Passive Seismic Monitoring: Listening for the Snap, Crackle, Pop

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Outline

• What is microseismic activity?
• Where else is it used?
• What causes microseismic activity & what does it tell us?
• Hardware Options
• Potential Workflow
• Integration with geomechanical modelling
• Feasibility Studies
• Conclusions
What Is Microseismic Activity?

- Microseismic monitoring is based on global seismology
  - P- and S-wave arrivals are used to locate an event in x, y, z space
What Is Microseismic Activity?

- Micro-earthquakes: Detected by Surface Sensors
- Earthquakes: Felt by Humans
- Detected by Downhole Sensors

Ritcher Magnitude vs. Frequency (Log_{10})

-3 -2 -1 0 1 2 3 4

Earthquakes
Felt by Humans
Detected by Surface Sensors
Detected by Downhole Sensors
Where Else Is It Used?

- Mining Industry
- Geothermal Industry
- Underground waste disposal  
  - Could be fluids or cuttings
- Geotechnical projects  
  - Slope stability, dams, tunnel stability
- Hydrofracture monitoring

Courtesy of Natural Resources Canada
Mining

- Monitor 4D stress release
- Caving
- Underground gas emissions
- Rock burst prediction
- Slope stability

Courtesy of ISS International
What Causes Microseismic Activity?

- Associated with brittle deformation
- Caused by stress changes related to production or injection
- Events may occur on failure surfaces such as faults and fractures
- May be related to stress transfer to the surrounding rock bodies
Potential Reservoir Information

- Event location
- Orientation of failure surface
- Mode of failure
- Shear wave source

Hodograms: Direction & Location

- P-timing
- S-timing

Polarity

- Fault plane solutions
- Fracture orientation

Source Params
- Amp
- Freq

Sheet wave splitting

Reservoir Properties

Distance to Location

P to S delay

Duration

Amplitude

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What Can We Monitor With It?

- Cap rock integrity
- Fault/ fracture re-activation or propagation
- Can reveal fractures and compartments on a sub-seismic scale
- Fault transmissibility
- May image the pressure fronts associated with fluid movement
- Monitor deformations that may result in well integrity problems
What Can We Monitor With It?
Hardware Options

- Seismometers at the surface
- Geophones in monitor wells: temporary to permanent
Potential Workflow

1. Begin Initial Site Characterization & Data Acquisition
2. Build Initial Geomechanical Model
3. Conduct Microseismic Feasibility Study
4. Design Geophone Array For Passive & Active Seismic Monitoring
5. Begin CO₂ Injection
6. Analyze Microseismic Data
7. Update Geomechanical Model & Microseismic Modelling
8. Install Geophone Array & Obtain Baseline Noise Profile
Integration With Geomechanics

Geomechanical modelling can:
• Predict stress changes with time
• Estimate future fault activity
• Risk analysis for wellbore stability

Microseismic data can:
• Verify & update geomechanical models
• Map how stress tensors change with time
• Indicate fault re-activation or generation

Vertical displacement
(Moment magnitude)
Initial Stress Orientation

From Visage
Change in Stress Orientation

N

Final State

From Visage
Feasibility Studies

- Geomechanical model
- Requires velocity model, well trajectory, operational info, etc
- Modelling can determine
  - Potential size of events detected with distance
  - Uncertainty in positioning
Conclusions

- Microseismic monitoring is an established technology in a number of other industries
- Microseismic installations can effectively be deployed to monitor a range of activity at CO₂ storage sites
  - Cap rock integrity
  - Illumination of sub-seismic features
  - Re-activation or propagation of faults/fractures
- Microseismic monitoring should be used in conjunction with geomechanical modelling
- Feasibility studies should be completed to ensure that the microseismic monitoring system meets objectives
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Find a couple of geophones

Connect 'em up

Chuck 'em in a well

BINGO!

SORTED

New Permanent Technology development meeting (Acme Tools Ltd)