Passive seismic monitoring of CO_2 sequestration

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Microseismic Monitoring - talk outline

- What is passive seismic monitoring?
- Motivation for passive seismic monitoring.
- The passive seismic toolbox: Examples from passive seismic monitoring in other fields
  - Event location
  - Focal mechanisms
  - Anisotropy and fractures
  - Temporal variations due to stress changes
- Example from Weyburn CO_2 injection project.

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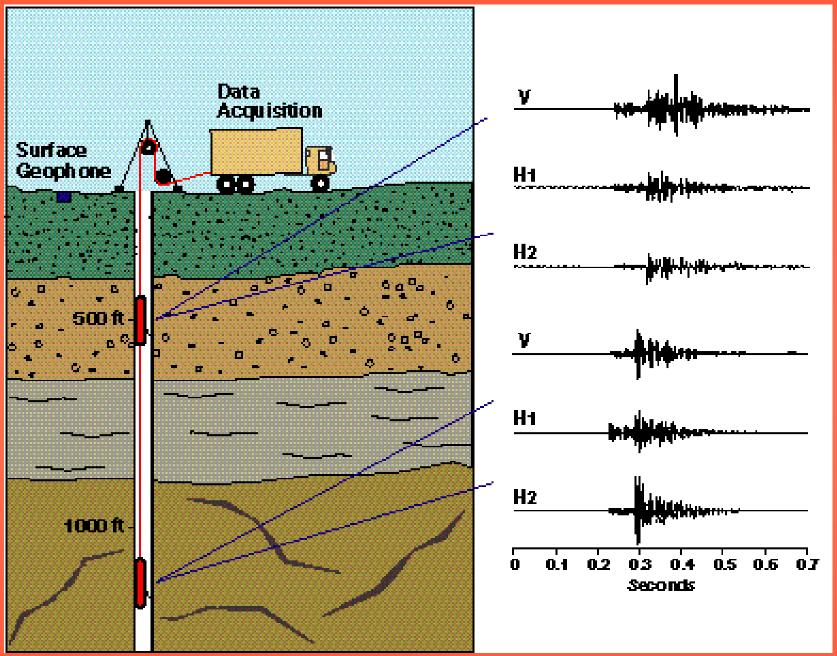
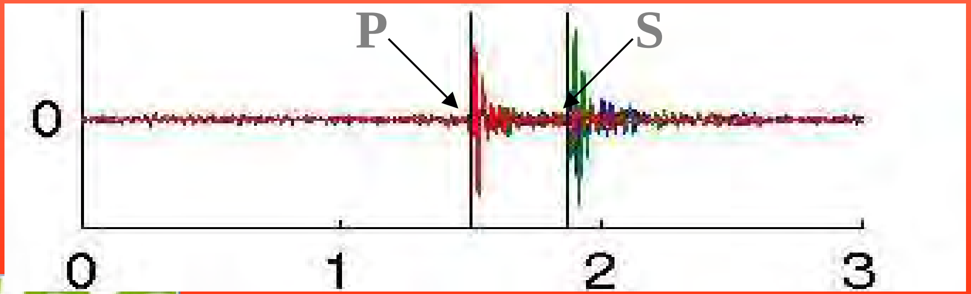
Passive seismic reservoir monitoring: Microseismicity



- 3C geophones installed in boreholes.
- Monitoring stress state of the reservoir.
- Imaging tool.
- Many applications from conventional earthquake seismology.
- Relatively new technology.



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Motivation for passive seismic monitoring

- 4D controlled source seismic experiments:
  - Expensive to run.
  - Return to field every 6/12 months.
  - Information from discrete time intervals only.
  - Information from all of field.
- Passive seismic monitoring:
  - Once installed, array requires little maintenance.
  - Data collection is automated.
  - Provides continuous information.
  - Information from active areas only.
- Prices:
  - Site specific but as a guide:
    - 1 sq mile 3D survey costs Can$110,000 without analysis
    - 12 level 3C geophone system inc data analysis costs Can$120,000

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Long-term CO_2 monitoring objectives

- Identify zones of CO_2 saturation.
- Identify fracture networks - flow pathways.
- Assess the risk of fault/fracture formation and activation and loss of top-seal integrity.

The microseismic toolbox - examples from other fields

- Location of events and clustering.
- Focal mechanisms.
- Anisotropy and fractures
  - Fracture orientation
  - Frequency dependence and fracture size
  - Temporal variations.

