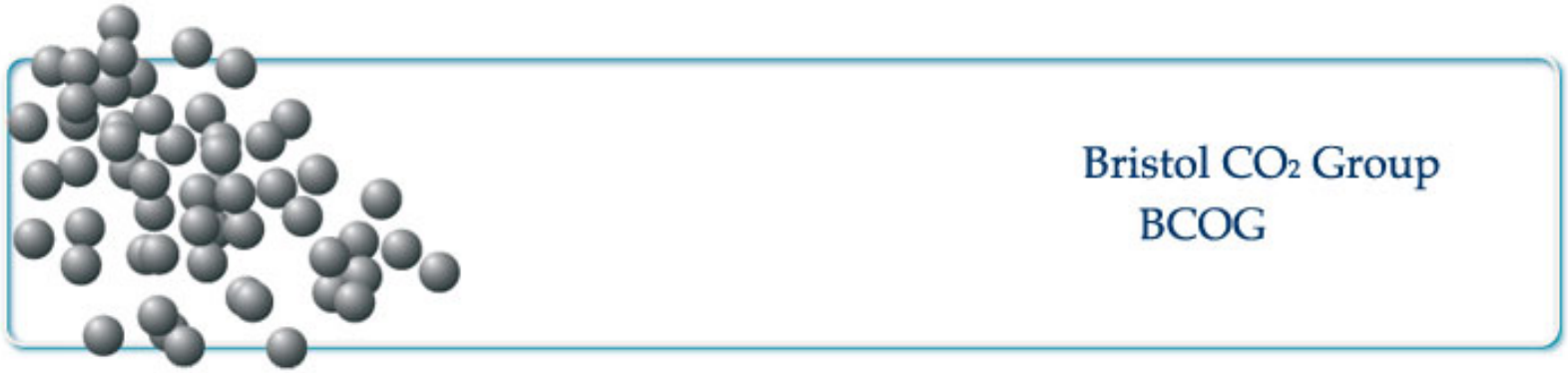
The need for passive seismic monitoring at CO_2 storage sites

Michael Kendall

https://www1.gly.bris.ac.uk/BCOG/



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Projects and Funding

Weyburn (Phase II): Petroleum technology research centre (Sask, Canada); NERC-UKCCSC. (JMK, James Verdon, Don White – GSC), CAN$110k, £50k

PhD studentship: UKERC funding. (James Verdon), £60k

Integrated Petroleum Engineering, Geomechanics, and Geophysics: JIP - BP, Statoil, BG-Group, ENI. (Quentin Fisher -Leeds, JMK, Tony Crook, Martin Dutko – Rockfield), £580k

BUMPS – Bristol University Miroseismicity Projects: consortium of oil (+ mining) companies, BGS and regulatory agencies, £1.3M

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Projects and Funding

Still or Sparkling - In Salah microseismicity: NERC partnership grant with BP. (JMK, JV, Anna Stork, Rob Bissell – BP), £281k

Aquistore (passive seismic monitoring and imaging): UKCCSC; PTRC; BUMPS (Anna Stork, JMK, Don White - GSC), £10k

MORE – Microseismic monitoring for operators and regulators: NERC - follow on fund, (JMK, James Wookey), £92k

Field Research Site (passive seismic monitoring): CMC; UKCCSC; BUMPS (Anna Stork, JMK, Don Lawton – U. Calgary), £30k.

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Geological issues with CO2 storage

Likely leakage pathways:

Wells. Abandoned and not.....

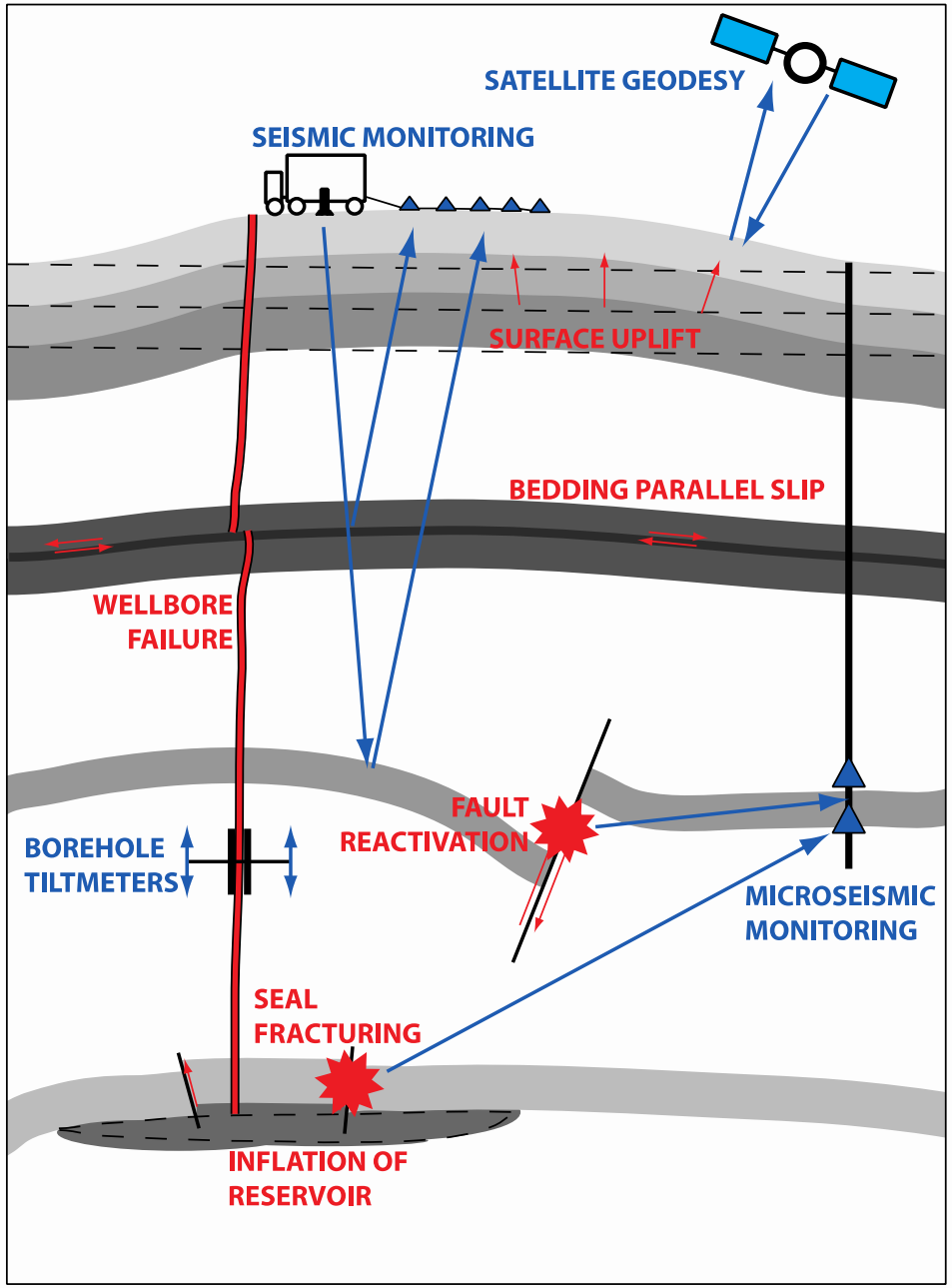
Loss of caprock integrity:

