Characterization and Modeling of a CO_2 Huff 'n' Puff to Predict and Verify EOR Production and CO_2 Storage*

Damion J. Knudsen[1], Charles D. Gorecki[2], Jordan M. Bremer[2], Yevhen I. Holubnyak[2], Blaise A. Mibeck[2], Darren D. Schmidt[2], Steven A. Smith[2]; James A. Sorensen[2], Edward N. Steadman[2] and John A. Harju[2]

Search and Discovery Article #80097 (2010)
Posted August 31, 2010

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, April 11-14, 2010

[1]Energy and Environmental Research Center, Grand Forks, ND (dknudsen@undeerc.org)
[2]Energy and Environmental Research Center, Grand Forks, ND

Abstract

A CO_2 Enhanced Oil Recovery (EOR) Huff 'n' Puff project was commenced in the E. Goetz 1. well in the Northwest McGregor Field of Williams County, North Dakota. The Northwest McGregor huff 'n' puff is a Plains CO_2 Reduction Partnership (PCOR) Phase II project in which CO_2 was injected into a fractured carbonate reservoir for the dual purpose of EOR and associated storage. The perforated interval and injection target is the fractured upper Mission Canyon Formation. Oil produced from this zone is generally trapped in small lenses of partially dolomitized grainstones and packstones interbedded in lime mudstones. Northwest McGregor shows are generally found in peloidal, ooidal, and pisolitic grainstones and packstones bearing skeletal remains of calcareous algae, coral, or crinoid fragments. Above the Mission Canyon are typical sub- to supratidal mixed-layer carbonate anhydrite sequences capped by a thick salt zone.

In order to understand short- and long-range temporal dynamics of the CO_2 injection, a static geologic model was produced. Characterization and modeling in support of dynamic simulations included normalizing all logs and performing an error-minimizing stochastic multimineral petrophysical and fluid analysis. Neural networks were used to produce matrix permeability, fracture density, and missing zones or logs in the study area. Petrophysical results were verified with Qemscan, x-ray diffraction, petrographic analysis, and cutting and core descriptions. This produced the main components for a macro/micro-facies and fluid model, with the major lithofacies being limestones, dolomites, and anhydrites. Within the dolomites and limestones, the diagenetic depo-facies consisted of grainstones, packstones, and mudstones. Large-scale trend modeling used traditional sequential indicator and Gaussian simulations, while small downscaled injection models used discrete and continuous multiple point statistics to model the gradational

mudstone to grainstone sequence common with platform carbonates. Vertical seismic profiles (VSP), temporally resolute reservoir saturation tool (RST) logs, and produced fluid analysis were used to history-match fluid and gas saturations as well as rock matrix mineralogy, produced water, and petroleum compositions. The short-term outcome of the CO_2 huff 'n' puff was a definite increase in produced oil and a decline of produced water in comparison to historic data.

References

Djebbar, T., and E. Donaldson, 2004, Petrophysics, theory and practice of measuring reservoir rock and fluid transport properties, 2d Ed.: Gulf Professional Publishing, Boston, MA, 889 p.

Lucia, F.J., 2007, Carbonate reservoir characterization, 2d Ed.: Springer Publishing, New York, NY, 336 p.

EERC Technology… Putting Research into Practice

American Association of Petroleum Geologists 2010 Annual Convention

New Orleans, Louisiana, April 11−14, 2010

Characterization and Modeling of a CO_2 Huff 'n' Puff to Predict and Verify EOR Production and CO_2 Storage

