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NRAP Recommended Practices for Least Principal Stress ("Fracture Pressure") Characterization at Geologic Carbon Storage Sites

Jeff Burghardt[1]; Jean Desroches[2], Delphine Appriou[1], Wenjing Wang[1], Kayla A. Kroll[3]

1 Pacific Northwest National Laboratory, Energy and Environment Directorate, 902 Battelle Blvd, Richland, WA 99354

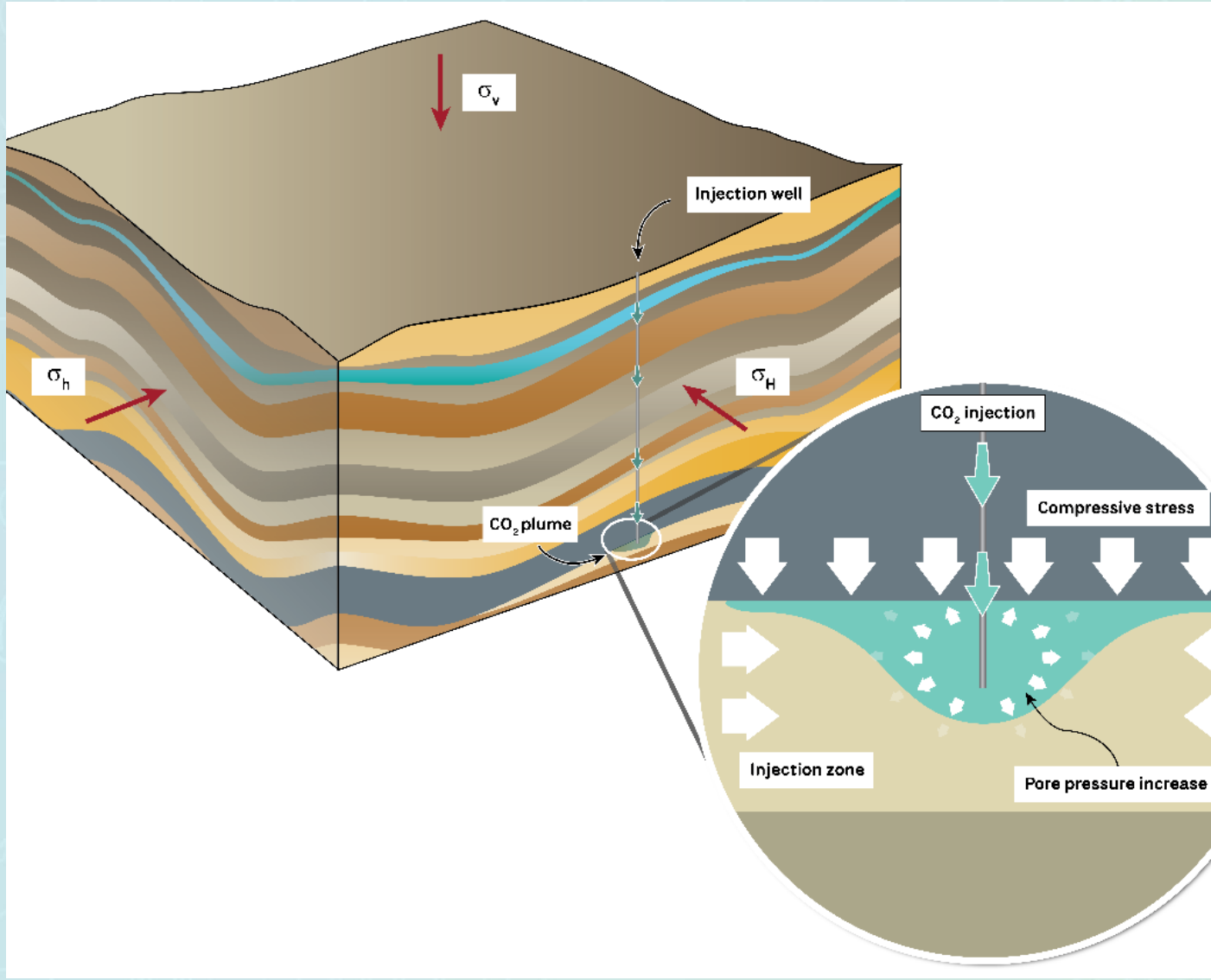
2 Rocks Expert SARL, 244 Chemin de Bertine, 04300 Saint-Maime, France