- *Geochemical dissolution*
- *Geomechanical deformation*
- *Fault reactivation*

Seismic monitoring methods:

Controlled source 4-D – detect spatial extent of CO_2

***Passive seismic** – detect fracturing, fluid flow and **geomechanical** deformation; microseismicity*



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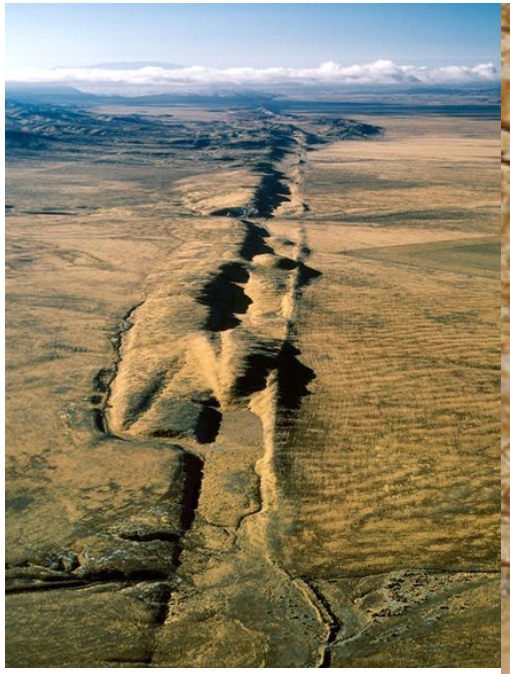
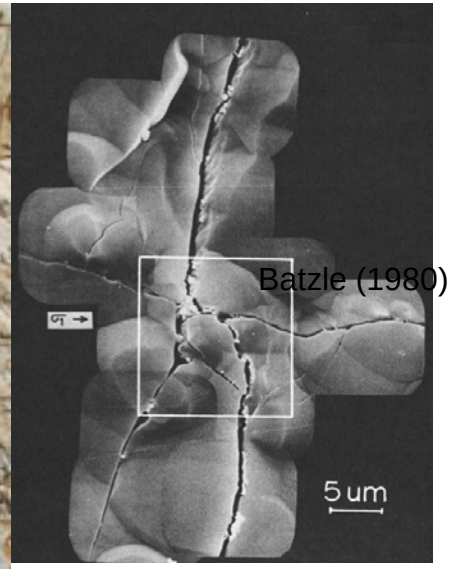
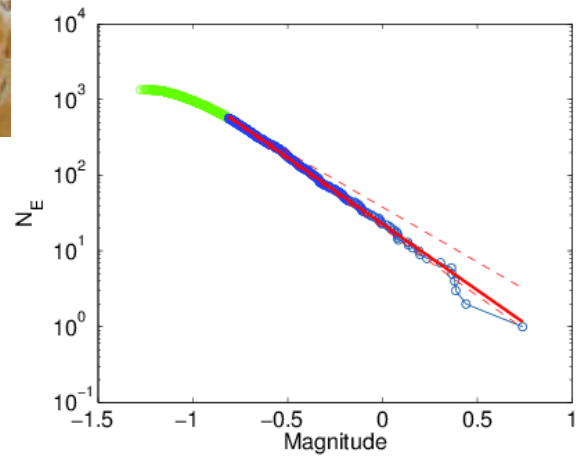
What are microseismic events?





- Small, usually unfelt, earthquakes
- Gutenberg-Richter = fractal (scale independent) process
- Same physics at every scale



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When are microseismic events a problem?

