Investigating the Subsurface Heterogeneity of a Naturally Fractured Reservoir in relation to CO_2 Geological Storage at the Kevin Dome site, Montana

Minh C. Nguyen[1], Ye Zhang[1], Wade Zaluski[2], Tsubasa Onishi[3], J. William Carey[4], Philip H. Stauffer[4]
Department of Geology & Geophysics, University of Wyoming, USA
Schlumberger Carbon Services, Calgary, Alberta, Canada
Department of Petroleum Engineering, Texas A&M University, USA
Earth & Environmental Science, Los Alamos National Laboratory, USA

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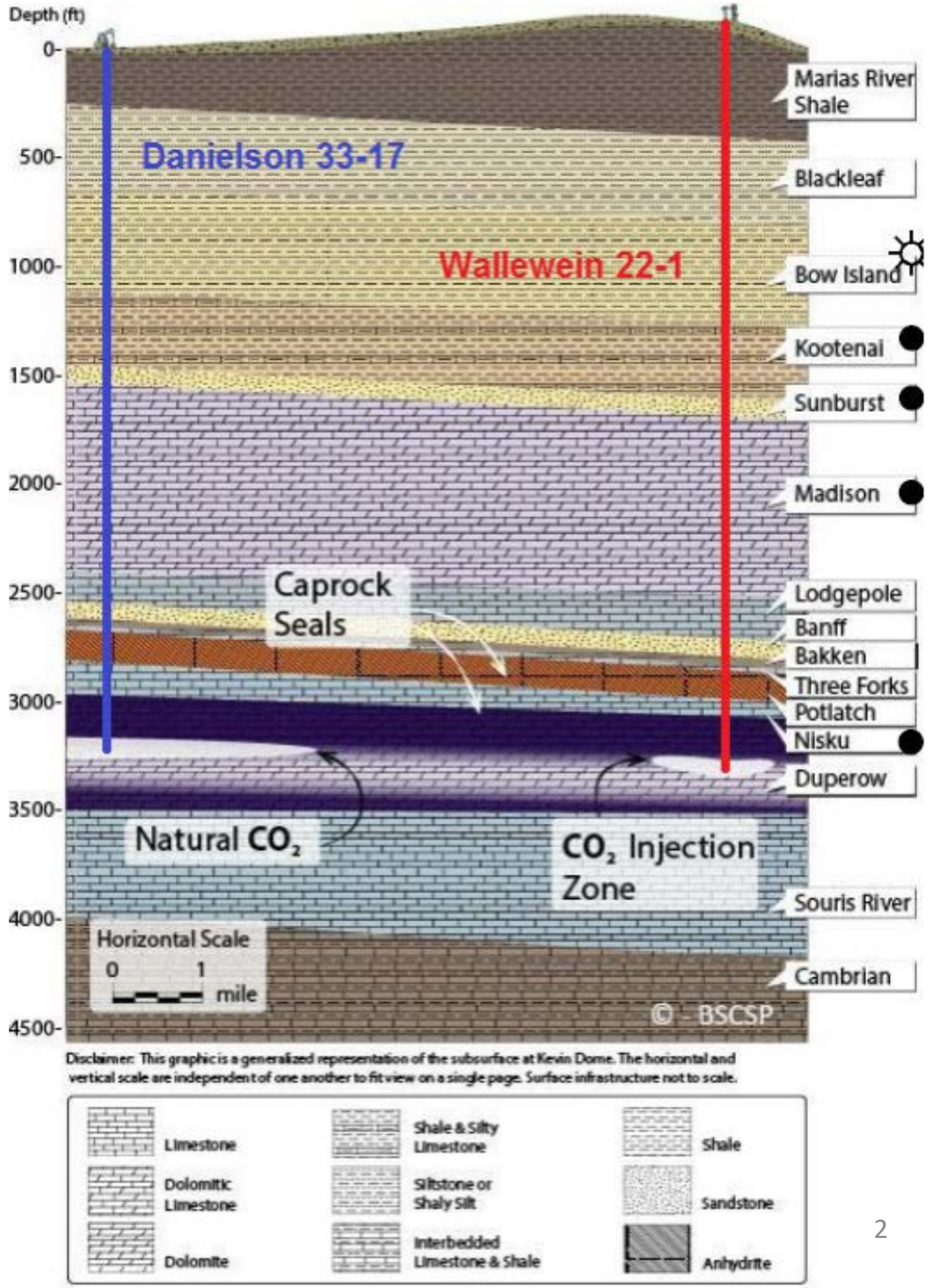
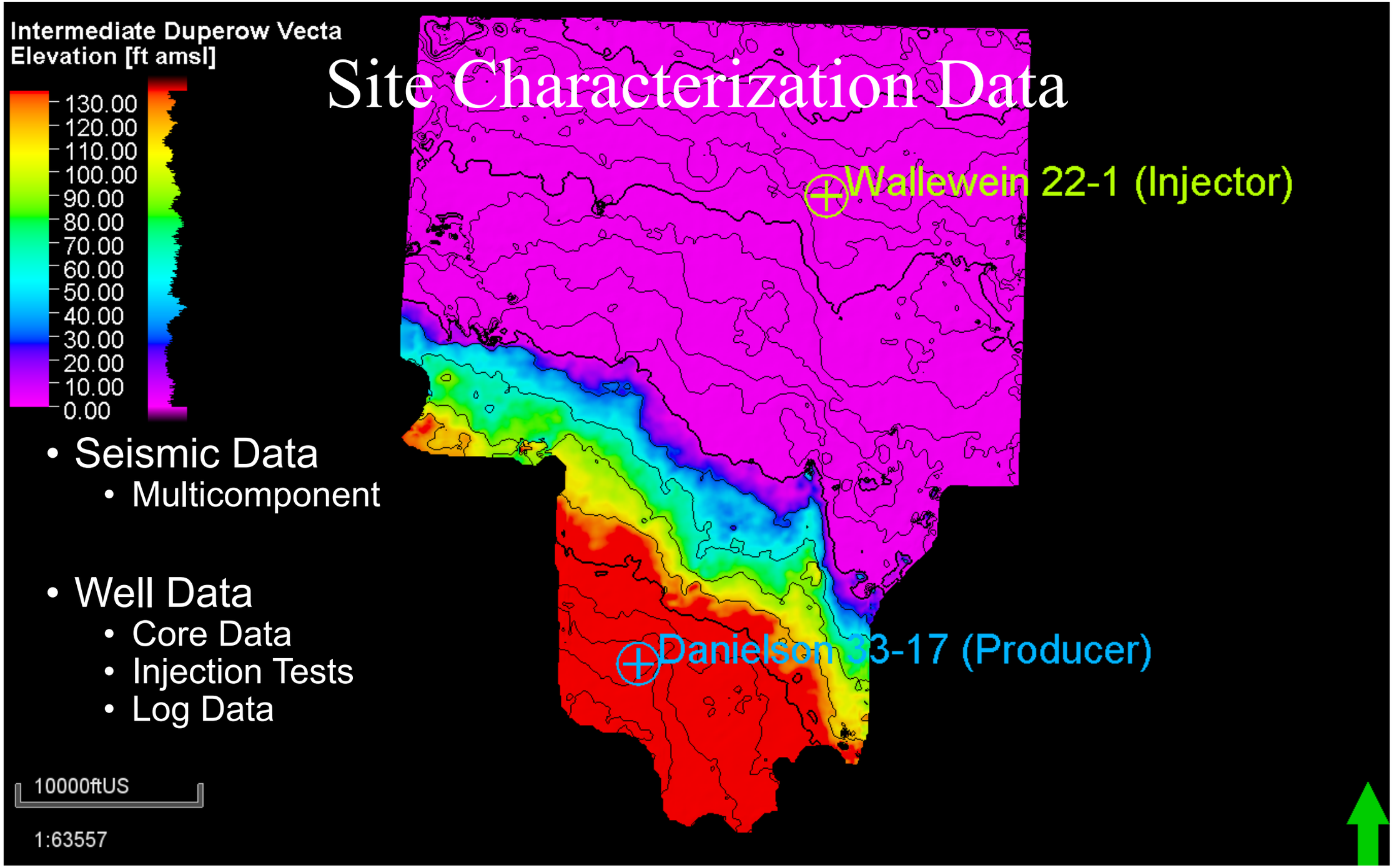
Overview