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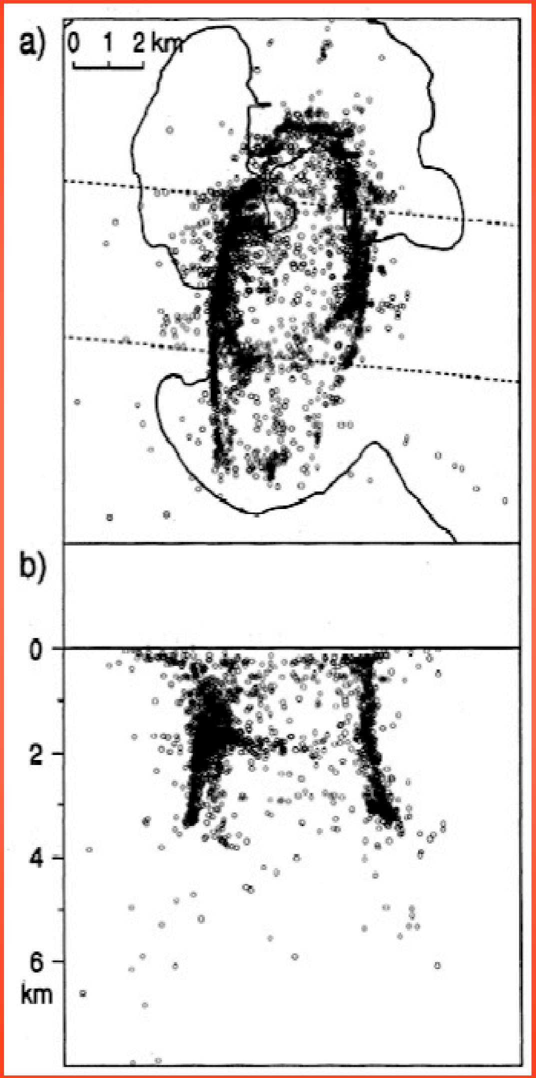
Location of events and clustering

- Crucial for further interpretation.
- Automated algorithms for multicomponent arrays are available (de Meersman 2006).
- Clustering can indicate reactivation of faults.