MOMENT MAGNITUDE	MOMENT (MNM)	SLIP (MM)	RADIUS (M)	EXPLOSIVE CHARGE	COMMENTS
-4.0	0.001	0.01	0.03	1mg	Smallest recordable
-3.0	0.04	0.04	0.1	30mg	
-2.0	1.2	0.12	0.3	1g	Typical HF
-1.0	40	0.4	1	30g	
0.0	1,200	1.2	3	1kg	Limit of surface detection
1.0	40,000	4	10	30kg	Big for geothermal
2.0	1,200,000	12	30	1 ton	Felt earthquake
3.0	40,000,000	40	100	30 ton	Minor earthquake
4.0	1,200,000,000	120	300	100 ton	Light earthquake
5.0	40,000,000,000	400	1000	300 ton	Moderate earthquake

Typical injection related magnitudes

M_L0.5 UK-TLS 'red light'

Felt events; fault reactivation

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Fluid induced seismicity

Mohr-Coulomb failure criteria:

$$\tau = \tau_0 + \mu(\sigma_n - p)$$

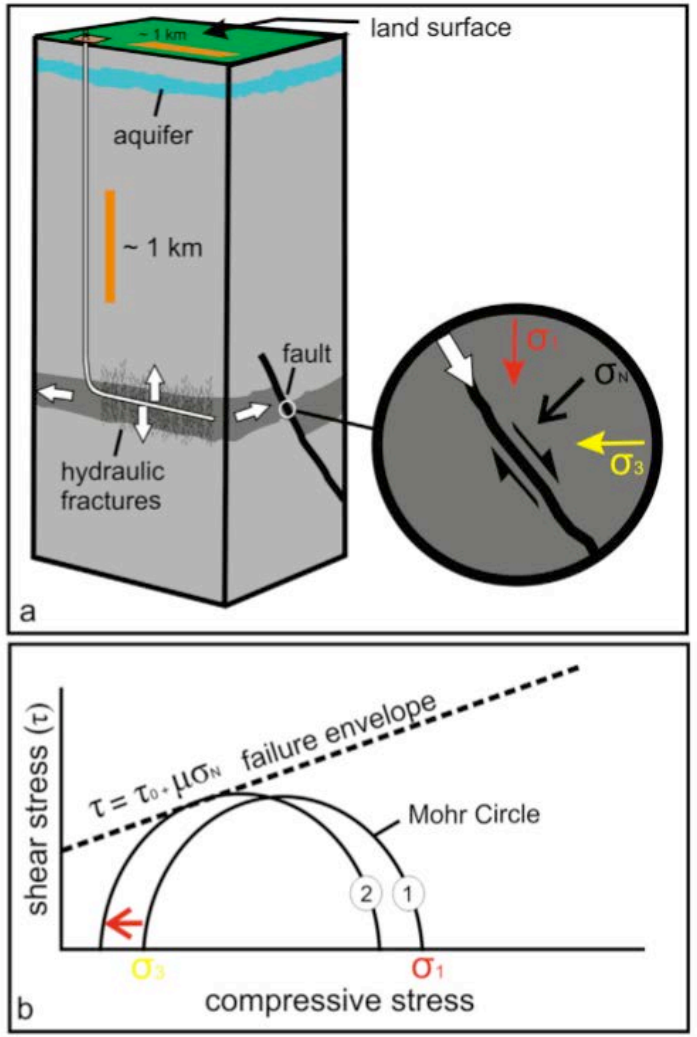
‘Cohesion’
(critical threshold)

‘Friction coefficient’

Pore pressure

Normal stress

Shear stress



CO_2 injection will induce seismicity

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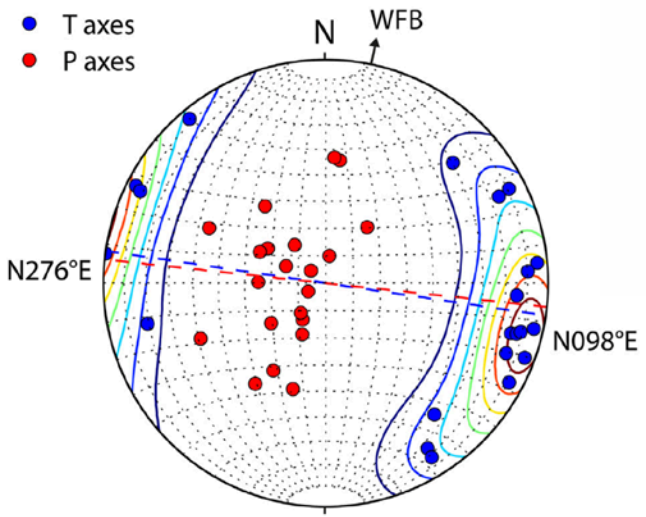
Microseismicity