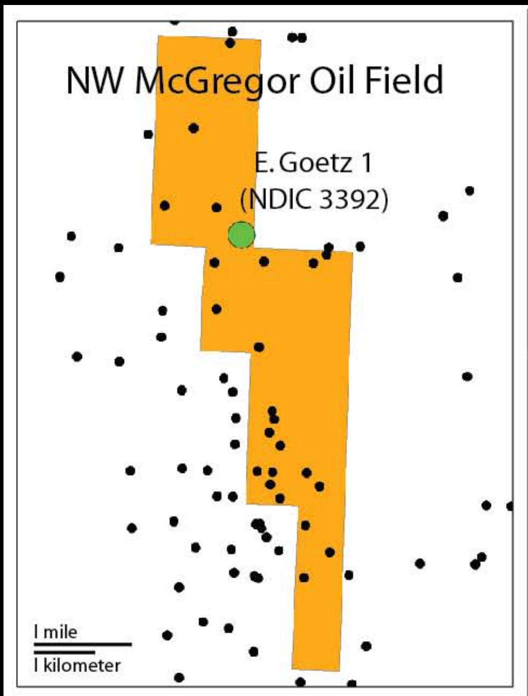
Damion J. Knudsen*, Charles D. Gorecki, Jordan M. Bremer, Yevhen I. Holubnyak, Blaise A. Mibeck, Darren D. Schmidt, Steven A. Smith, James A. Sorensen, Edward N. Steadman, and John A. Harju

