

Can controlled microseismic stimulation be used to enhance permeability in geological CO₂ sequestration targets?

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MOTIVATION & METHODOLOGY

ABSTRACT

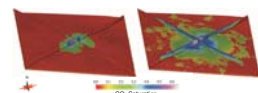
Deep saline rock formations have great potential for geologic sequestration of CO₂. As such units are widespread in many parts of the U.S. and the world, they are, in theory, easily accessed from point sources of CO₂, such as power plants, factories, refineries, cement plants, etc. Unfortunately, many deep saline rock formations of the mid-continental U.S. appear to have moderate to low porosity and permeability, there is limited injectivity and storage capacities (Lucier et al., 2006). A demonstration CO₂ sequestration project is proposed in the Michigan Basin, the Otsego County Test Site, as part of the Midwest Regional Carbon Sequestration (MRCSF) test site of the DOE/NETL regional carbon sequestration program. The potential targets for sequestration include several Paleozoic reservoirs that may have moderate to low permeability. In particular we analyze the Silurian Bass Island dolomite (BILD) at approximately 1050 m (3450 ft) depth. The source for this project is the associated CO₂ removed from the Antrim Shale gas at 6 centralized gas-processing plants in the Otsego and adjacent counties, which averages ~1.2 million metric tons per year. We propose a controlled microseismic experiment to enhance the permeability and injectivity of the target reservoir. The State Charlton 4-30 well will be used for injection, the State Charlton C3-30 well (approximately 150 m away) and the State Charlton 2-30 (approximately 550 m) away, would serve as excellent monitoring wells.

Microseismicity is induced by increasing the fluid pressure following hydraulic fracturing, thus reducing the effective normal stress on optimally-oriented faults and fractures triggering slip and creating high-permeability pathways within the reservoir. This technique is a frequent and safe practice for enhancing permeability and recovery in the oil and gas industry. We have developed a preliminary geomechanical characterization, that will be the base for the proposed experiment. To develop the geomechanical model, we analyzed FMI, density and sonic logs from two of the wells mentioned above as well as leak-off tests and pore pressure measurements from wells in the vicinity. This analysis also provided us with the theoretical pressure (P_t) needed to hydrofracture the target formation and the expected fracture direction propagation.

The field experiment would begin injecting several thousand m³ of CO₂ for several days into the Bass Island dolomite (at well 4-30) to first induce a hydraulic fracture and then induce microseismicity. An array of seismometers will be deployed in the two monitoring wells to record the induced events. Due to the very small magnitude (<1) of the triggered events, they cannot be detected with surface seismometers and require a borehole array.

Microseismic monitoring of this stimulation will provide valuable information on the resultant fluid-flow network of the reservoir, as well as characteristics of the hydraulic fracture itself. In addition to providing information about the reservoir and fracture properties, the results of this test will be used to empirically establish an upper-bound pressure for CO₂ injection for the sequestration phase to avoid accidentally inducing seismicity that might compromise the reservoir seal.

MOTIVATION & METHODOLOGY



Low porosity & permeabilities of some deep saline formations are one of the biggest challenges for CO₂ sequestration.

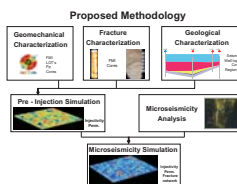
Microseismic stimulation is a frequent practice in the oil industry to enhance permeability (Phillips et al., 2002). Fluid injection reduces the effective normal stress on optimally-oriented pre-existing faults & fractures triggering slip, creating high-permeability pathways within the reservoir.

Microseismicity is mainly triggered by a diffusive process of pore pressure perturbation. The induced failure often occurs as a sequence of many very small events.

The volume of rock stimulated by hydraulic fracturing can be imaged by locating the microearthquakes (Albright & Pearson, 1982) to show the geometry of slipping fractures.

Some examples in sedimentary rocks: Frio sandstone, Cotton Valley tight gas sands; Carbonates: Austin chalk; low porosity carbonates in Clinton County, Kentucky; Crystalline geothermal hot-dry-rock: Fenton Hill, New Mexico; Soultz, France.

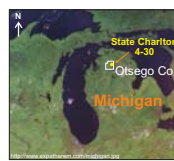
Yufutsu Oil & Gas field, Japan: injectivity increased eight times following a massive hydraulic injection (Tezuka, 2006).