(Adapted from Nguyen et al., 2017)

Big Sky Carbon Sequestration Partnership has turned to maximizing the value of data acquired at the Kevin Dome site over the course of this project. Kevin Dome is a regional structure and has thick layers of sealing caprock.



Site Characterization Data



- Seismic Data
  - Multicomponent
- Well Data
  - Core Data
  - Injection Tests
  - Log Data

Questions to Answer

- Could the Middle Duperow formation allow injectivity up to 1 million tons (MT) of CO_2 over 4 years given the most recently available data?

- What factors would have the most impact on calculated fracture permeability?

Model Development: Matrix System Properties

Rock Type Probability

- A 3-rock type method was used to calculate facies from well logs
- Well logs, seismic inversion, and geological modeling data were integrated to provide an estimate of the most probable lithology in the inter-well geologic model space.

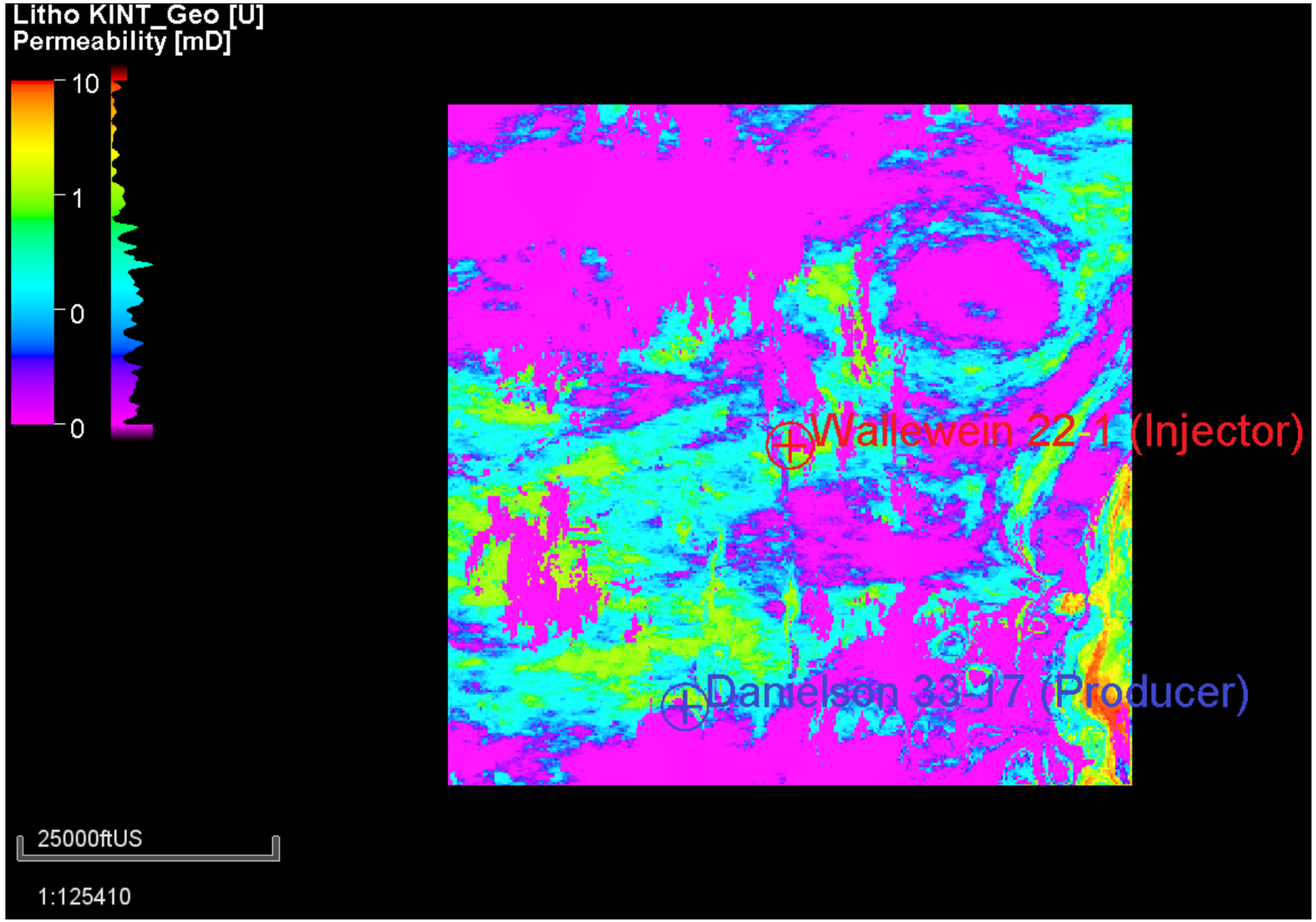
Facies Modeling

- Sequential Indicator Simulation was used to interpolate the 3-dominant rock types (dolomite, limestone and anhydrite) throughout the model domain using the aforementioned probability properties.

Property Modeling

- Using geostatistics from the variogram analysis, Gaussian Random Function Simulation was used to interpolate effective porosity within each of the 3 dominant rock types as well as to interpolate permeability co-krigged to effective porosity.

Model Development: Matrix System Properties

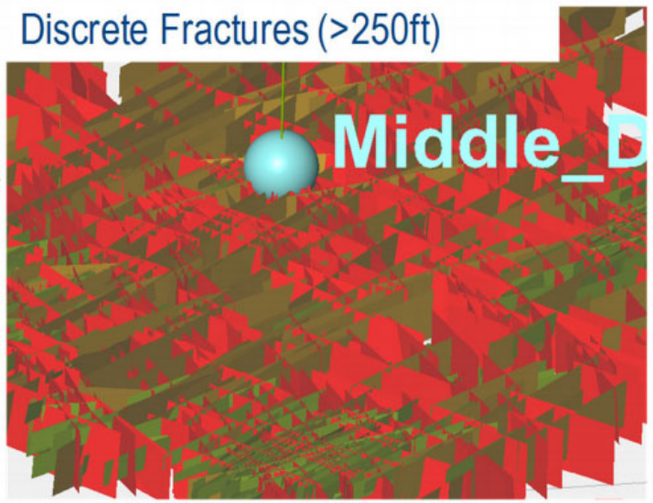


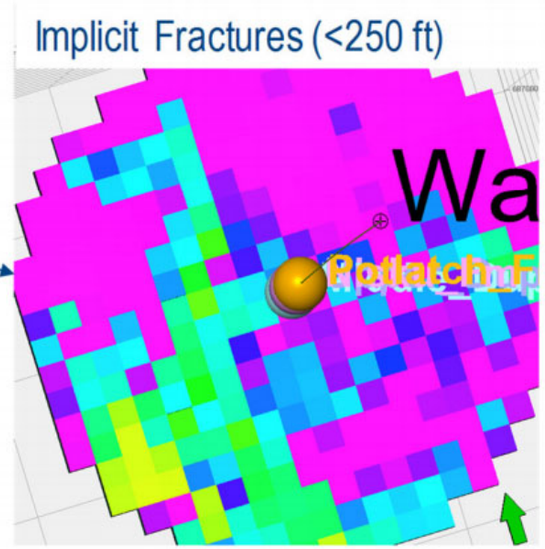
Model Development: Fracture System Properties

Fractures were observed from core samples and FMI logs (Formation MicroImager)