3 Lawrence Livermore National Laboratory, Earth and Energy Division, 7000 East Avenue, Livermore, CA 94550-9234

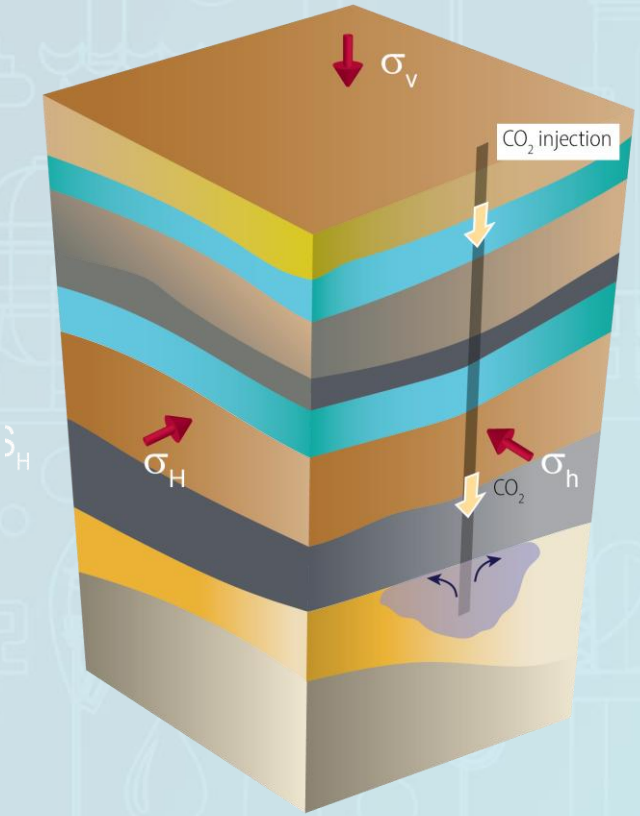
Outline

- Background
  - In-situ stress
  - Stress measurement approaches
- Recommended practices
  - Operational planning
  - Pre-test logging and zone selection
  - Fracturing procedure
  - Interpretation

- **Subsurface operations involving fluid injection, such as CO_2 injection, can alter in situ stress conditions by affecting pore pressure, which could potentially lead to:**
  - **Unintentional propagation of hydraulic fractures through the caprock**
  - **Fault or fracture slippage leading to possible leakage**
  - **Seismic events generated by seismic fault activation**

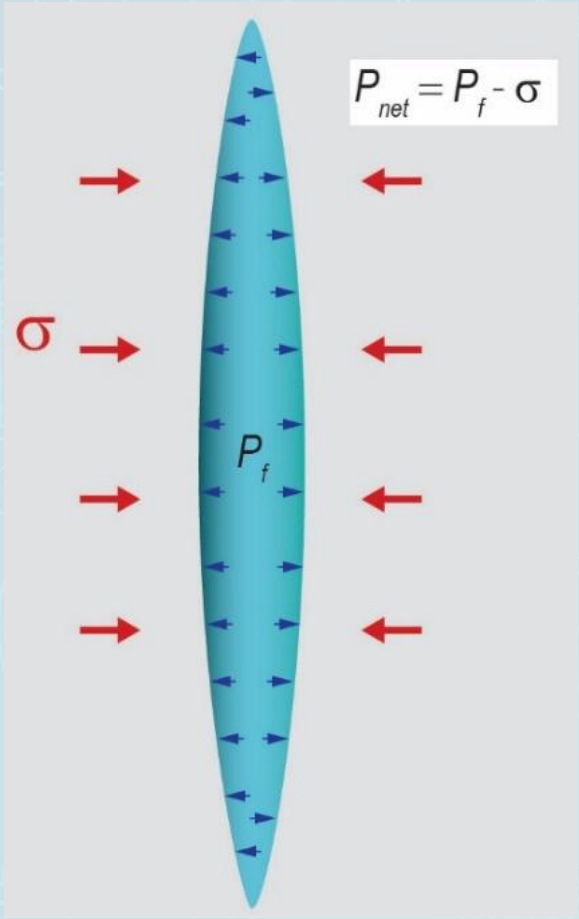


In-Situ Stresses



- Stress defined by three principal stresses and their orientations
- At depth, generally oriented vertical/horizontal

