Quantifying the Effects of Spatial Uncertainty in Fracture Permeability on CO$_2$ Leakage through Columbia River Basalt Flow Interiors

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After Reidel et al (2013)

After Long (1986)
Research Question

How does uncertainty in fracture permeability affect CO$_2$ leakage in a basalt fracture network?

- Spatially?
- Temporally?
- Near the critical point of CO$_2$?
Approach

I. LiDAR scanning to make fracture maps
II. Model of fracture permeability applied to a fracture map
III. Monte Carlo simulation of $N=50$ iterations with spatially random permeability

After Long (1986)
Field Work

- Field work: acquire terrestrial LiDAR scans of outcrop fracture networks to image fracture networks.
- Data processing: use surface roughness algorithm developed by Pollyea and Fairley (2011) to produce fracture maps.
Fracture mapping

- Discretization of roughness boxes was 2.5 cm
- Binary transform of roughness values based on histogram produces a grid where each cell is considered either fractured or not
Permeability model

Lindberg et al 1989

- Statistical analysis of CRB flow interior cooling joints
- Lognormal distribution
- Mean of 0.226 mm
- Standard deviation of 0.489 mm
- No spatial correlation

Permeability model continued

- Use random number generator to produce a lognormal set of apertures
- Convert to permeability using cubic law
- Hydraulic tests suggest that in situ fracture permeability is much lower
- Estimated new mean $k_f$ based on weighted geomean

\[ k_{eff} = \exp\left( \frac{\sum_{i=1}^{n} w_i \ln k_i}{\sum_{i=1}^{n} w_i} \right) \]

\[ k_f = \exp\left( \frac{\ln k_{eff} - w_m \ln k_m}{w_f} \right) \]
Model built using TOUGH3 (Jung et al, in press)
ECO2M equation of state (Pruess 2011)
This model does not account for chemistry due to short time-scales
Example results from Monte Carlo simulations

- Phase transition occurs at different depths (approximately 1 meter difference)
- Corresponding pressure profiles suggest this is caused by pressure
- Spatial permeability differences affect fluid pressure
Results

- E-type analysis
- Standard deviation of free-phase CO$_2$ saturation (left) and fluid pressure (right) across N=36 simulations
Conclusions

• Spatial uncertainty in fracture permeability has little effect on free-phase CO$_2$ saturation

• Distribution of fluid pressure, and thus the location of the critical point, is affected by the spatial distribution of fracture permeability