THE UNIVERSITY OF WESTERN AUSTRALIA

Natural & Induced Seismicity

Prof David Lumley, UWA Geophysics

Centre for Energy Geoscience

Natural & Induced Seismicity

- *What is 'Seismicity' ?*
- *What are the causes of Seismicity?*
- *How do we measure Seismicity?*
- *How can Seismicity be useful?*

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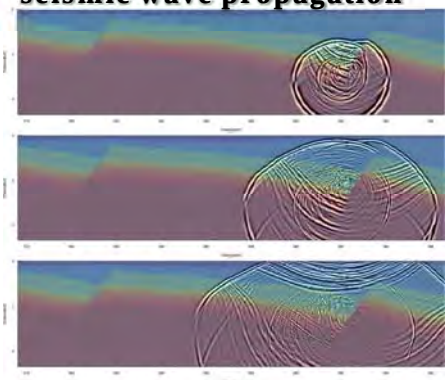
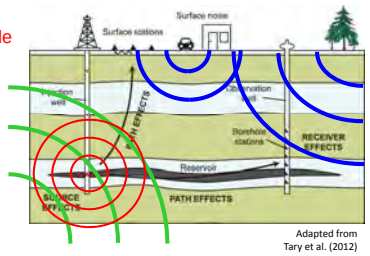
seismic wave propagation



What is seismicity?

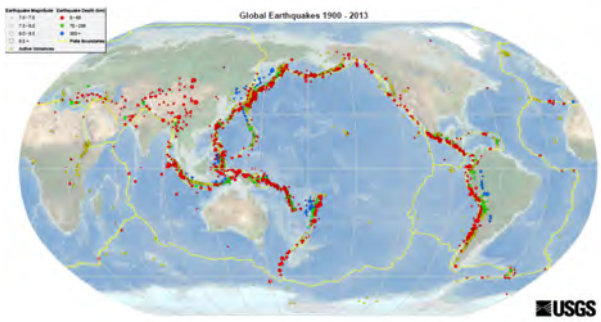
Seismicity

- Natural earthquakes
- Ambient noise
- Induced man-made

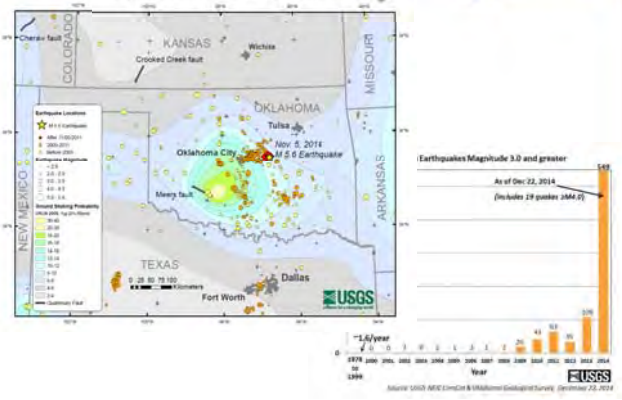


Adapted from Tary et al. (2012)

World seismicity map



Induced seismicity



Natural & Induced Seismicity

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$$\textbf{Stress} = C_{ijkl}\ \textbf{Strain}$$

Force on Surface Area, Pressure…

Deformation, Fracturing, Displacement, slip, Ground motion…

$$\textbf{Stress} = C_{ijkl}\ \textbf{Strain}$$

Rock + Fluid properties, Compressive strength, Tensile strength, Shear strength…

No Seismicity

$$\delta\textbf{Stress} = C_{ijkl}\ \delta\textbf{Strain}$$

Small changes δ : no seismicity

Seismicity

$$\Delta\textbf{Stress} = C_{ijkl}\ \Delta\textbf{Strain}$$

Large changes Δ : seismic energy source!

Natural Seismicity

$\Delta Stress = c_{ijkl} \Delta Strain$

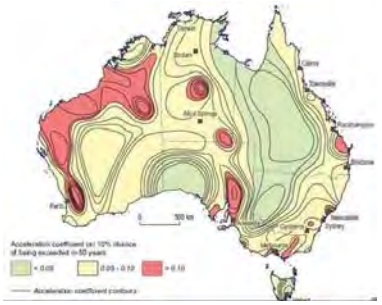
Applied force on surface area
Stress/pressure change…

Tectonic motion…
Deformation
Fracturing, faulting
Fault slip (reactivation)

San Andreas fault

Lundgren, 2014

the Darling Fault is > 1By old, and is a potential source for fault reactivation and seismicity...