In-Situ Stresses

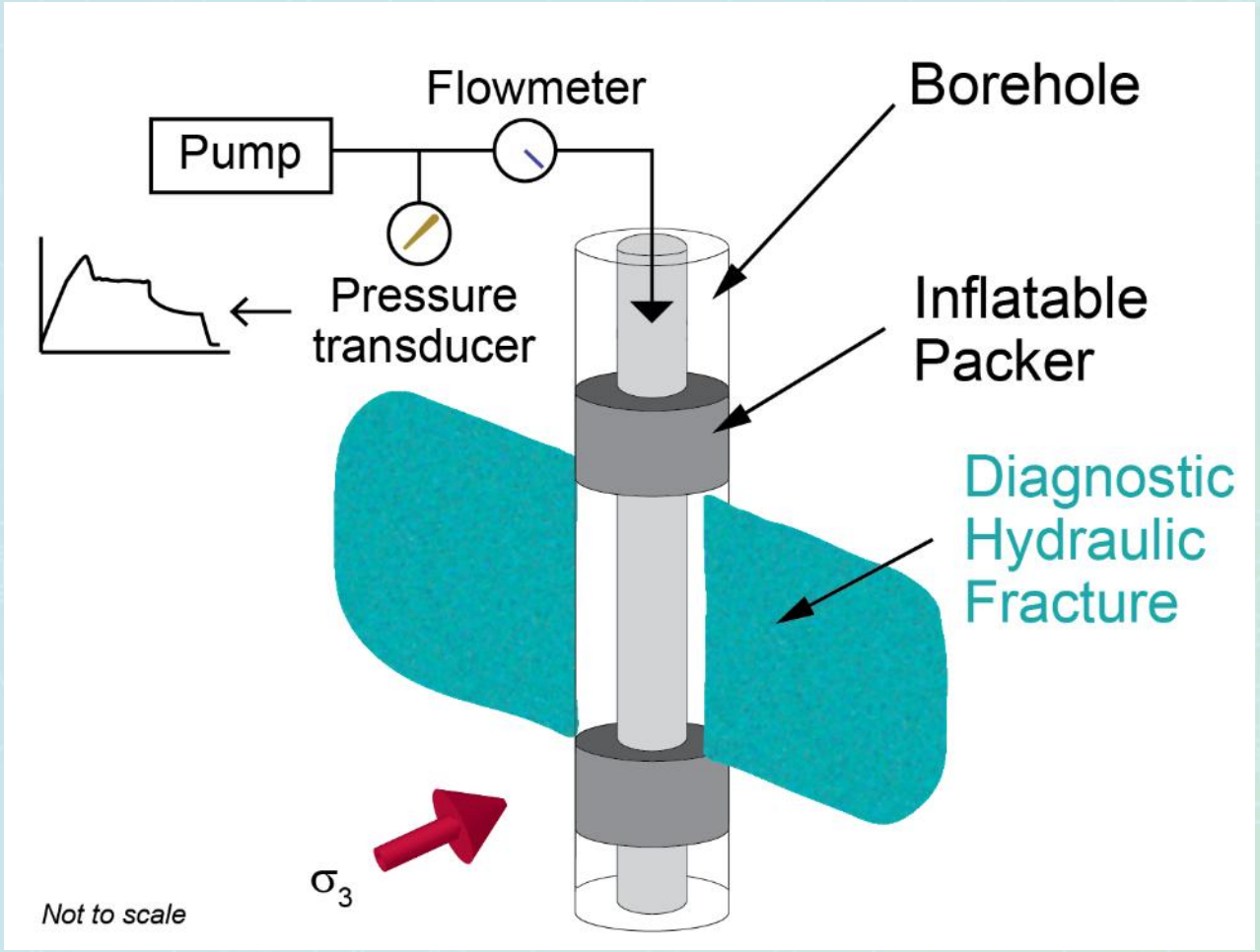


Factors controlling initiation and propagation of tensile fractures:

- **Magnitude of the *least compressive* principal stress**
- **Fluid pressure**
- **Material strength**