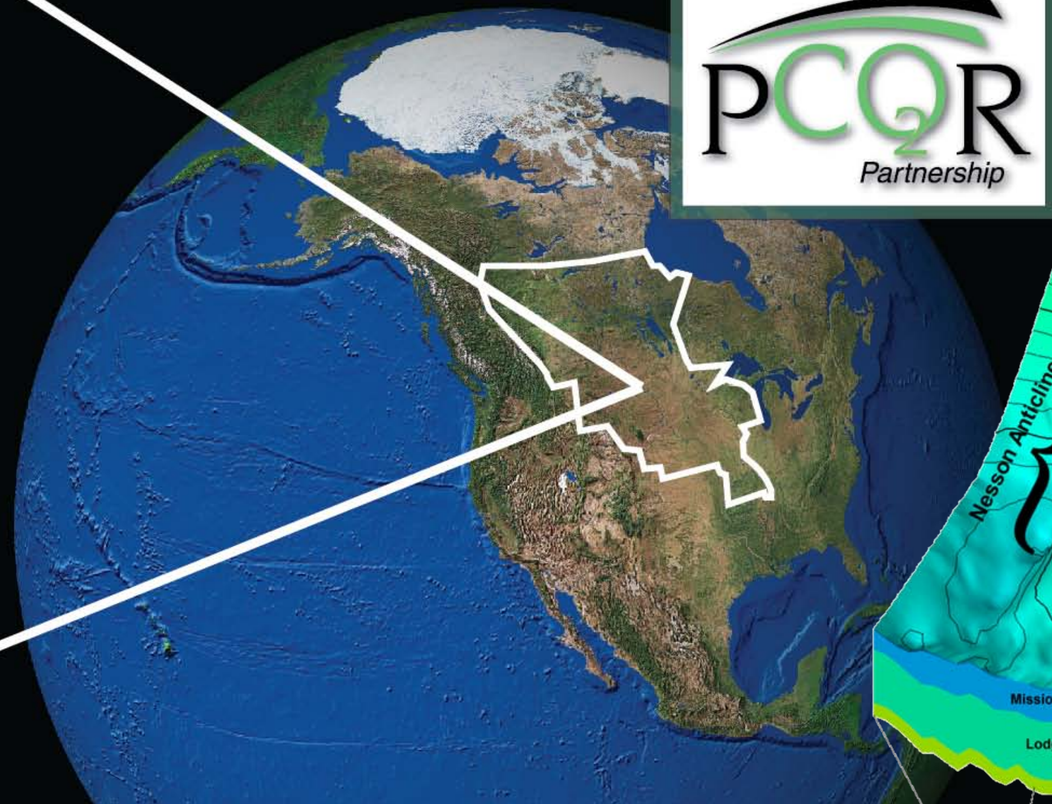
PCO2R Partnership

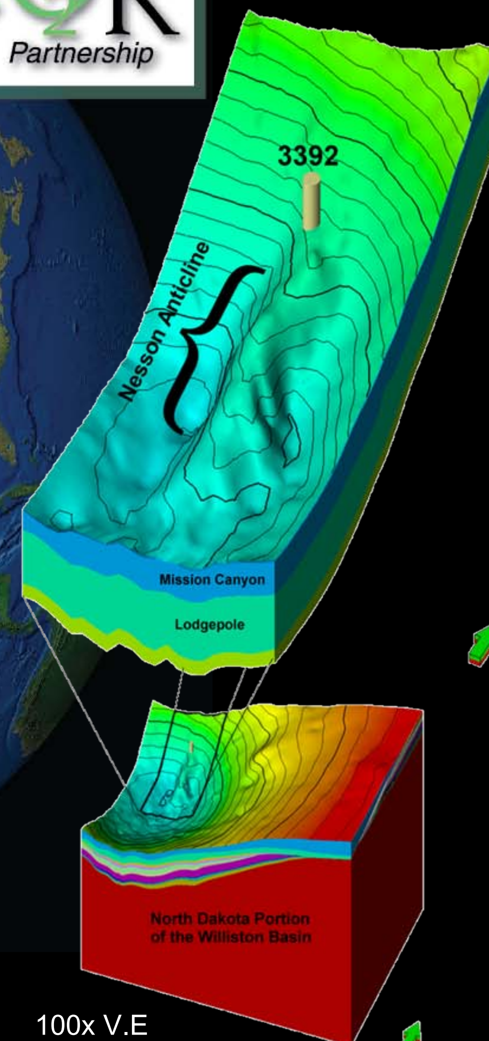
PCOR Partnership 2003 – Present

10/09

The Plains CO_2 Reduction (PCOR) Partnership is a collaborative program assessing regional CO_2 storage opportunities. Its primary sponsor is the U.S. Department of Energy National Energy Technology Laboratory, with additional support from its more than 80 partners.







- Fractured carbonate huff ‘n’ puff (HNP) in E. Goetz 1 of the NW McGregor oil field located in the Mission Canyon Formation.

- Fractured carbonates present many challenges.

- Challenges met using state-of-the-art modeling methods.

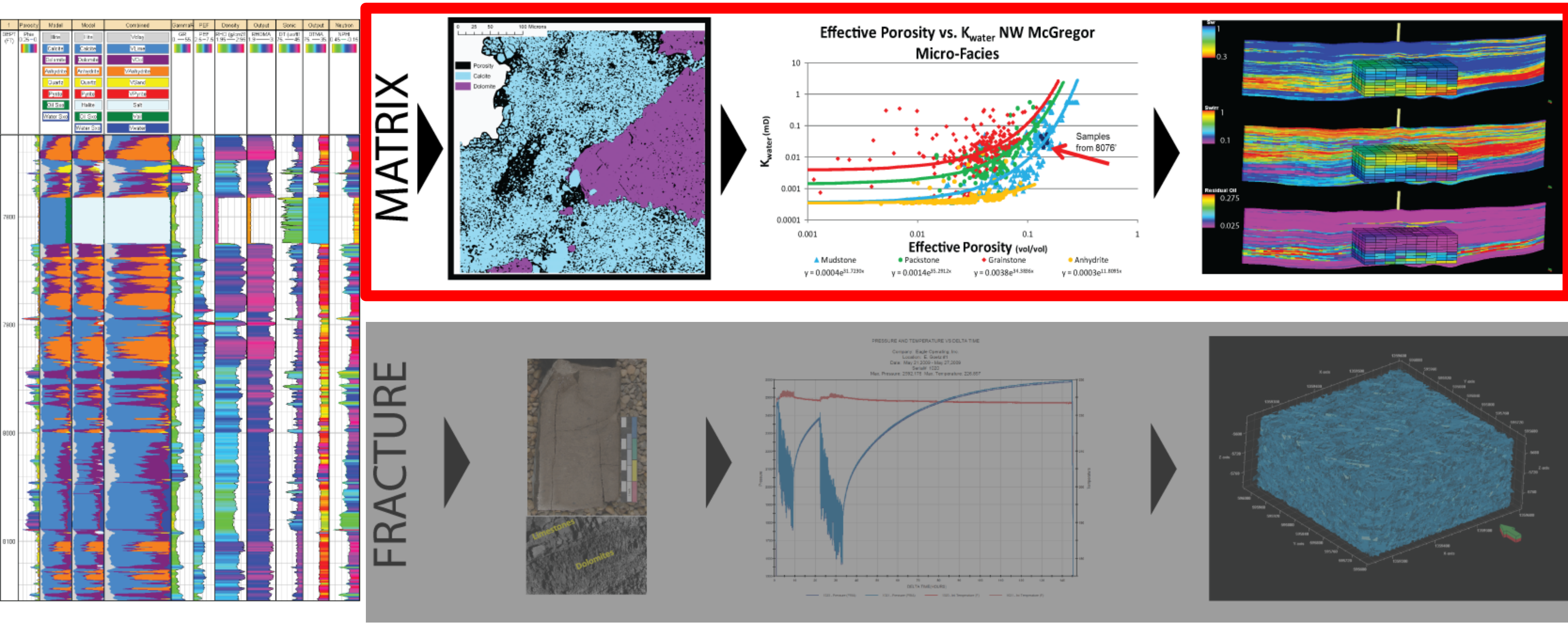
Major goals of this PCOR Partnership pilot project are aimed at determining:

1. Fate of injected CO_2.
2. Effectiveness of HNP.
3. Methods scaling to larger injections.
4. Monitoring, verification, and accounting (MVA) techniques.

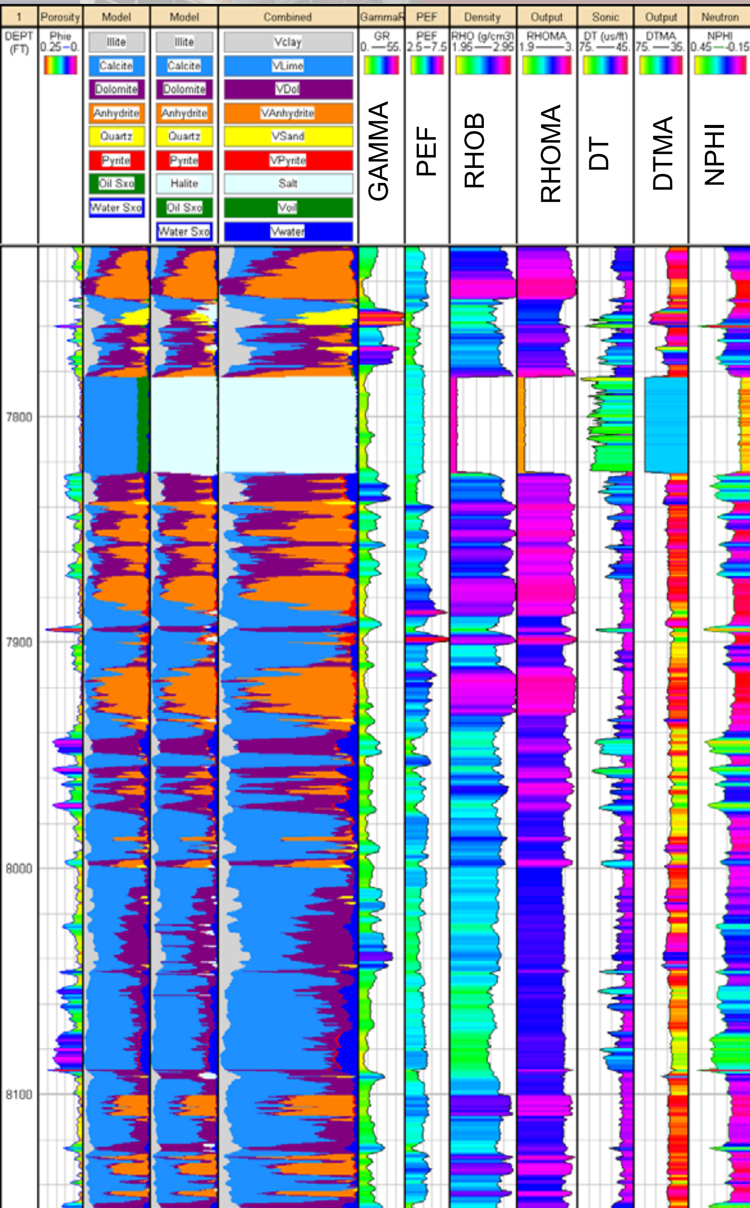
EERC
Energy & Environmental Research Center