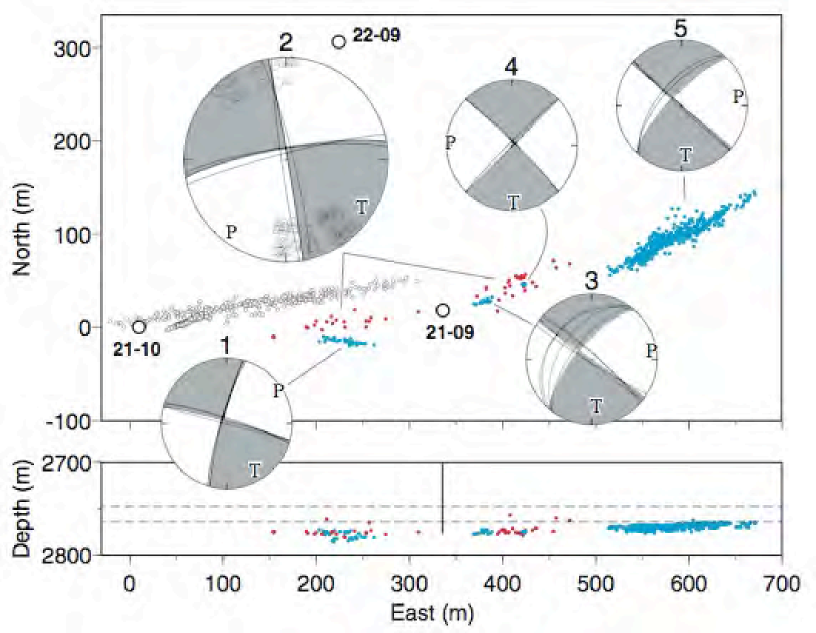


K. De Meersman, M van der Baan, JM Kendall 2006, BSSA v96

R.H Jones and R.C. Stewart 1997, JGR v102

Focal mechanisms

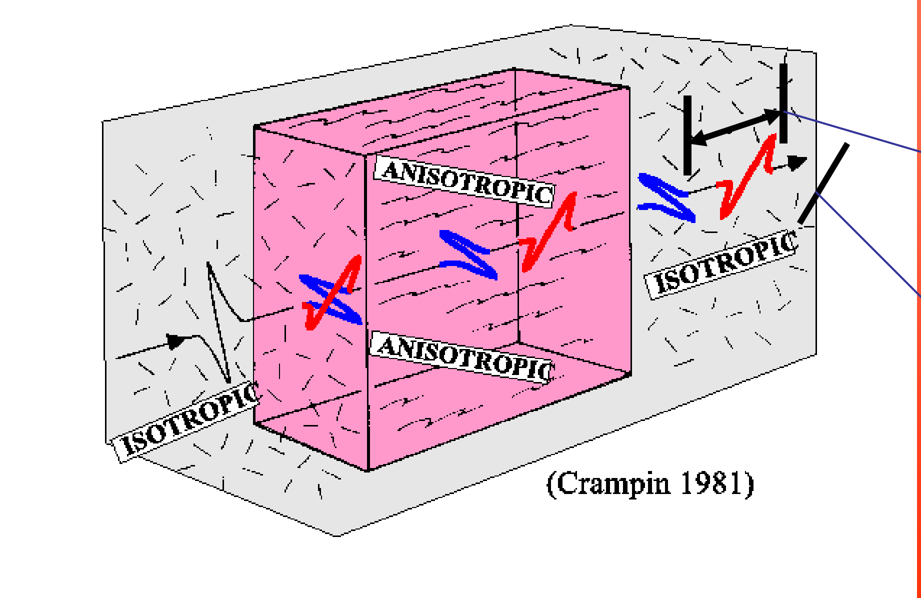
- Determination of focal mechanisms can indicate the nature of the effective stress changes and orientation of failure planes.
- Focal mechanisms determined by polarisation analysis of P and S waves assuming double couple (pure shear) source.
- Hydrofrac experiment (Rutledge et al 2004) - focal mechanisms show fault planes and directions of principle stress caused by water injection.



J.T. Rutledge et al 2004, BSSA v94

Anisotropy and shear-wave splitting

- Indicator of order in a medium.
- Indicator of style of flow, stress regime or fracturing.
- Insights into past and present deformation.
- Major source of anisotropy in reservoir rocks is fracturing.
- Effect of fractures on anisotropy can be predicted using effective medium theory (e.g. Hudson *et al* (1996).