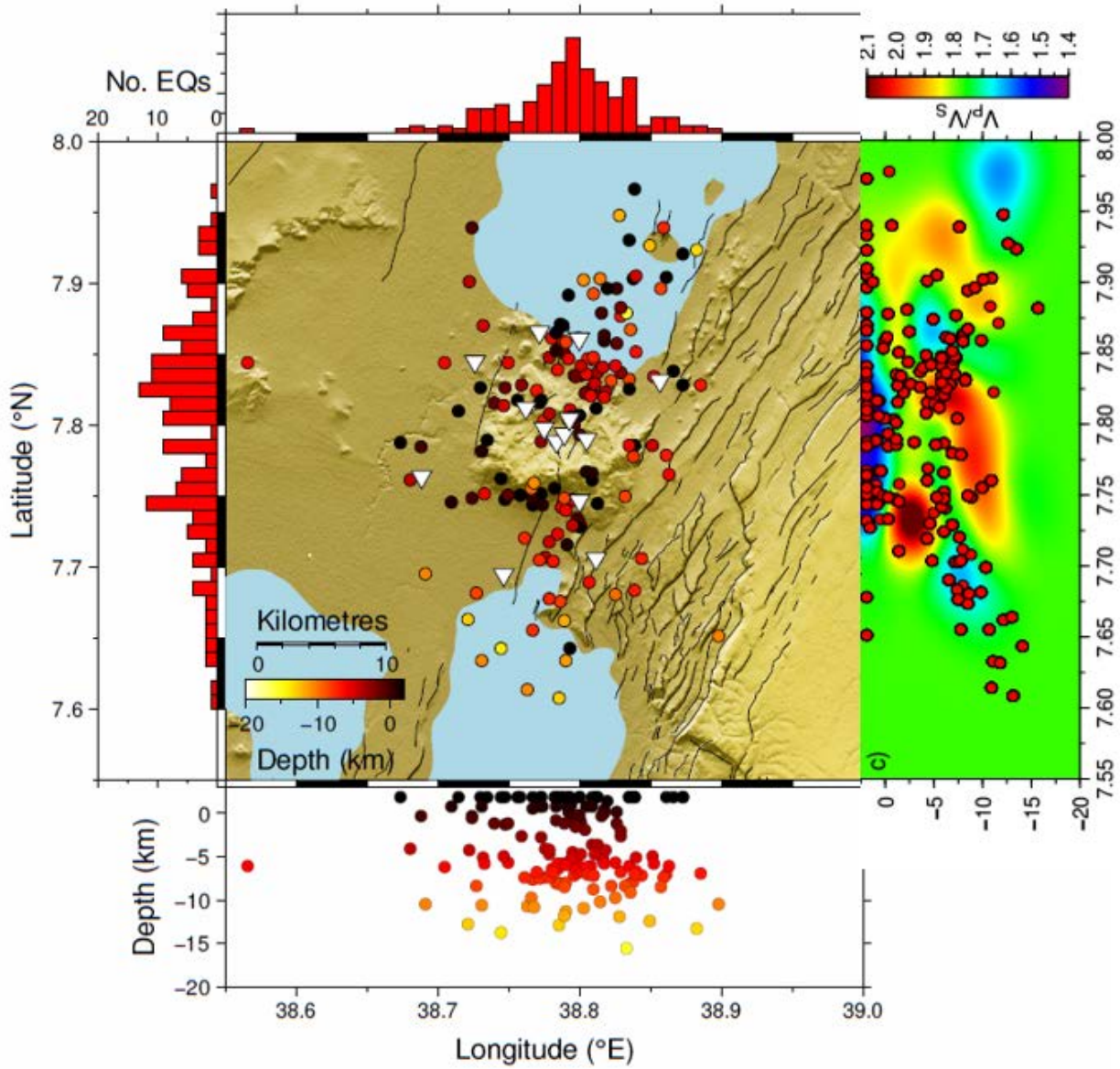
The source:

- Location
- Mechanism
- State of stress

Imaging tool:

- Structure- reflections, tomography
- Anisotropy - fracture characterisation, stress
- Geomechanics





Wilks et al., 2017

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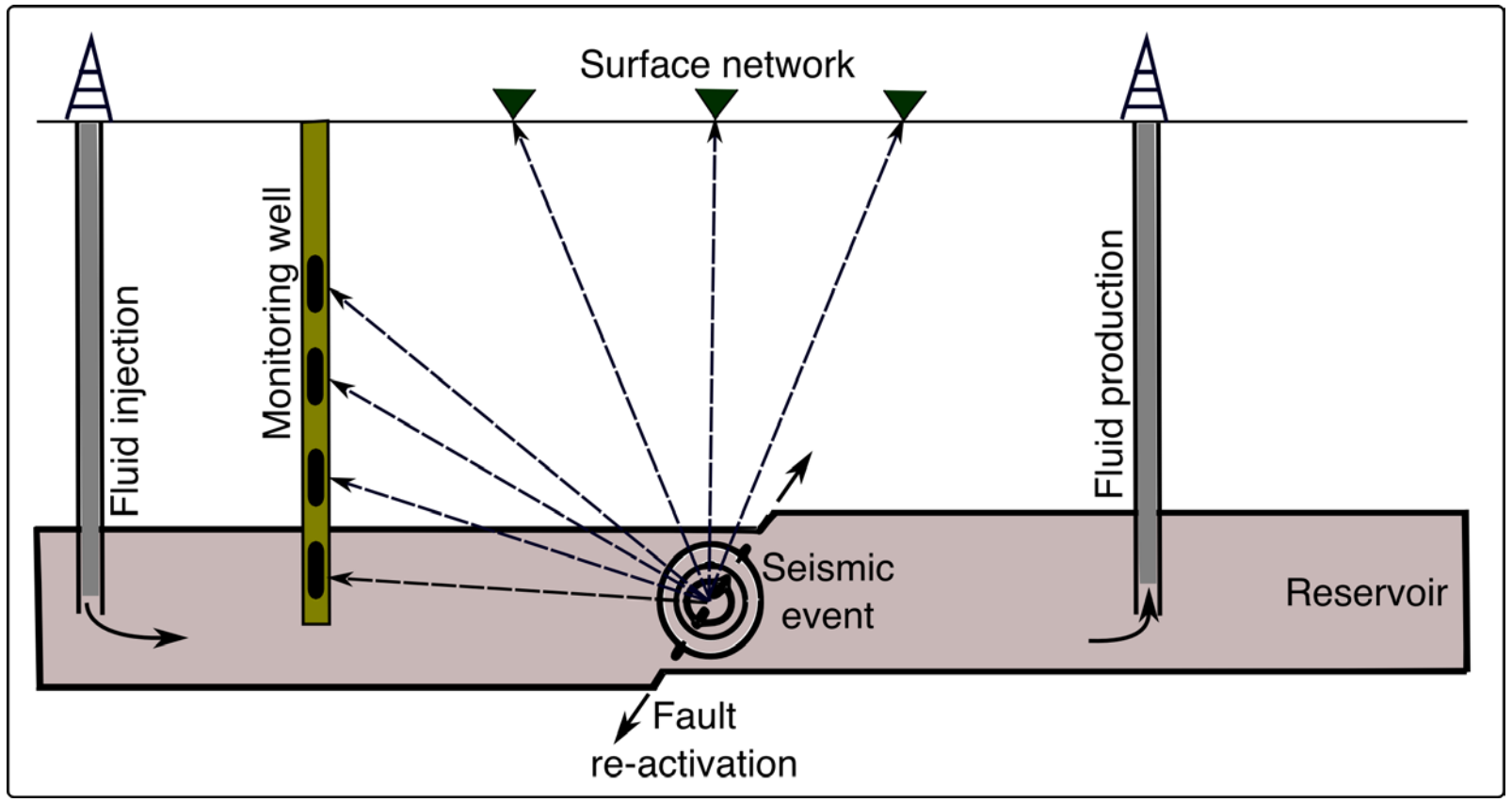
How do we monitor CO_2 reservoir microseismicity?