Geoscience Australia

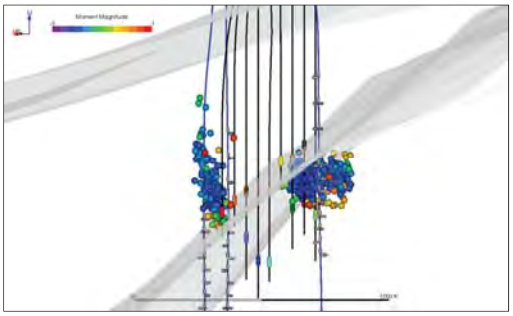
Induced Seismicity

$\Delta Stress = c_{ijkl} \Delta Strain$

Δ Pore pressure
Fluid injection (water, CO2…)
Fluid withdrawal (water, oil, gas…)

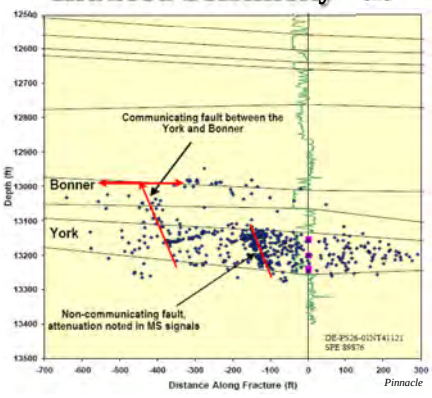
Deformation
Fracturing
Fault slip (reactivation)

Induced Seismicity



ESG, 2015

Induced Seismicity



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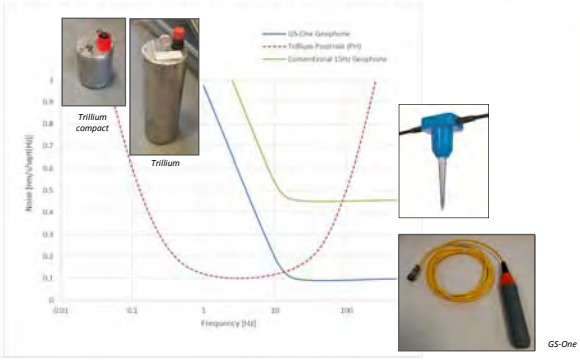
Geophones: ground motion sensors



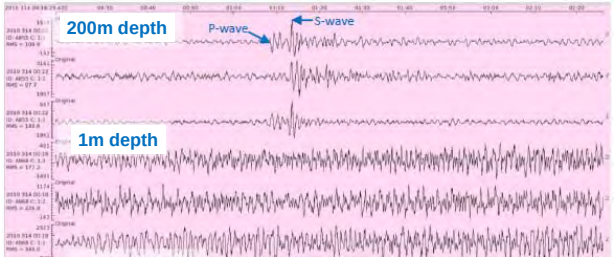
Phase 1

Langhi et al. (2013)

SWHub borehole monitoring station

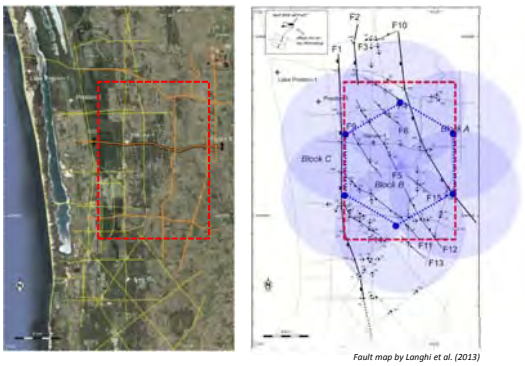
UWA seismic station

100x S/N improvement @ 200m depth



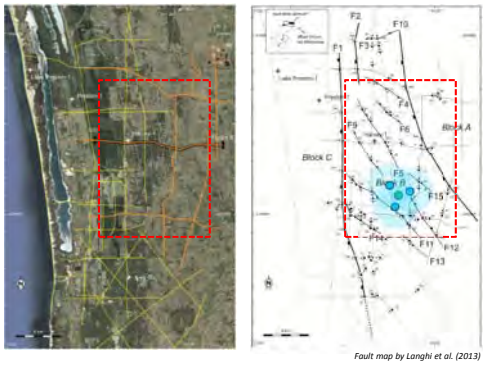
UWA, IESE

Phase 2



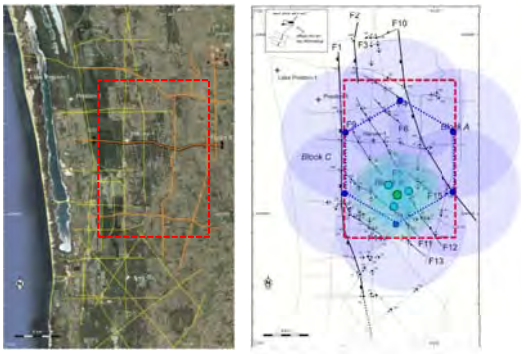
Fault map by Langhi et al. (2013)