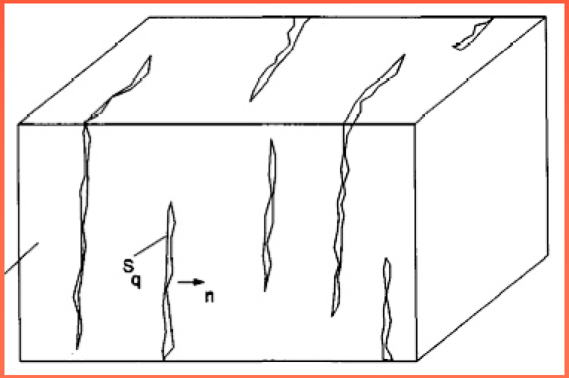
Shear-wave splitting

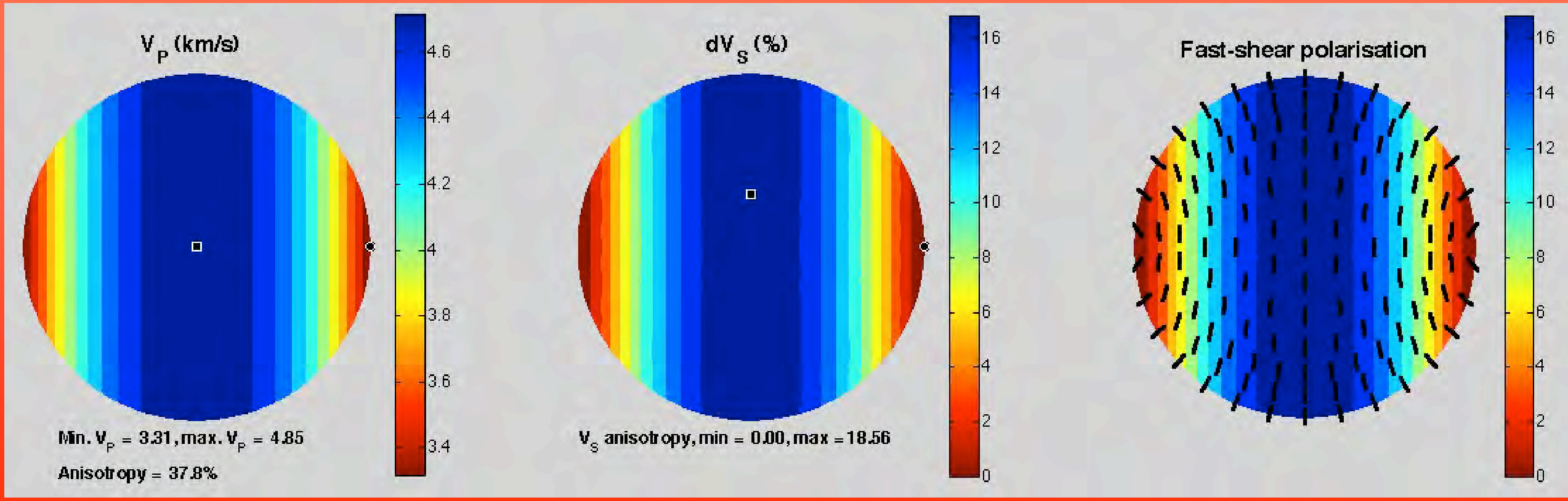
Time lag between fast and slow phases, Δt

Polarisation of fast phase, ϕ

Anisotropy and shear-wave splitting

- The presence of aligned mineral fabric and/or cracks can lead to elastic anisotropy.
- This can be modelled with effective medium theory (e.g. Hudson *et al* 1996)

