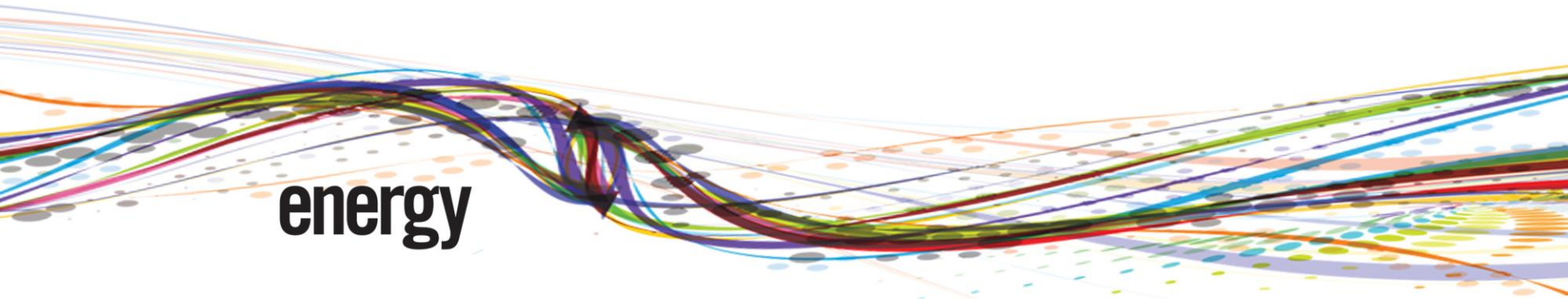
Challenges

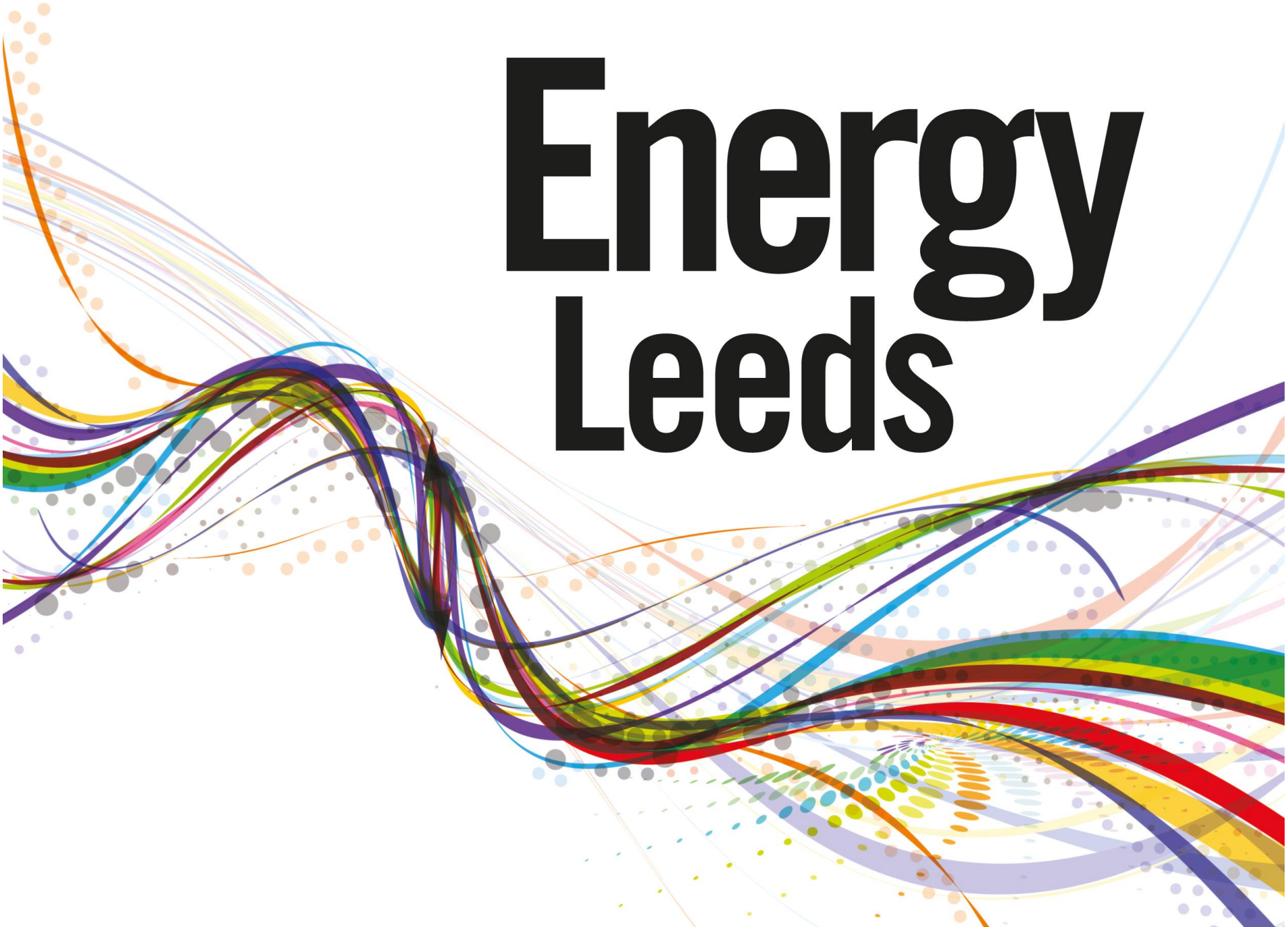
- Calibrated rock physics models
  - Multiphase fluids, anisotropy, geochemistry, thermal
  - More data, greater breadth of sampling
- More advanced models
  - Fractures and joints
  - Scaling (static to dynamic)
- Improved integration with fracture modelling and microseismic modelling



Bigger challenges

- Calibration
  - History match multi-physics models
  - Iterative approach between geophysics and hydro-mechanics
- Systematic approach to model building
  - Structure (i.e. geometry)
  - Meshing (i.e. gridding) – water-tight geometries
  - Constitutive models from rock and petro-physics with up-scaling

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