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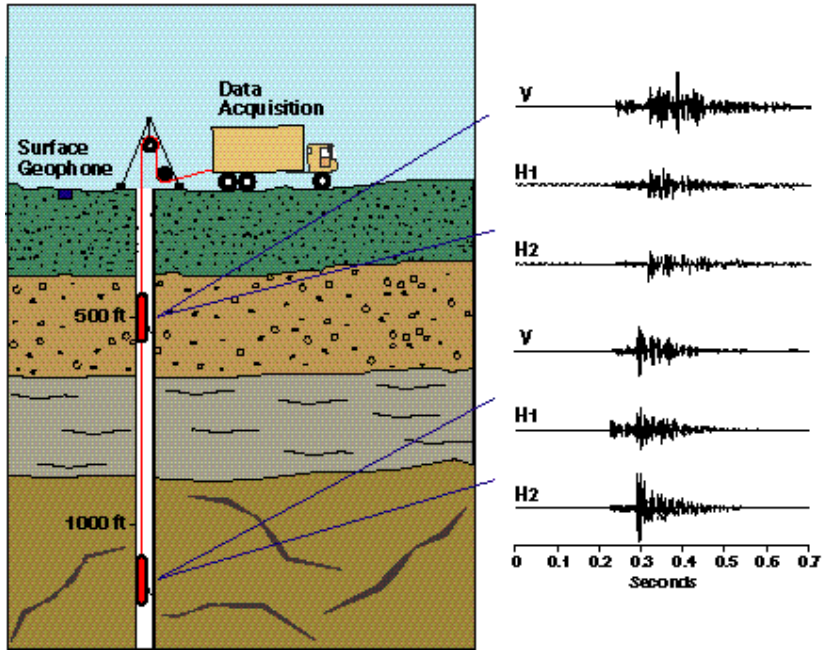
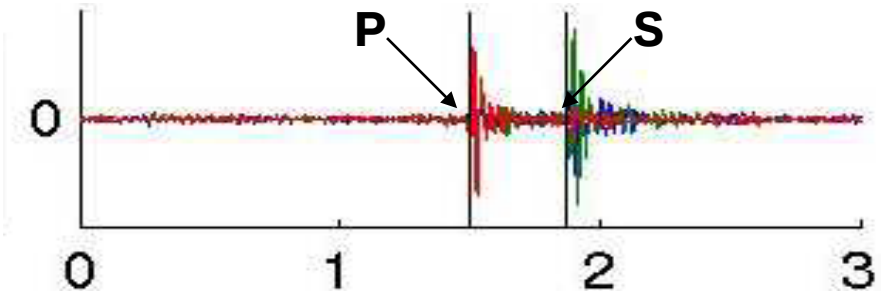
Borehole monitoring



- Low-magnitude event detection level
- Limited areal coverage (vicinity of well)
- Cost scales with number of wells
- Can’t always use a well (expensive)