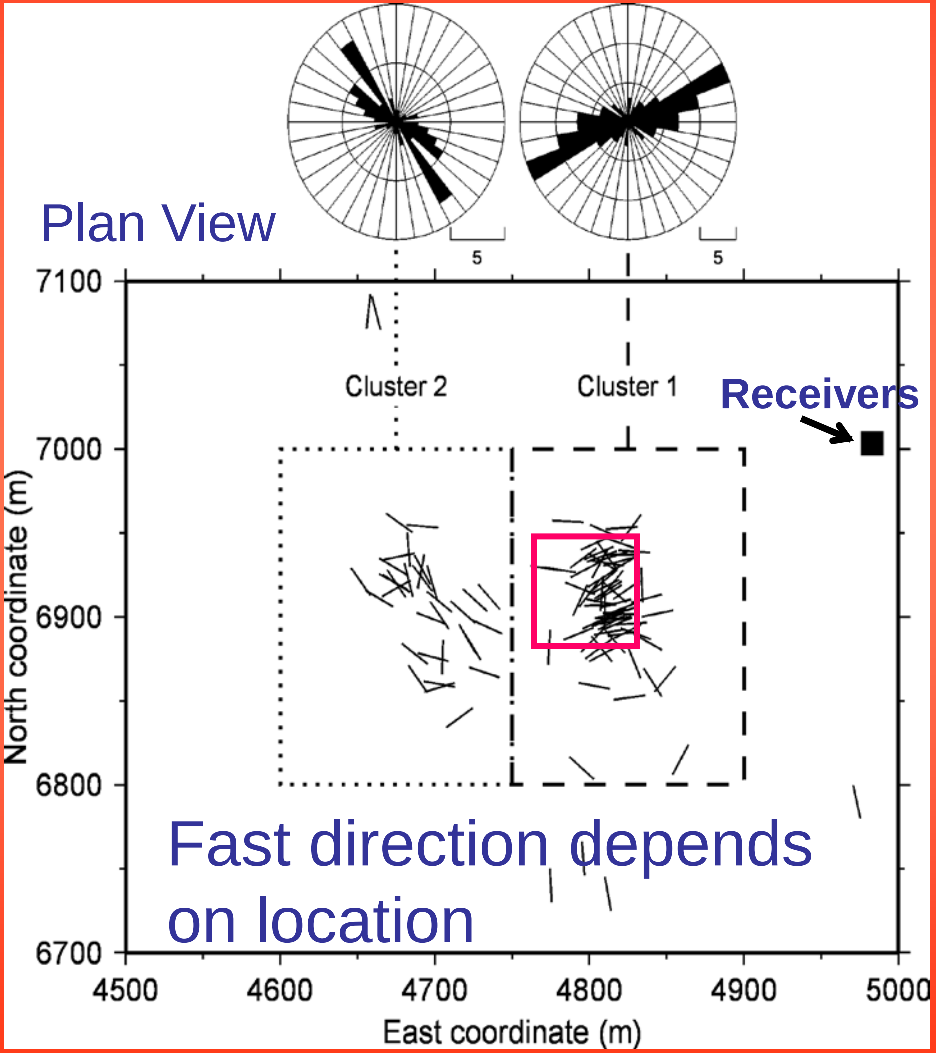




Splitting results - location and fast direction

Valhall field

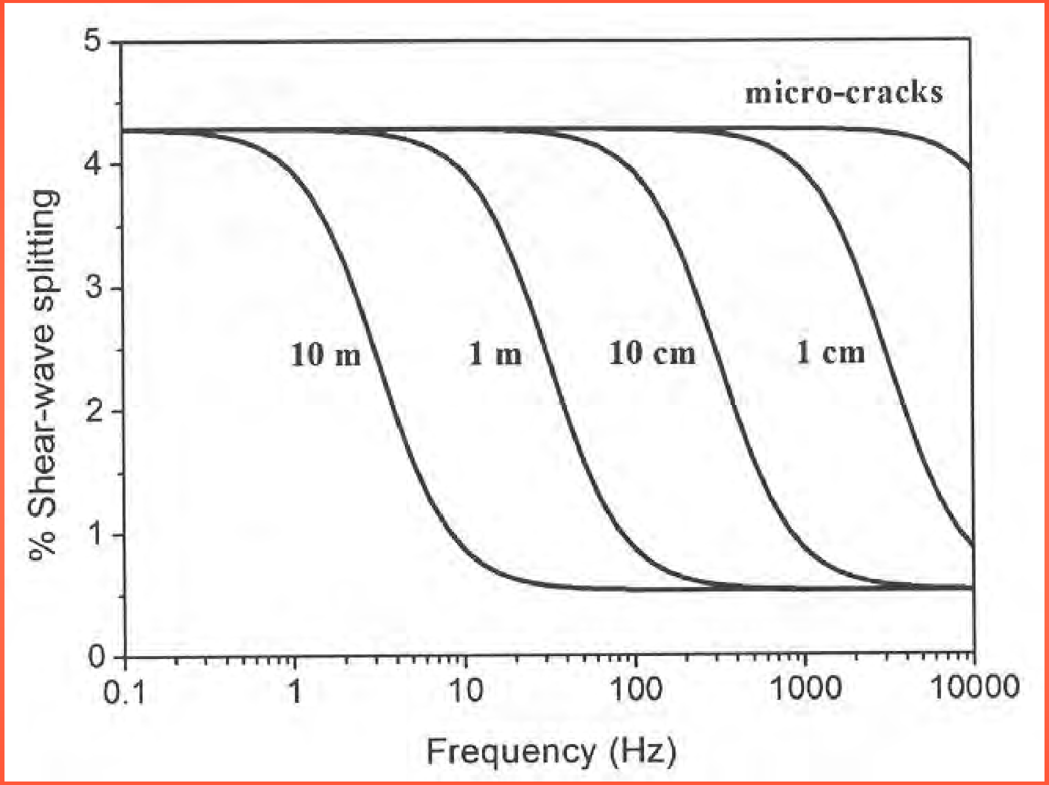
- Two distinct clusters of events. Fast polarisation is spatially dependent.
- Teanby *et al* use an effective medium approach to determine the density and orientation of cracks in the reservoir.



N. Teanby et al 2004, GJI, v156

Fracture size estimation using frequency-dependent shear-wave splitting.