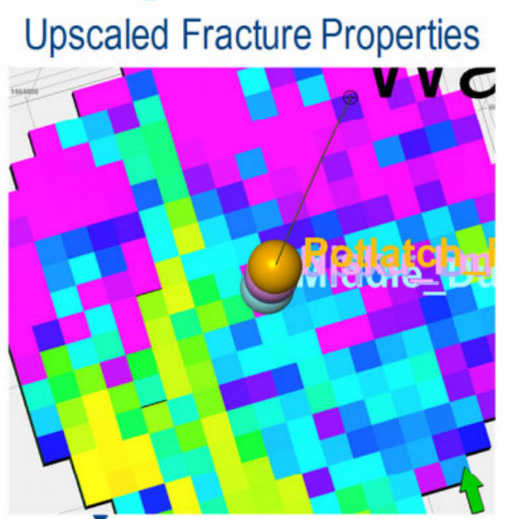
Input Parameters

- Fracture Aperture
- Fracture Intensity Interpolation
- Fracture Length
- Fracture Height
- Fracture Orientation
- Fracture Concentration





The DFN Model resulted in two components: discrete fractures and implicit factures



Fracture Cell

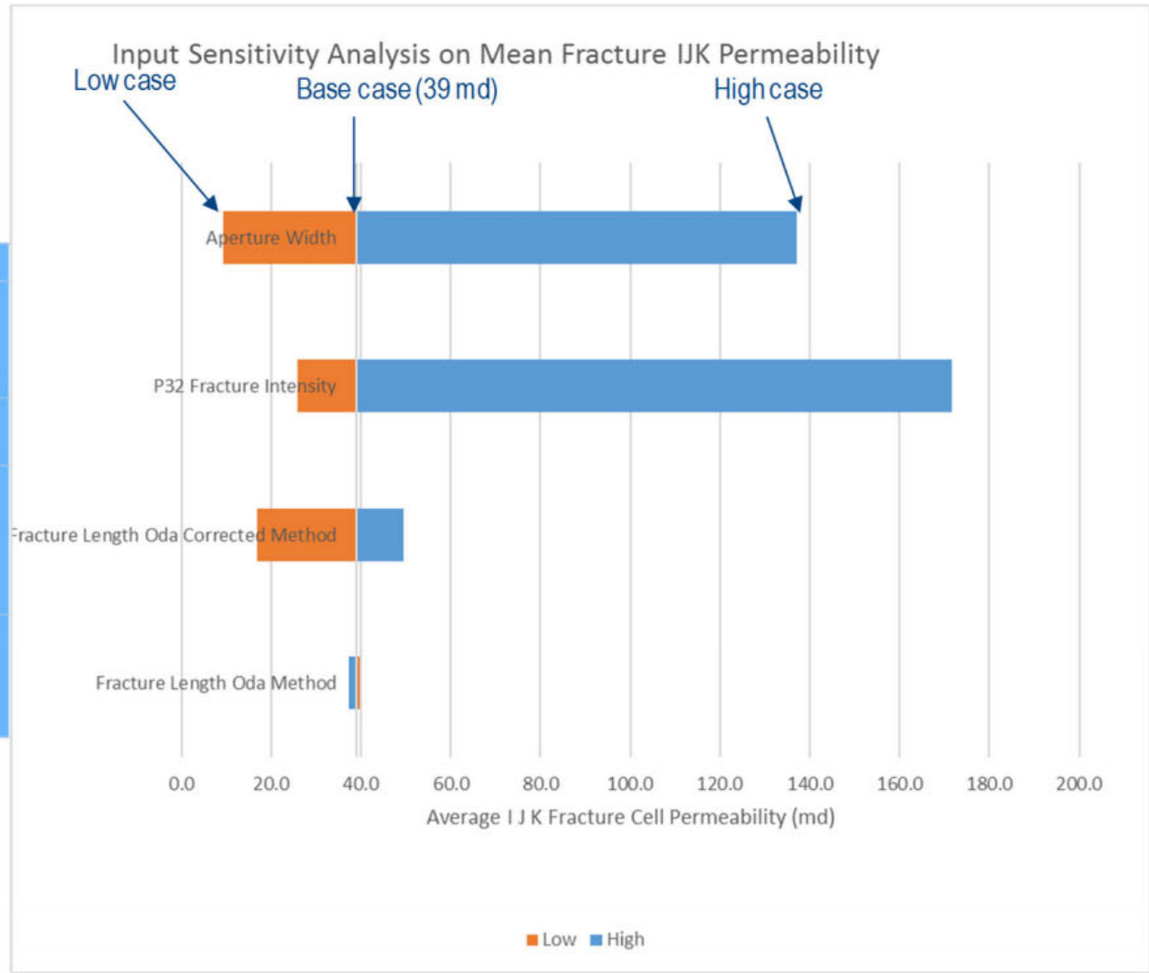
- Permeability IJK
- Porosity
- Fracture Matrix Coupling

A Discrete Fracture Network (DFN) Model was developed from FMI logs and core slab viewing

Both discrete fractures and implicit factures are upscaled into the 3-D grid to generate fracture permeability

Model Development: Fracture System Properties

Variable Input	Low	Base case	High
Aperture (ft)	0.00004 (0.012mm)	0.00007 (0.021mm)	0.00014 (0.042mm)
P32	P10	P50	P90
Fracture Length Oda Corrected Fracture Upscale method (ft)	10	100	200
Fracture Length Oda Fracture Upscale method	10	100	200