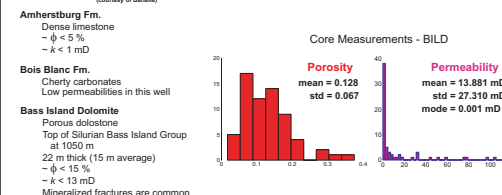
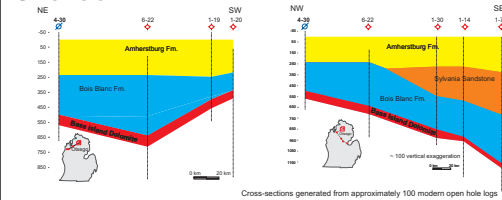
CASE STUDY & PRELIMINARY GEOMECHANICAL RESULTS

OTSEGO COUNTY TEST SITE

- NETL/DOE - MRCSF project to investigate CO₂ sequestration potential in Upper Silurian to Middle Devonian strata
- Sponsored by DTE ENERGY and Core Energy. It is located in the Charlton 3031 gas fields near a DTE gas processing plant (Turtle Lake)
- Pilot well Charlton 4-30 was drilled in Nov. 2006 to perform small injection test (~10,000 metric tons of CO₂)
- Source: Associated CO₂ removed from Antrim Shale gas (15-30% high purity CO₂) at 6 centralized gas-processing plants in Otsego and adjacent counties. Gas-processing plants in Otsego area ~1.2 million tonnes/year. Currently majority of CO₂ vented to atmosphere.
- Already compression & pipeline facilities in place EOR operation in Niagara Reefs for up to ~650 metric tonnes per day of CO₂.



GEOLOGY

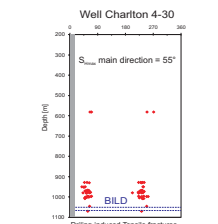


GEOMECHANICAL CHARACTERIZATION

Parameters to define the stress tensor

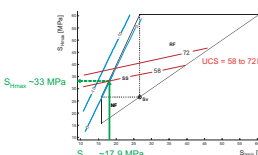
Parameter	Data
Stress Orientation	Orientation of wellbore failures
S ₁	S _{1(z),m} [psi-ft]
S ₂	LOT, XLOT, minifrac
S ₃	Modeling wellbore failures
Pore Pressure	Measurements, sonic logs
Rock Strength	Sonic Logs, lab. modeling
Faults & Fractures	Seismic, wellbore imaging after Zoback et al. (2003)

Stress Orientation From FMI logs



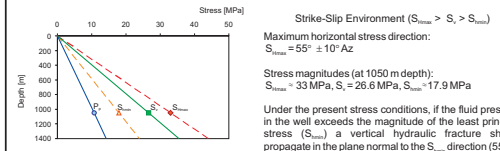
The average S₁ orientation estimated from the FMI analysis is: 55° ± 10° Az (red arrows in the map), which is in very good agreement with the regional stress orientations (modified from Reinecker et al., 2005)

- Assumptions & parameters for S₁ & S₂ estimation:
 - Present day Strike-Slip Faulting Environment - Drilling induce tensile fractures in wellbores
 - S₂ = 17.9 MPa (Haimson, 1978)
 - Rock Strength: 58 - 72 MPa
 - Computed from the following empirical relationships: 143.8 exp(-6.95k) + 143.8 exp(-4.8k) (Chang et al. 2006)



Range of allowable values for the horizontal principal stresses based on Coulomb faulting theory and Anderson's stress and faulting classifications system, provided depth, pore pressure and a particular coefficient of friction.

Summary of Stress State



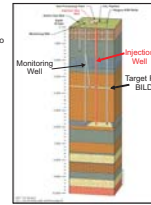
Under the present stress conditions, if the fluid pressure in the well exceeds the magnitude of the least principal stress (S₃) a vertical hydraulic fracture should propagate in the plane normal to the S₃ direction (55°)

EXPECTED RESULTS & SUMMARY

INJECTION EXPERIMENT

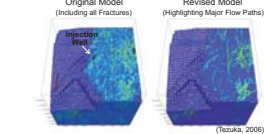
Injection and Monitoring Setup

Injecting several thousand m³ of CO₂ for three weeks. First induce a hydraulic fracture and then keep pumping at lower rate for several days to induce microseismicity. An array of seismometers will be deployed in the two monitoring wells to record the induced events. Due to the very small magnitude (<1) of the triggered events, they cannot be detected with surface seismometers and require a borehole array.



Expected Results

- Improve injectivity (increasing k)
- Field measurements for validation (wellbore tests)
- Analytical calculations
- Delineate fracture network geometry
- Post-stimulation modeling
- Constrain calculated permeability
- Improve fluid simulation with better k & fracture network geometry



SUMMARY

We propose an injection-induced microseismicity experiment to enhance the permeability and injectivity of the potential storage reservoir the Silurian age Bass Island dolomite (~1050 m depth) in the Michigan Basin.

In addition to the increase in permeability, microseismic monitoring of this stimulation will provide valuable information on the resultant fluid-flow network of the reservoir, as well as hydraulic properties of the reservoir.

The preliminary geomechanical characterization indicates a Strike Slip present day stress state. Under this conditions, at the interval depth, a vertical hydraulic fracture is expected to propagate in the plane normal to the S₃ direction (55° Az) if the injection pressure exceeds the magnitude of the least principal stress (S₃ ~ 17.9 MPa).

The results of this injection experiment will be used to empirically constrain the upper-bound pressure for CO₂ injection for the sequestration phase to avoid accidentally inducing seismicity that might compromise the reservoir seal.

Furthermore we will be able to improve and update our reservoir model with more realistic permeability values and fracture network geometry.

ACKNOWLEDGMENTS

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