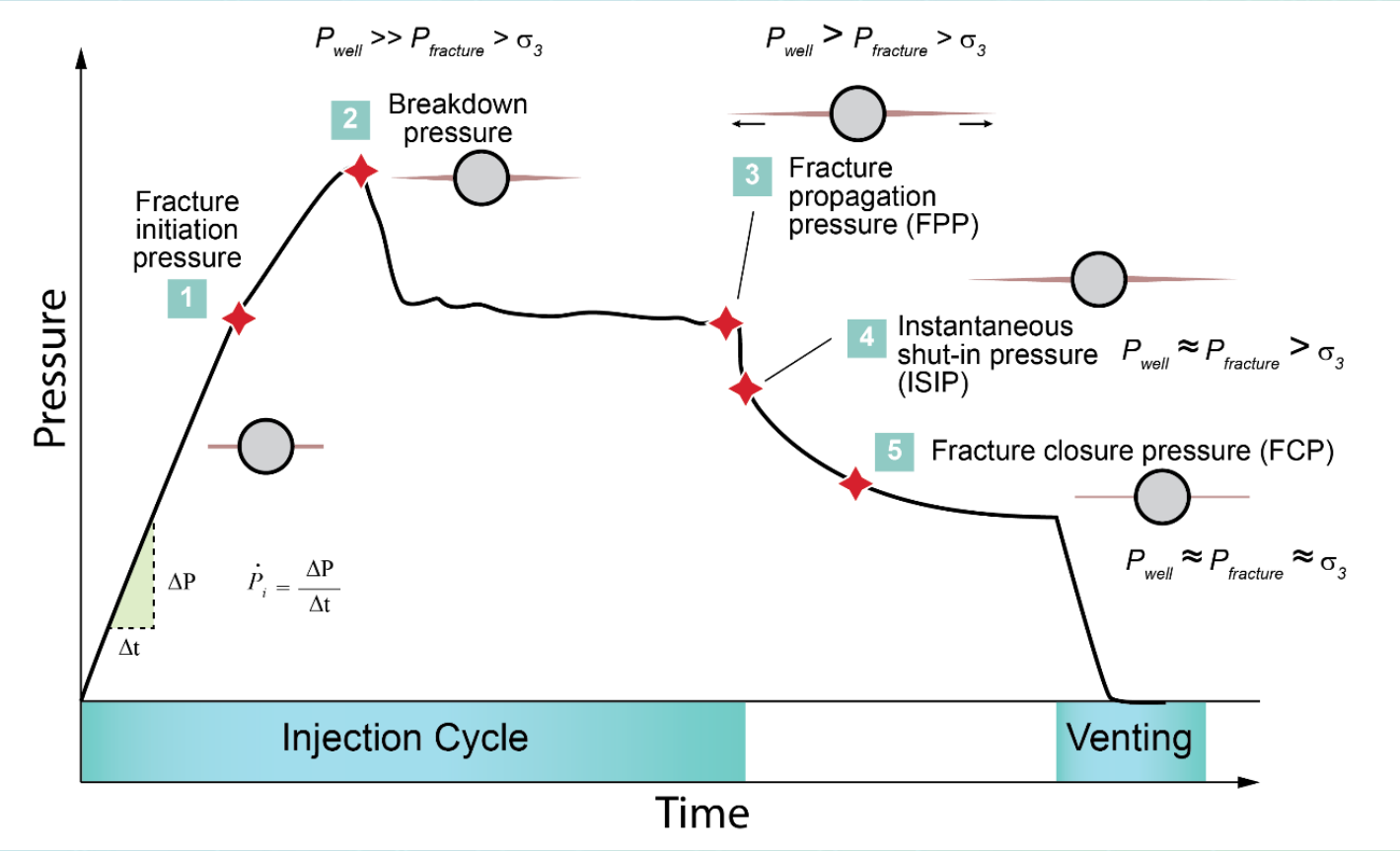
Stress Measurement Tests

- Hydraulic fractures are the most reliable method of measuring the least compressive stress magnitude at depth
- Can be performed in cased or open holes
- Can use downhole pump on wireline tools or surface pumping with drill pipe or coiled tubing
- Downhole pressure measurement critical



Stress Measurement Tests

- "Fracture pressure" is an ambiguous term
- Fracture closure pressure is the best estimate for the magnitude of the least compressive stress
- Fracture propagation pressure, ISIP, and breakdown pressures all over-estimate the stress magnitude
- Over-estimating stress magnitude increases risk of unintentional hydraulic fracturing during CCS operations



Step 1: Operational Planning

- Select equipment and deployment strategy
  - Pressure, capacity, integration with other testing
- Preliminary choice of testing parameters
  - Use analytical or numerical model to select fluid type, rate, and volumes
- Preliminary plan for number and locations of tests

Step 2: Pre-test Logging and Final Zone Selection

- Recommended logs:
  - Image log, multi-arm caliper, triple-combo, and ideally di-pole sonic
- Select final zones based on:
  - Hole conditions (informed by image and caliper)
  - Heterogeneity (image, density, neutron, GR, sonic)
  - Avoid existing fractures where possible
- Balance sampling heterogeneity and providing redundancy

Step 3: Fracture Initiation, Propagation, and Closure

- Propagate fracture to desired size in 3-5 cycles
- Inflate packers and perform slug test
- Propagate fracture, measure ISIP
- Pump-in/flowback and/or pump-in/shut-in tests to determine closure pressure
- Slam-back (rapid flowback) / rebound to verify existence of fracture

Step 4: Post-test Logging

- If test performed in open hole, recommend post-test image logging
- Identify existence and orientation of fractures

Step 5: Interpretation and Reporting

- Reconciliation plot with:
  - Fracture opening/re-opening pressure
  - ISIP
  - Fracture closure pressure
  - Rebound pressure from slam-back/rapid flowback test
- Look for consistency and convergence to confirm
  - Formation of fracture
  - Fracture has escaped stress concentration near wellbore

Conclusions

- Injection pressures should be below the magnitude of the least compressive principal stress
- Fracture closure pressure is the best estimate for the least compressive principal stress
- Shut-in decline or pump-in/flowback tests are recommended to measure the fracture closure pressure
- Fracture propagation pressures or instantaneous shut-in pressures (ISIP) are upper-bound estimates
- Upper-bound estimates may allow injection pressures to exceed minimum principal stress even with 10% safety factor