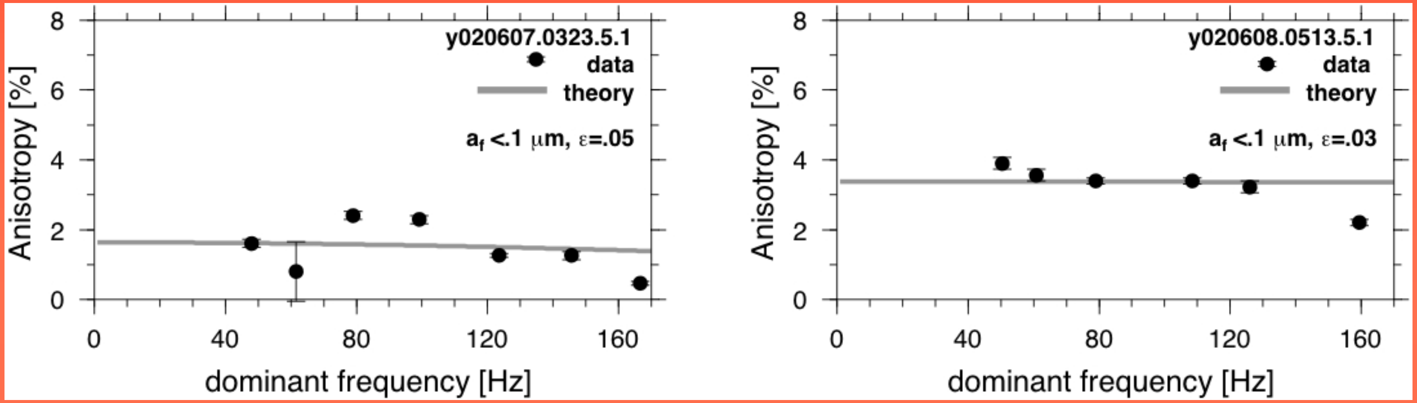
- Due to scattering by inhomogeneities or fluid flow (squirt flow).
- Transition frequency is a function of crack size.
- Modelling is dependent on: fluid properties (bulk modulus), porosity, crack dimensions, relaxation time (permeability and fluid viscosity) (Chapman, 2003).
- This is potentially very useful in assessing cap-rock integrity in CO_2 reservoirs.



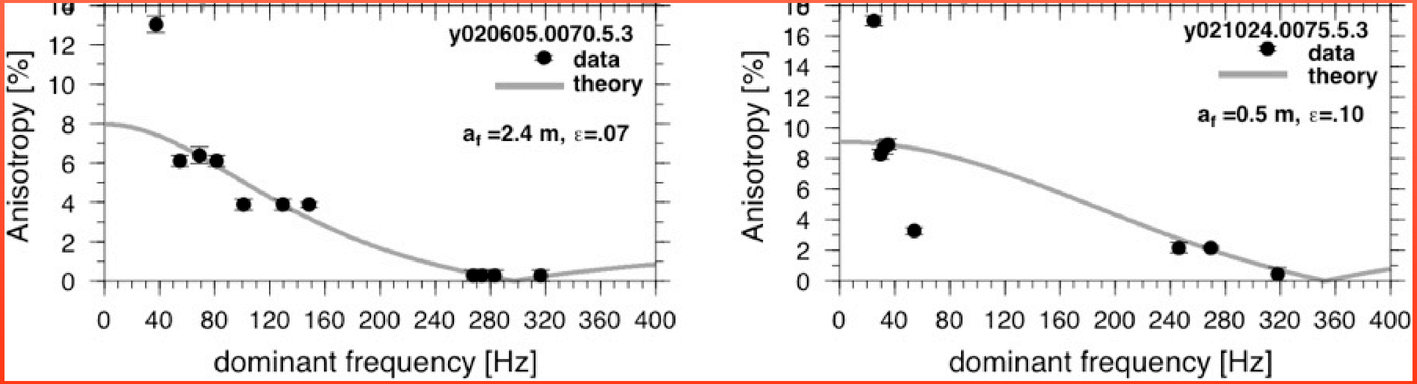
Chapman 2003, Geophys Pros, vol 51

Yibal - frequency dependent shear-wave splitting and fracture size

- Caprock: No frequency dependence - suggests length scales smaller than 1μm - rock is acting as a seal.



