CO₂ Sequestration, Fault Stability and Seal Integrity at Teapot Dome, Wyoming

Laura Chiaramonte¹, Mark Zoback², Julio Friedmann¹ & Vicki Stamp³
¹Stanford University, ²LLNL, ³RMOTC

INTRODUCTION & SITE CHARACTERIZATION

ABSTRACT
We report a preliminary investigation of the effects of CO₂ sequestration on seal integrity at Teapot Dome oil field, Wyoming, USA, with the objective of predicting the potential risk of CO₂ leakage along reservoir-bounding faults. CO₂ injection into reservoirs creates a compressive stress field that could potentially alter the initial seal by either hydraulically fracturing the caprock or by triggering slip on reservoir-bounding faults. The Tensleep formation, a Pennsylvanian age aeolian sandstone is evaluated as the target horizon for a pilot CO₂ EOR-carbon storage experiment, in a 3-way closure trap against a bounding fault (S1). A preliminary geochemical model of the Tensleep has been developed to evaluate the potential for injection-induced slip of the S1 fault and thus threaten seal integrity. The uncertainties in the stress tensor and fault geometry have been incorporated using Monte Carlo simulation. The authors find that even the most pessimistic scenario risk-wise would require ~10 MPa of excess pressure to cause the S1 fault to reactivates and provide a potential leakage pathway. This would correspond to a CO₂ column height of ~1500 m, whereas the structural closure of the Tensleep in the pilot injection area does not exceed 100 m. It is therefore apparent that CO₂ injection is not likely to compromise the S1 fault stability. Better constraint of the least principal stress is needed to establish a more reliable estimate of the maximum reservoir pressure required to hydrofracture the caprock.

INTRODUCTION
One of the main issues to be addressed for CO₂ sequestration to be a viable carbon management solution is the risk of CO₂ leakage. In particular, oil reservoirs hold great promise as storage locations due to the fact that if hydrocarbons were held in them to geological periods of time this implies the presence of effective trap and seal mechanisms. However, it has long been known that fluid injection causes change in the stress field that could potentially alter the initial seal of the reservoir by either hydraulically fracturing the caprock or by triggering slip on pre-existing faults by reducing the effective normal stress on the fault plane. In either case, large-scale fluid migration out of the reservoir may occur.

Based on the assumption that permeable faults are optimally oriented for shear failure (critically stressed) in the existing stress field (Findikbeiner et al., 2001, Wiprut & Zoback 2002), it becomes essential to study the relationship between faults and the present-day stress field to predict which faults could be potential leakage routes. Another way of compromising seal integrity is by hydraulically fracturing the caprock, which occurs when the pore pressure at the reservoir is as high as or less than the stress principal in the overlying unit. In both cases, through a geometrical characterization it is possible to establish pressures and rates of injection needed to reach those critical values and therefore predict the potential risk of leakage.

TEAPOT DOME CO₂ EOR-CARBON STORAGE PILOT

Fully owned by the US Government: Stable platform for long-term scientific projects.
Extensive data set is of public domain.
Allows joint research & international collaborations.

Is an elongated asymmetrical, basement-supported anticline with a north-northeast axis. It is part of the Salt Creek structural trend located in the southwestern edge of the Powder River Basin.

RESERVOR
Tensleep Fm: interbed deposits such as eolian sandstones, sabkha carbonates, evaporites, (mostly anhydrite), and extensive beds of very low permeability shales. Porosity = 10-15 % (5-20 % range). Permeability = 30 mD (100-1000 mD range). Mean net thickness = 15 m. Pressure = 16.2 MPa (strong aquifer drive). Temperature 88°C. The Tensleep Fm. is divided into several intervals, of which the B-Sandstone is the main producing horizon and the proposed storage interval for this experiment.

SEAL
Tightly cemented dolomitic eolian or interdune sandstone with diagenetic effects ±17 m thick. The Minnehaha Limestone (both members of the Goose Egg Fm).

The first CO₂ injection experiment (small, short-duration EOR pilot) will inject ~60 tons/day CO₂ for a minimum of ~1.5 months (V. Stamp, RMOTC and J. Friedmann, LLNL, personal communication, 2006).

GEOMECHANICAL ANALYSIS FOR POTENTIAL RISK OF LEAKAGE

Stress Tensor
Parameters to define the stress tensor:

- S : Lateral stress azimuth & dip
- τ : Mean horizontal stress
- τ : Mean vertical stress
- P : Reservoir pressure
- φ : Rock compressive strength
- ε : Log strain, load
- σ : Modelloving coefficient, models used
- P : Pressure
- Rock Pressure
- Stress Orientation From FMI logs

Stress Orientation From FMI logs

The stress orientation in vertical wells can be estimated from wellbore failure orientations. Drilling-induced tensile fractures propagate parallel to S₁, whereas breakouts are formed at the azimuth of S₃. Under normal drilling conditions, the occurrence of drilling-induced tensile fractures in a vertical well indicates a strike-slip faulting stress state (Zoback et al., 2003).

Conclusions
To evaluate uncertainties in S₁ and S₃ magnitudes & orientations, as well as in azimuth & dip of the fault with respect to the stress field, random distributions of S₁ and S₃ were generated based on the mean, minimum & maximum stress values estimated in each well. Monte Carlo simulations were also run for the geometry of the fault (azimuth & dip), evaluated with mean stress tensor.

Fault Slip Potential - Sensitivity Analysis

Fault surface color-coded with critical pressure perturbation value indicating the fault slip potential. At the Tensleep Fm. (red box) ~17 MPa of excess pressure would be required to cause the fault to slip.

Acknowledgments
We would like to acknowledge the Global Climate and Energy Project (GCEP) for funding the present research, as well as Brian Black, Tom Anderson and Mark Millikan from RMOTC, Tapan Mukerji and Kyle Spakos from Stanford University, and Tim McCutcheon. Additionally we would like to acknowledge GMI for providing some of the software used in the present research.

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