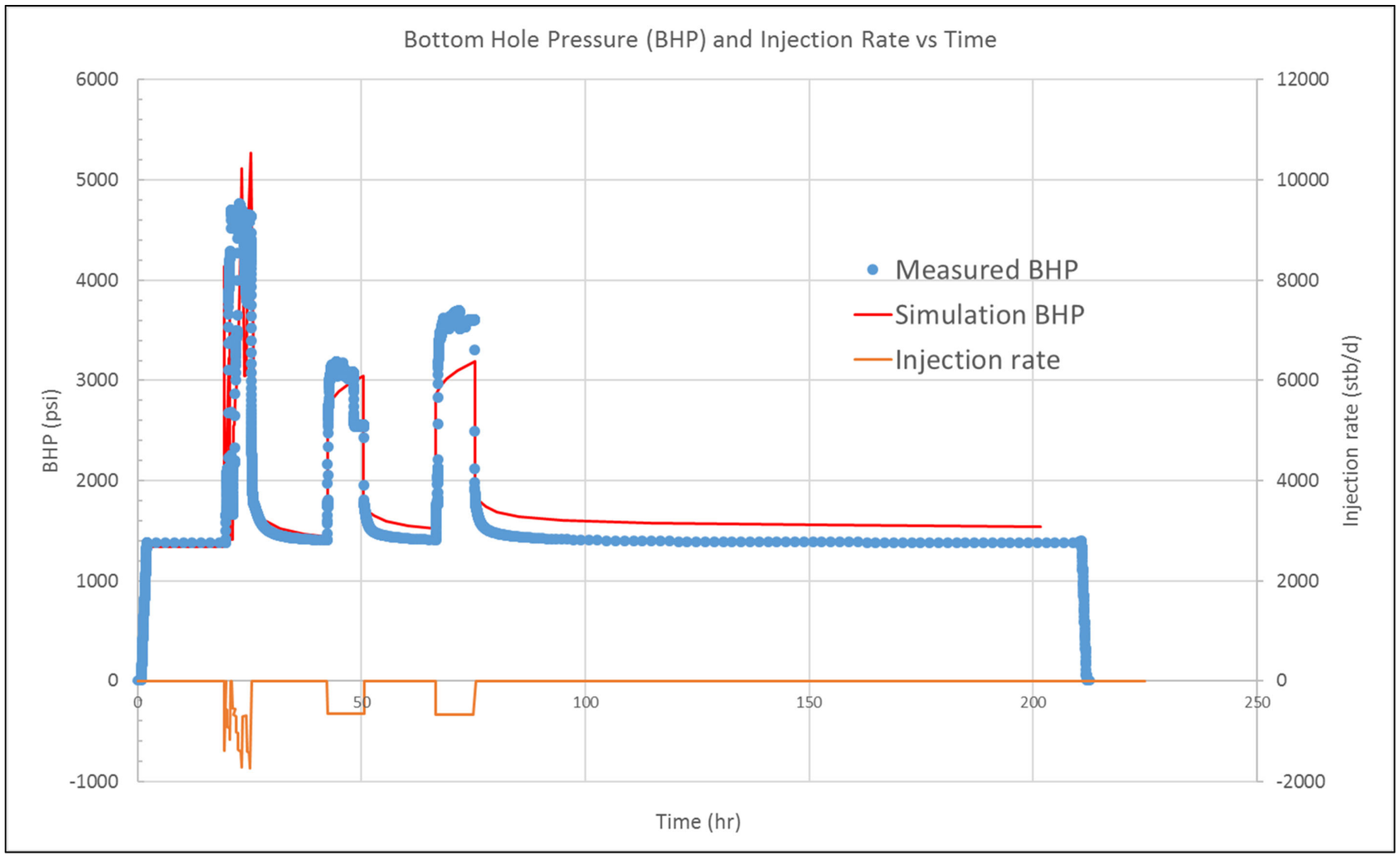


Tornado plot illustrating the sensitivity of input parameters on mean IJK fracture permeability

Model Development: Well Testing

- A step rate injection test and 2 single rate injection tests were carried out using brine at Wallewein 22-1 (the injector)
- Initial well test interpretation suggests a heterogeneous reservoir with increasing wellbore storage at early time and two-porosity transition happening late in the test.
- The reservoir has an effective permeability of 19 mD and a skin factor of -1.3 which is reasonable since it has been acidized