Phase 3

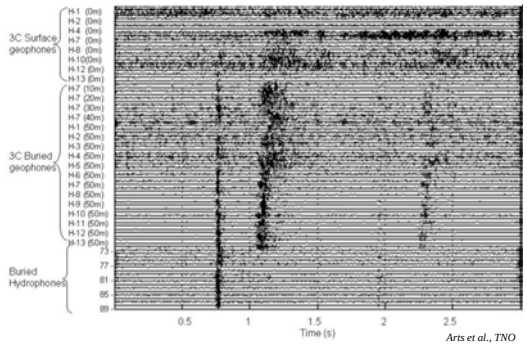


Fault map by Langhi et al. (2013)

Phase 1 + 2 + 3

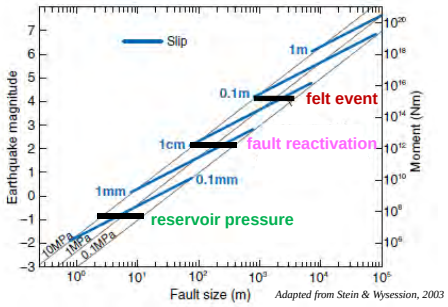


Ketzin CCS project, Germany



Arts et al., TNO

Natural and Induced Seismicity



Adapted from Stein & Wysession, 2003

$$M_w = 2/3 \log(M_o) - 6.07$$

Moment Magnitude

$$M_o = \mu A d$$

Seismic Moment

Natural & Induced Seismicity

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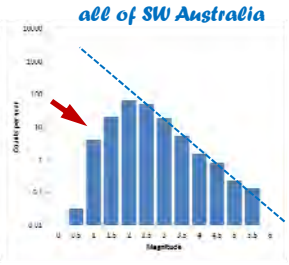
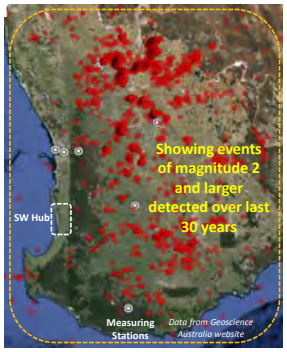
Passive Seismic monitoring objectives

- **Natural seismicity**
  - *Quantify background seismicity and assess seismic risk (PSHA)*
  - *Characterize 'in situ' stress regime (S_v, S_{Hmax}, S_{hmin})*
  - *Constrain geomechanics of faults, fractures, reservoirs, seals…*
- Ambient noise
  - *'Light' footprint, sparse 3D structural imaging & velocity analysis*
- Induced seismicity
  - *Track CO2 injection pressure & saturation fronts*
  - *Monitor faults, fractures, seals, non-containment…*
  - *Early warning system: monitor & mitigate.*

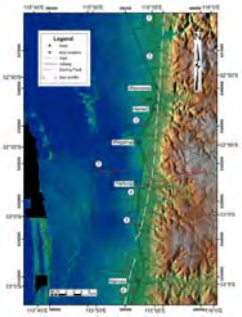
Natural seismicity



Issa & Lumley, 2014



These are our (Lumley et al.) current best estimates for natural seismicity in the SW Hub area… but we need more data!



Geoscience Australia

M7	~150,000 yrs
M6	~15,000 yrs
M5	~1,500 yrs
M4	~150 yrs
M3	~10-20 yrs
M2	~1-2 yrs
M1	~1-2 months
M0	~1-2 weeks
M-1	~1-2 days