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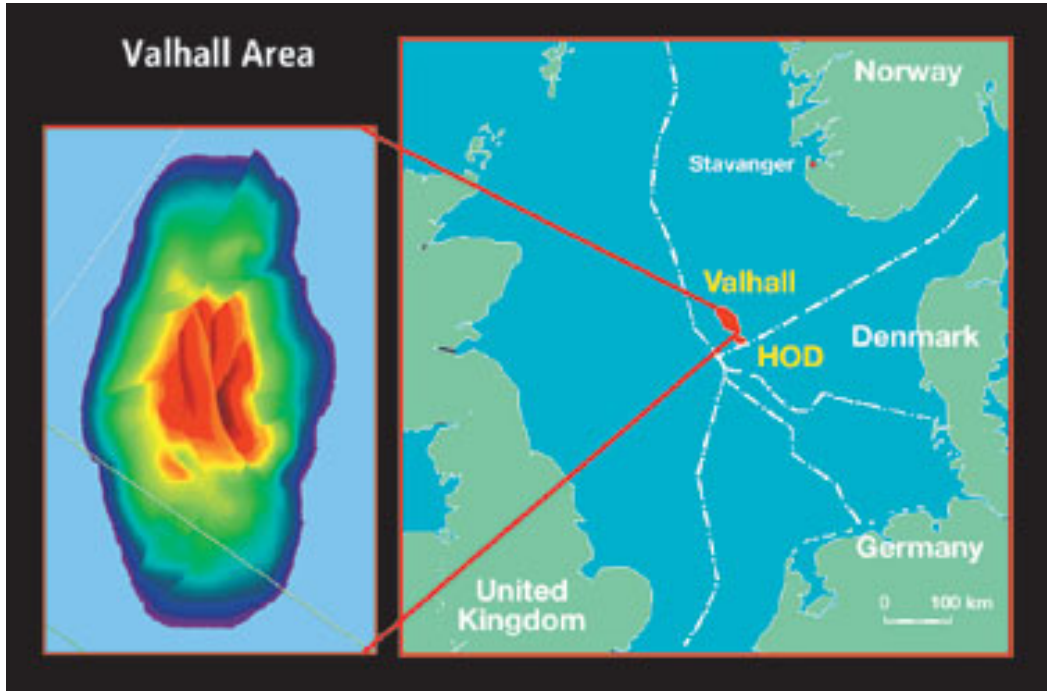
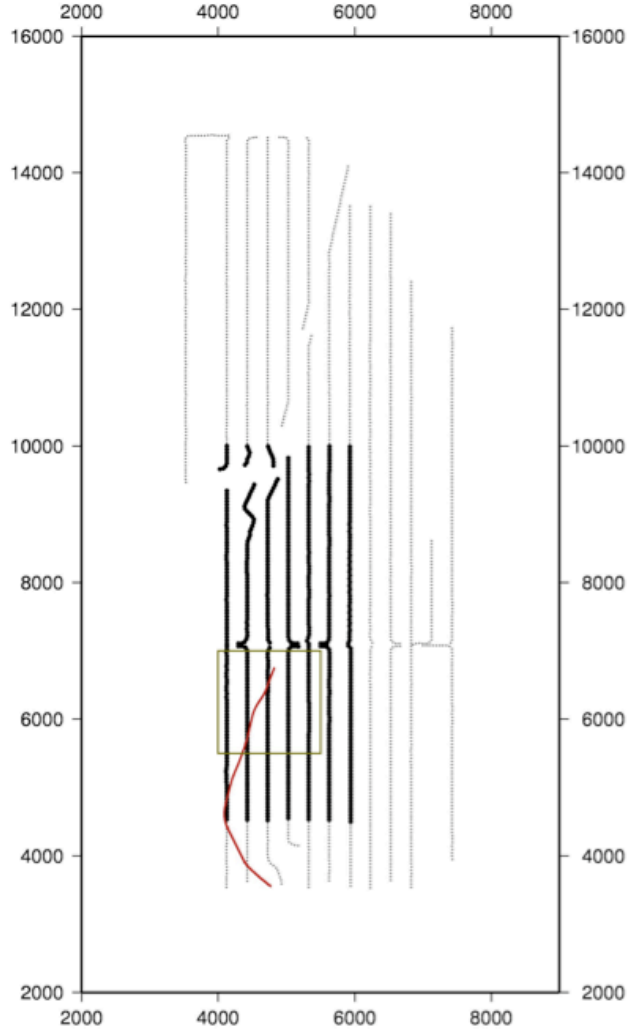
Surface monitoring

- 10,000 sensors at 2,500 locations on the sea bed.
- 2005 – NERC/BP partnership grant.
- Stacking, migration methods to locate microseismic events
- Computationally expensive, but good areal coverage





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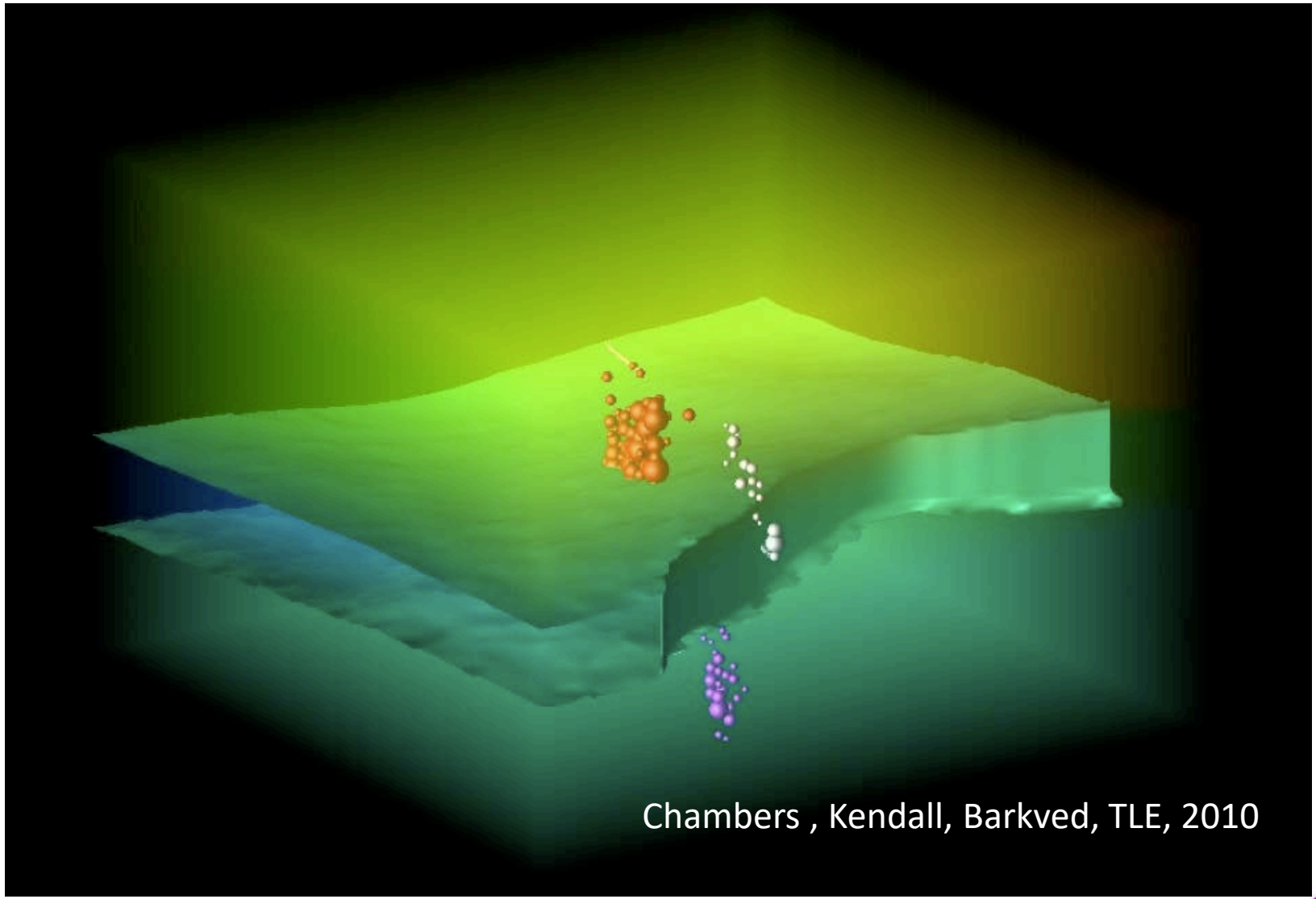
Images of induced seismicity at Valhall