Model Development: Well Testing

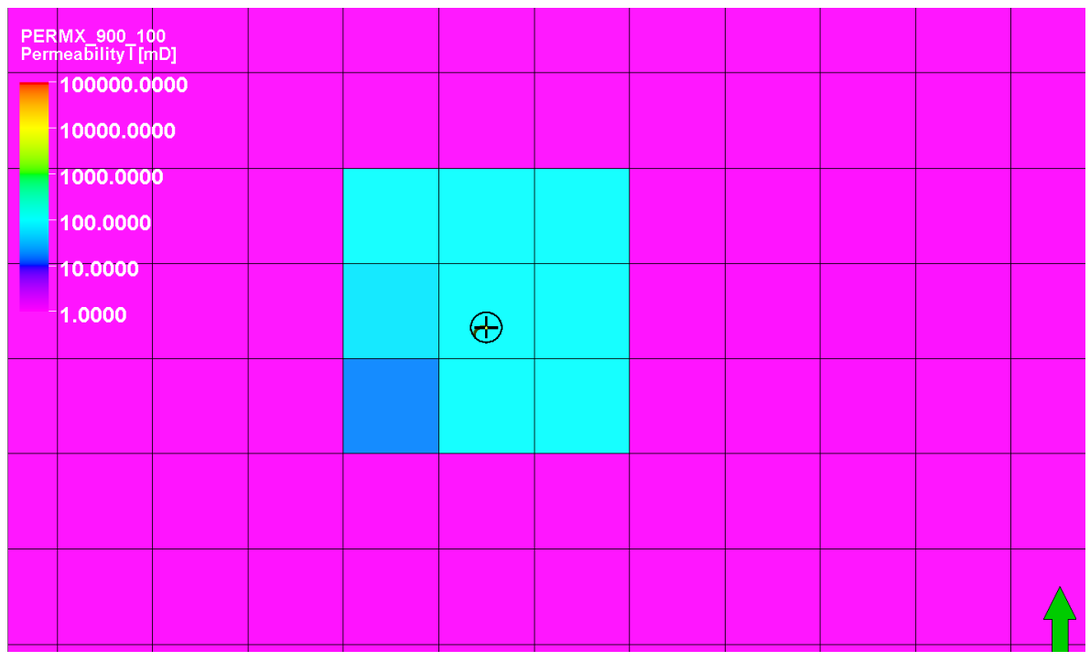


Model Development: CO_2 Injections

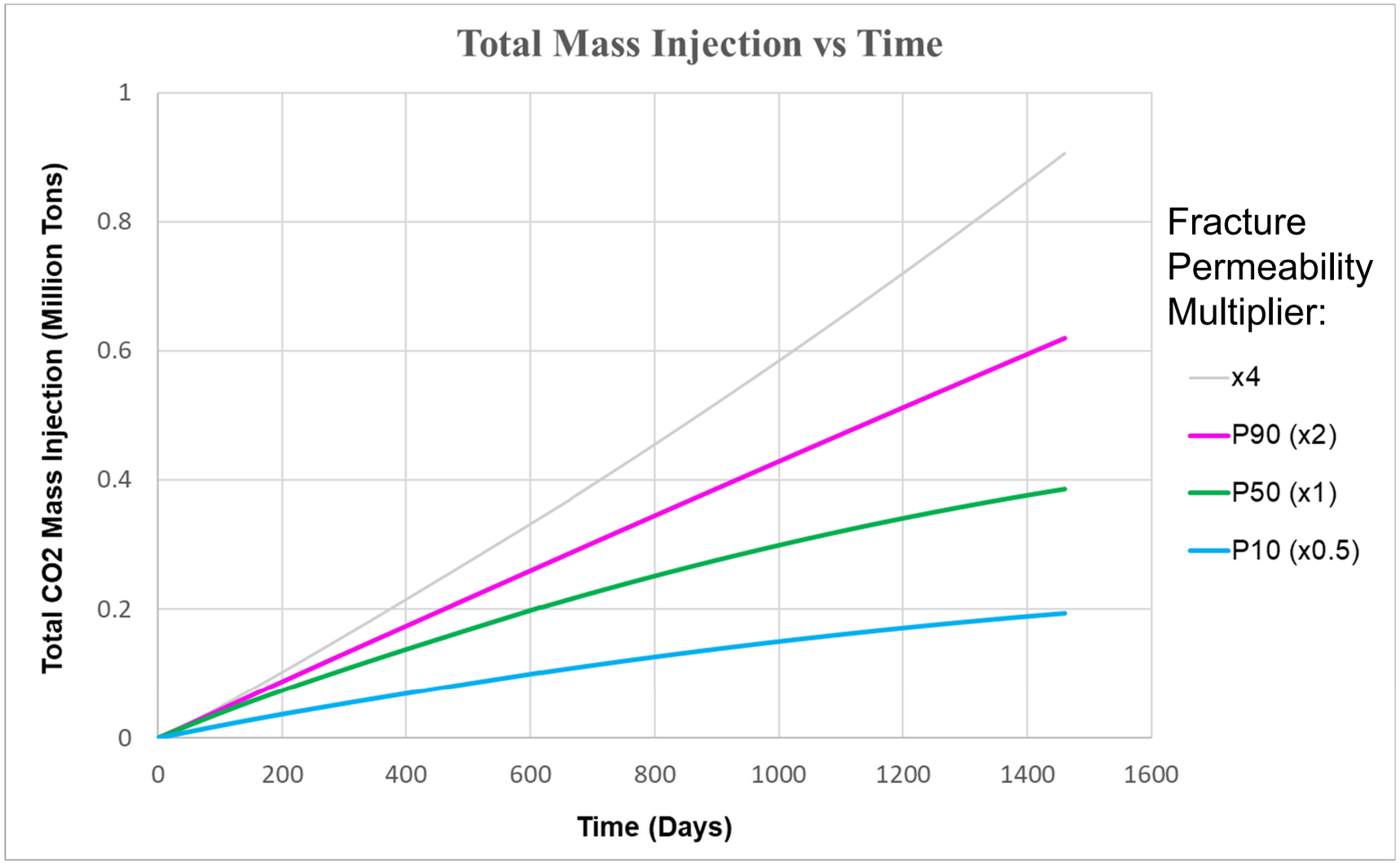
- Dual porosity model
- Dimension: 99 x 99 x 49
- Pore volume multiplier at the boundary
- 3 Phase (Water, Gas, Solid)
- 3 components (H2O, CO_2, NaCl)
- Van Genuchten relative perm and Pc
- EOS: Modified Redlich-Kwong (Onishi et al., 2017)