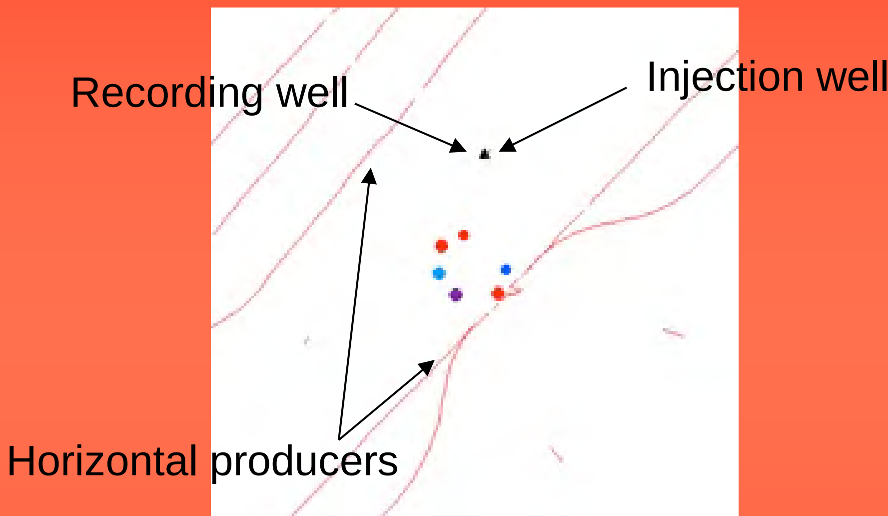
- Reservoir: Frequency dependence suggests fractures of ~1m scale, in agreement with outcrop and core analysis.



Weyburn CO_2 injection project, Canada

SEDIMENTARY BASIN

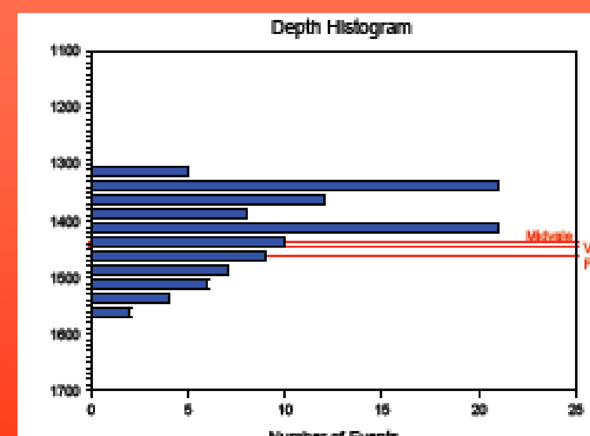
Weyburn CO_2 injection project, Canada



Geophone depths

#1	1356m	#5	1256m
#2	1331m	#6	1231m
#3	1306m	#7	1206m
#4	1281m	#8	1181m

Reservoir depth: 1440-1470m



- Phase 1A - Aug 2003 to Nov 2004.
- Geophones operational 15/08/03.
- CO_2 injection initiated Jan 2004.
- ~ 60 events recorded during injection period.