Lumley et al, 2015

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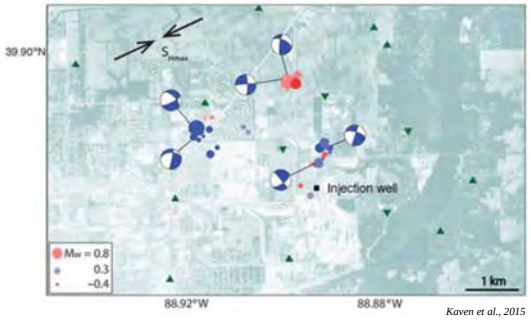
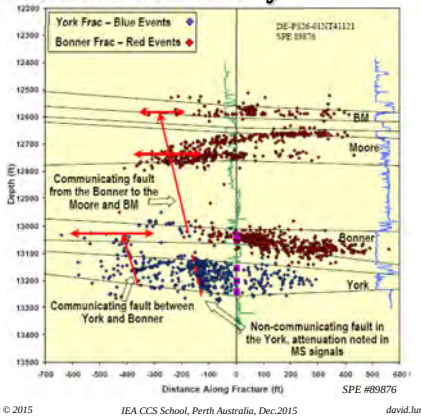
Decatur IL CCS project



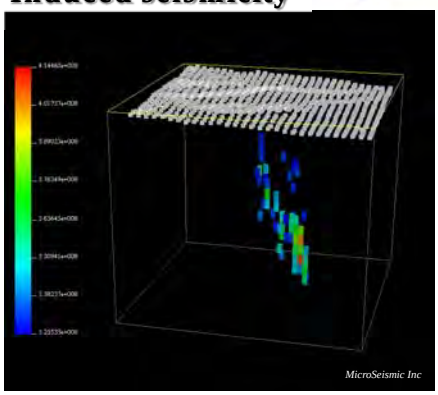
Kaven et al., 2015

Induced seismicity



SPE #89876

Induced seismicity



Seismic Risk

Risk = Probability x Impact

Risk = Probability x Impact

Likelihood of an M_w event

Estimate requires:
Seismology, Geophysics, Geology, Engineering…

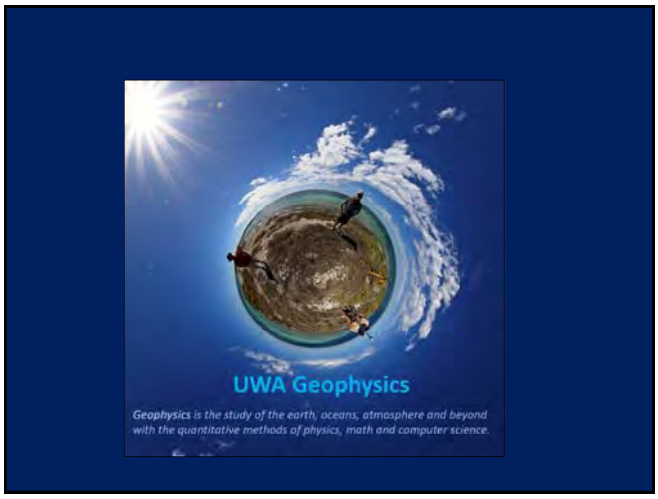
Risk = Probability x Impact

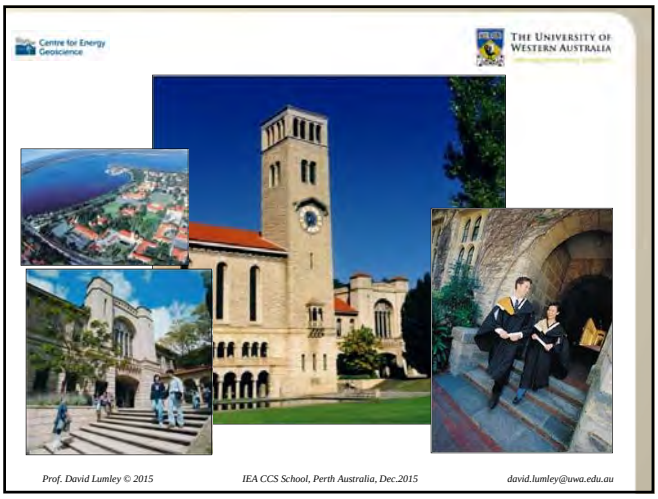
Possible impacts:

•Borehole damage	>M2
•Felt event	>M3,4
•Lose social license	>M4
•Project shutdown	>M5
•Physical damage	>M6
•Loss of life…	>M7

Risk = Probability x Impact

$$$
HSE
Reputation
Social license
Project shutdown
Loss of life…


UWA Geophysics
Geophysics is the study of the earth, oceans, atmosphere and beyond with the quantitative methods of physics, math and computer science.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IEA CCS School, Perth Australia, Dec.2015
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