Grid Upscaling for Simulation

Cell Dimensions (ft)	Total Number of Cells	Note
200 x 200 (Original)	5,193,900	
330 x 330	1,940,449	
660 x 660	480,249	**Most Optimal**

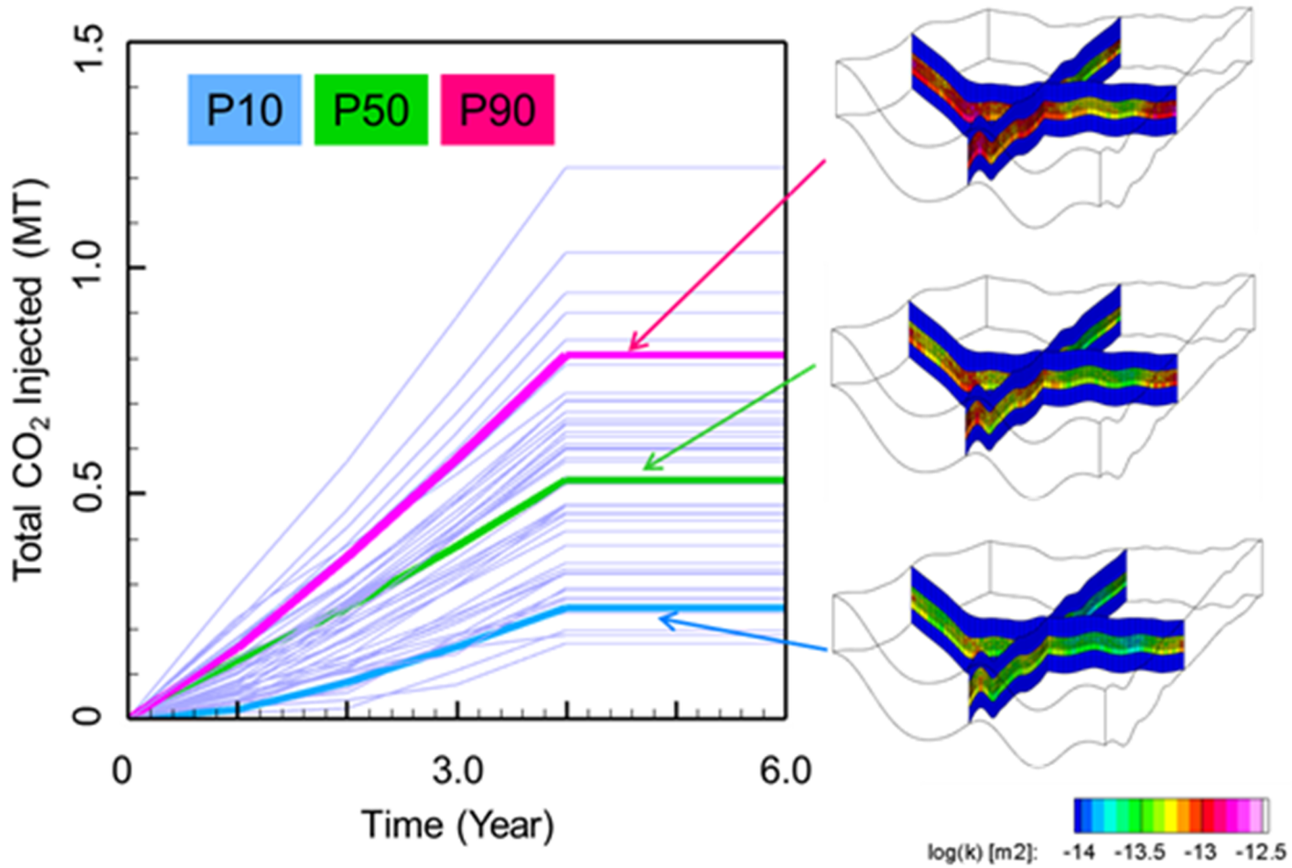


Model Development: CO_2 Injections



Results & Discussion

- Simulation results show lower probability of successfully injection than previous study based on (Dai et al. 2014; Nguyen et al. 2017; Onishi et al. 2018)
- More information on fracture permeability is needed to constrain the model.