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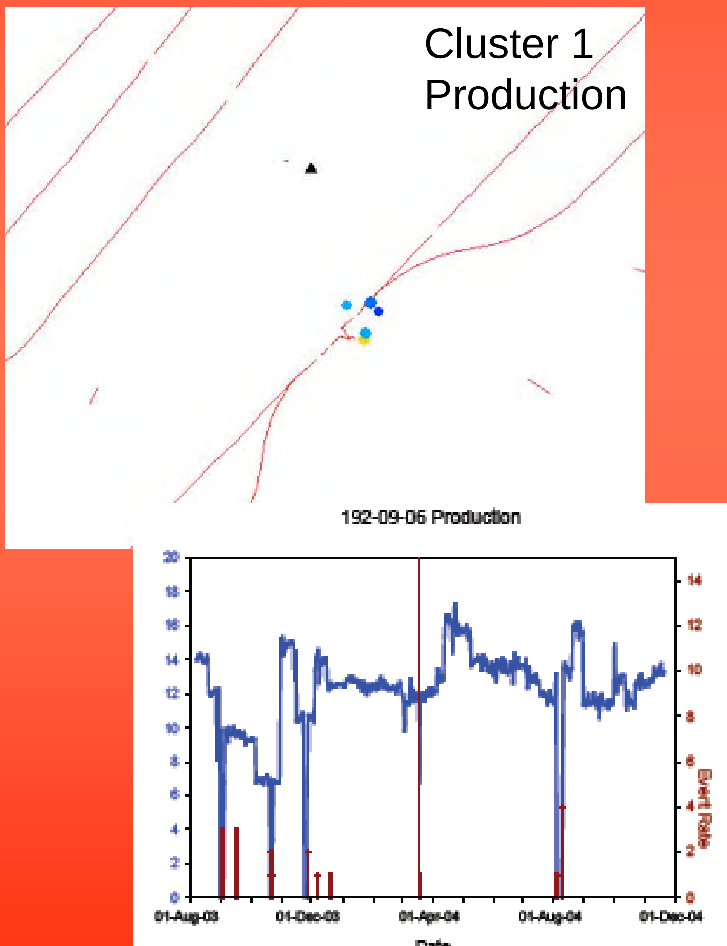
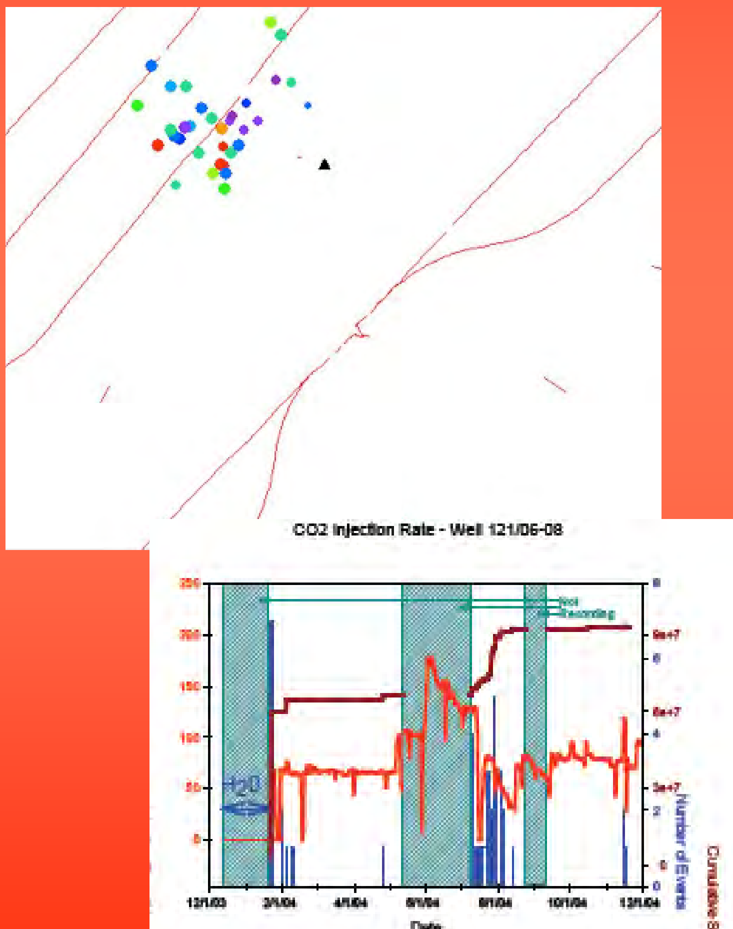
Weyburn CO_2 injection project, Canada



Cluster 1

- Centered around horizontal production well to the SE.
- Microseismicity appears to be associated with periods where production is stopped.
- Likely to be caused by a pore pressure increase.
- Shear wave splitting has been analysed but low event frequency has made any concrete conclusions difficult. Evidence for vertical fracture sets.

Weyburn CO_2 injection project, Canada



Cluster 2

- Located between injection well and producer to NW.
- Microseismicity appears to be associated with higher CO_2 injection rates.
- Communication between injector and producer via fractures.
- Relatively few events - agrees with observations from geomechanics that the reservoir is stiff and unlikely to deform. Hence, the caprock will retain its integrity.

Future Work - The Next Step

- Currently working with IPEGG to generate geomechanical models of CO_2 injection.
- Developing realistic rock physics models to map geomechanical predictions into changes in seismic properties - building 3D fully anisotropic elastic models that incorporate the effects of stress (or strain) on elasticity.
- Geomechanical models should allow us to anticipate deformation and assess the risk of fractures/faulting pentrating the top-seal. We hope to compare these predictions with observed microseismic activity.

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Conclusions

- After initial installation, can monitor cheaply for long periods.
- Most hydrocarbon companies have some passive seismic capability.
- Of particular concern for CO_2 sequestration is deformation and/or fracture networks leading to loss of overburden integrity.
- The passive seismic monitoring toolbox contains many useful mechanisms for assessing reservoir dynamics, and hence has the potential assess the risk of CO_2 leakage.
- At Weyburn, activity rates are very low, suggesting that any stress changes are well within the yield envelope.

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Thanks, any questions?

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