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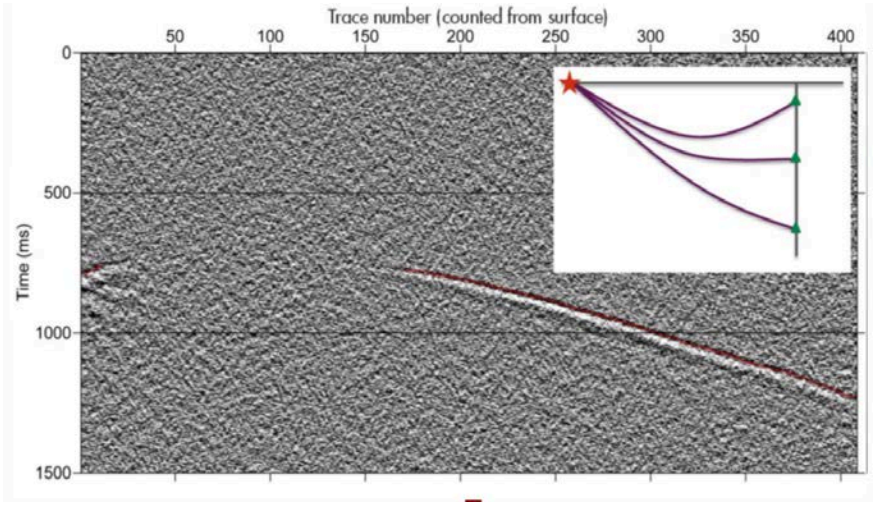
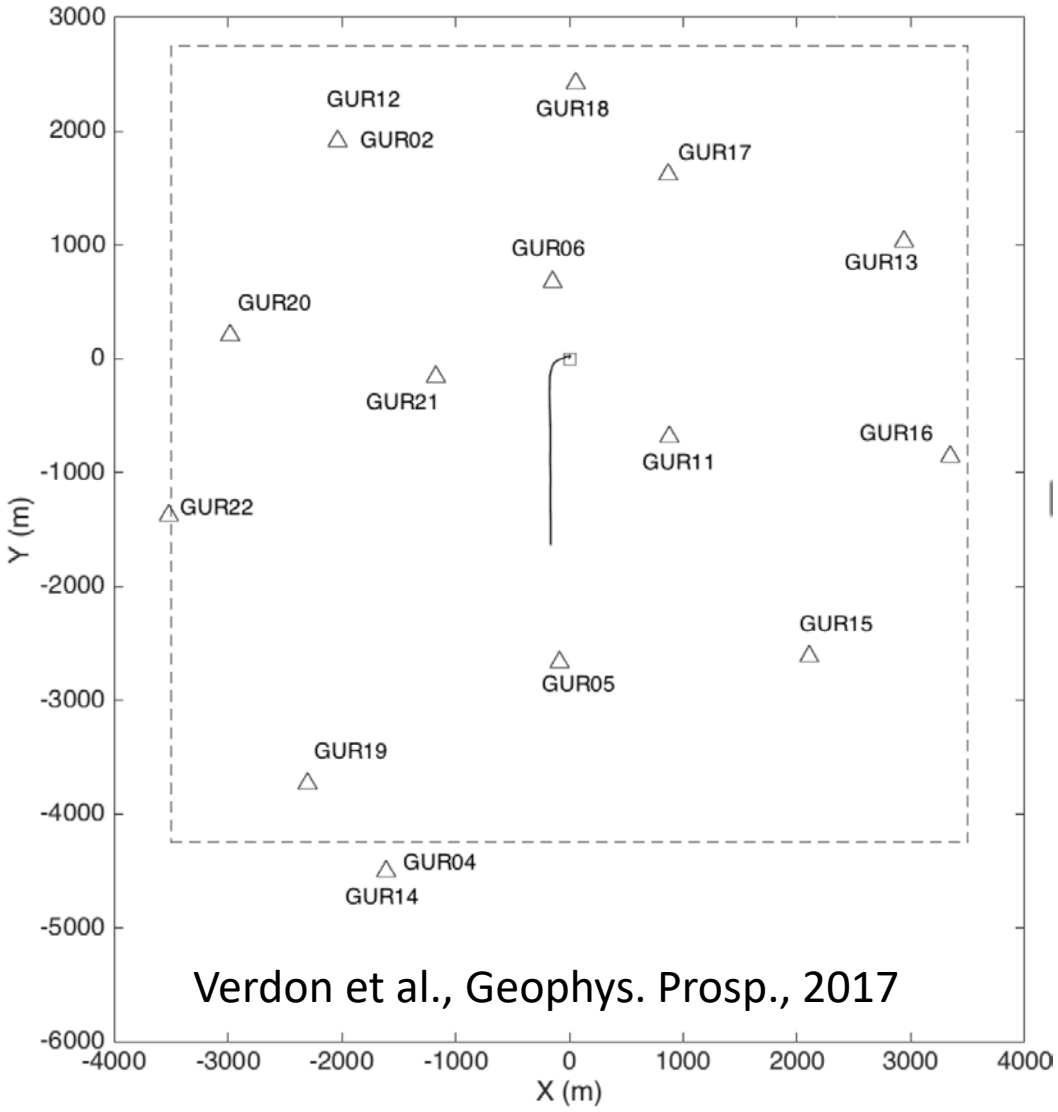
Monitoring with sparse arrays