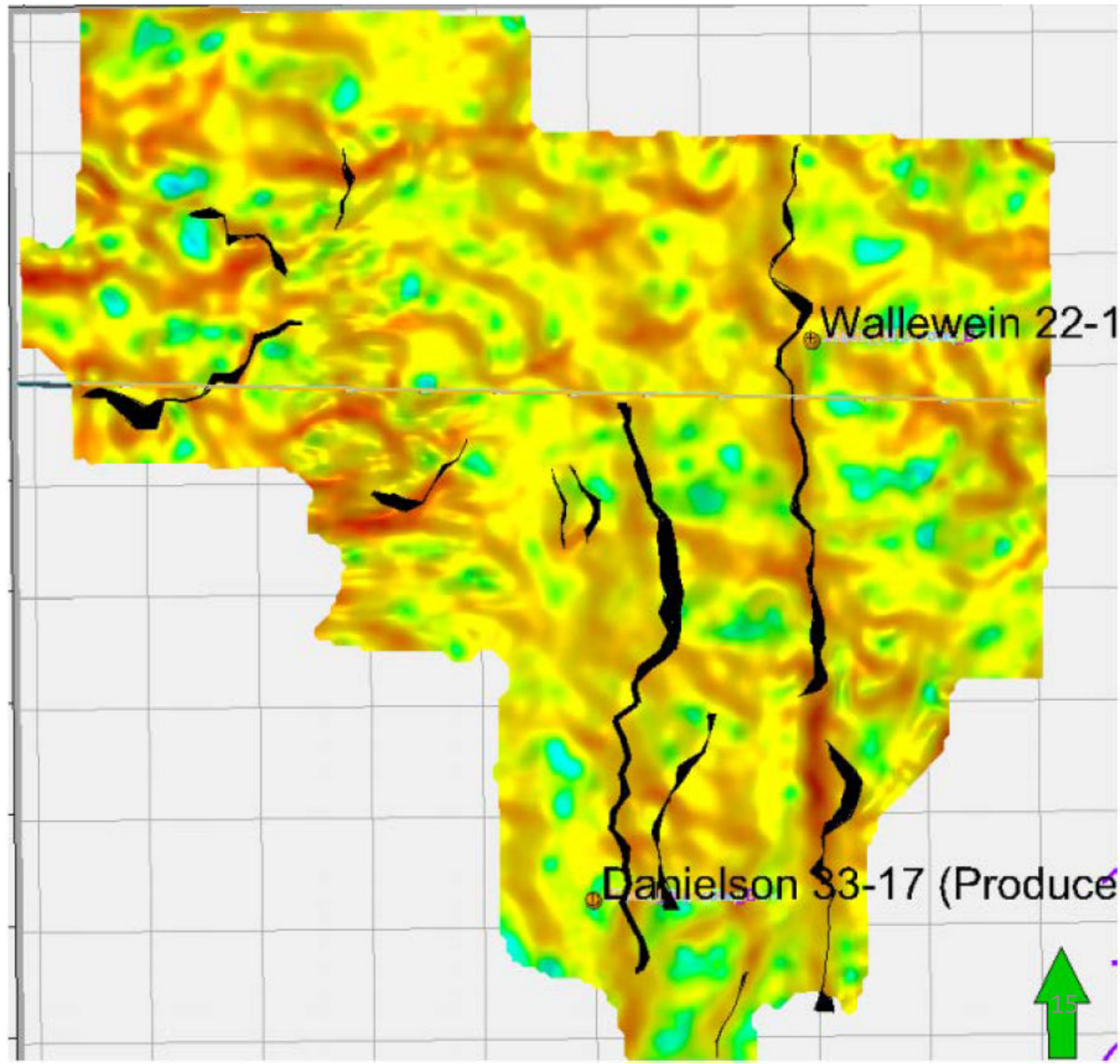
(Adapted from Onishi et al. 2018)

Summary

- Radius of well test investigation is small due to short duration and dual porosity effect was observed late in the test due to rather poor matrix-fracture communication.
- DFN modeling showed that fracture aperture and intensity have the most impact on calculated fracture permeability.
- Based on this study, Big Sky has a low probability of success injecting 1 MT of CO_2 into the Middle Duperow formation compared to previous study based on regional parameters.

Future Work

- Extend this study to other fluid/rock properties as uncertainty parameters to investigate CO_2 injectivity and post-injection trapping mechanisms
- Reanalyze well test data to better understand the fracture permeability in the vicinity of Wallewein 22-1
- Incorporate NRAP workflow to estimate the potential CO_2/brine leakage amount through fault pathways



Acknowledgement

Reference

- Dai, Z., Stauffer, P. H., Carey, J. W., Middleton, R. S., Lu, Z., Jacobs, J. F., ... & Spangler, L. H. (2014). Pre-site characterization risk analysis for commercial-scale carbon sequestration. Environmental science & technology, 48(7), 3908-3915.
- Nguyen, M., Onishi, T., Carey, J. W., Will, B., Zaluski, W., Bowen, D., ... & Stauffer, P. H. (2017a). Risk Assessment of Carbon Sequestration into A Naturally Fractured Reservoir at Kevin Dome, Montana (No. LA-UR-17-31501). Los Alamos National Lab.(LANL), Los Alamos, NM (United States).
- Nguyen, M., Zhang, Y., Carey, J. W., & Stauffer, P. H. (2017b). Application of an Integrated Assessment Model to the Kevin Dome site, Montana (No. LA-UR-17-29925). Los Alamos National Lab.(LANL), Los Alamos, NM (United States).
- Onishi, T., Stauffer, P. H., Nguyen, M., & Carey, J. W. (2017). Big Sky Project Preliminary Results June 28, 2017 (No. LA-UR-17-25222). Los Alamos National Lab.(LANL), Los Alamos, NM (United States).
- Onishi, T., Nguyen, M.C., Carey, J.W., Will, B., Zaluski, W., Bowen, D., Devault, B., Duguid, A., Zhou, Q., Fairweather, S., Spangler, L., and Stauffer, P.H. (2018) Potential CO2 and Brine Leakage through Wellbore Pathways for Geologic CO2 Sequestration Using the National Risk Assessment Partnership Tools: Application to the Big Sky Regional Partnership, International Journal of Greenhouse Gas Control, accepted with minor revisions