- Better for long-term monitoring
- Ideal for baseline surveys
- Broadband instruments – better constraints on magnitude, stress-drops, tremor and LP signals.

DAS and fibre-optic cables present new opportunities





Verdon et al., Geophys. Prosp., 2017

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Monitoring world's largest CCS projects

Weyburn: old, depleted oil reservoir

- Events not near injector; modest amounts of seismicity; single well, sparse array

In Salah: gas field; CO2 injected into water leg of reservoir; monitoring with a single sensor

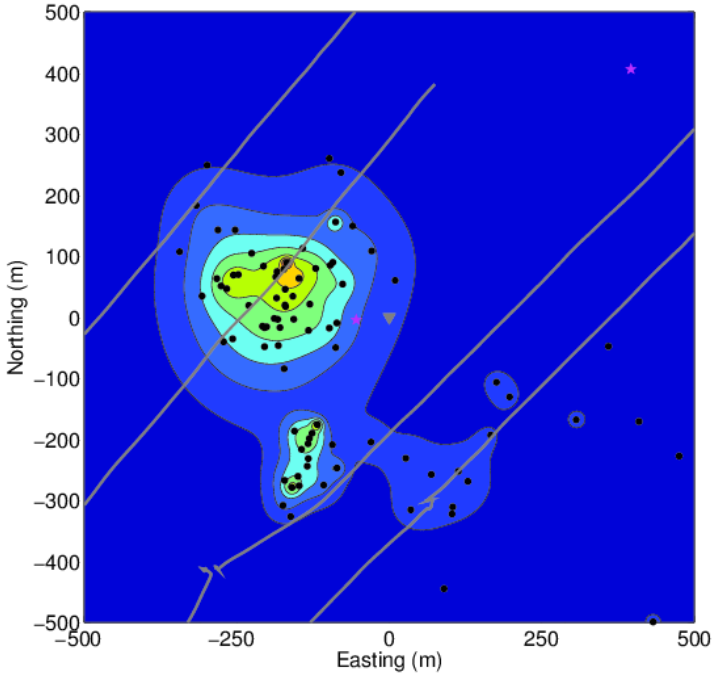
- ~10000events/yr; -1.0<Mw<1.7

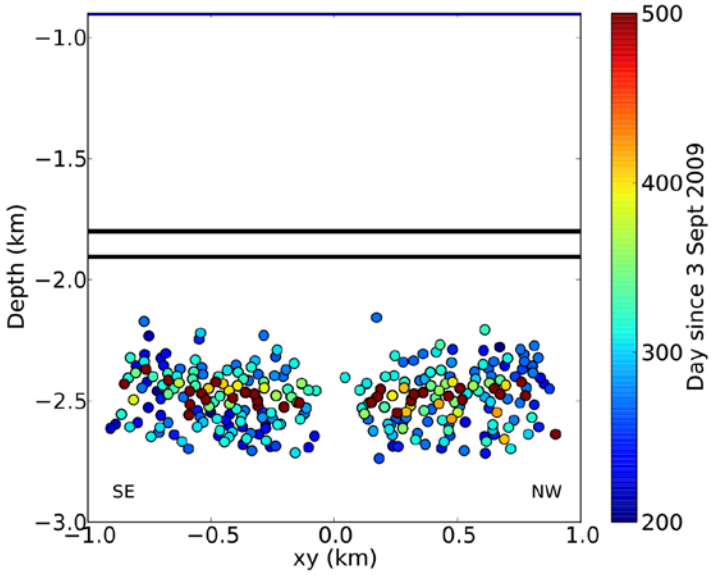
Sleipner: saline aquifer

- No microseismic monitoring

No evidence of leakage; poor passive seismic monitoring in all cases

Need 1000s of Sleipner's to accommodate worlds current CO_2 emissions





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See Verdon et al., PNAS, 2013

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Conclusions: Passive Seismic Monitoring

- CCS projects will aim to minimise geomechanical deformation, so ideally aseismic
- Passive seismic monitoring serves as an ‘early warning’ for leakage
- Serves to calibrate geomechanical models; important for long-term predictions
- Weyburn, In Salah and Sleipner: 3 very different geomechanical settings, 3 very different responses
- Seismicity can be used as imaging tool – numerous seismic attributes (*b*-values, fracture induced anisotropy, plume migration, stress changes)
- Need good baseline survey - need fit-for-purpose seismic monitoring array
- Learn to lean. Better to over-engineer early on – a felt seismic event is one of the single biggest threats to acceptance of CCS