Dual Porosity and Permeability Workflow

Matrix Workflow



Matrix Modeling Workflow



Initial petrophysical analysis methods

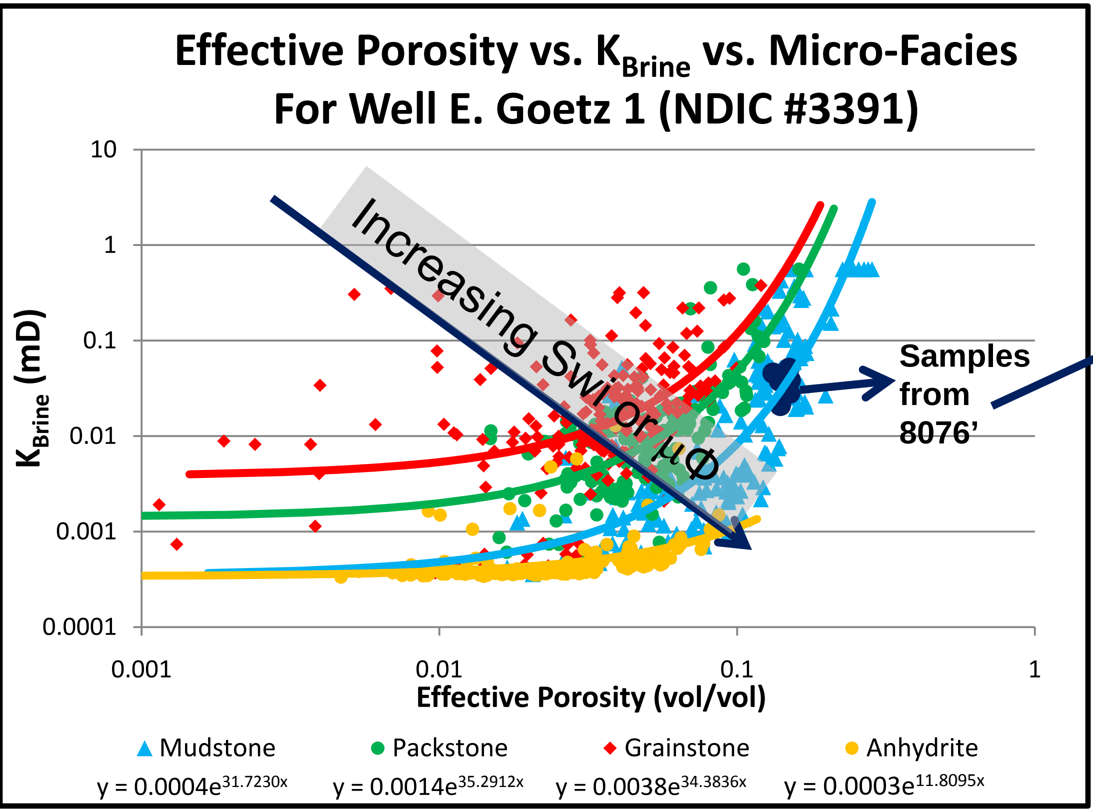
1. Vintage wireline log normalization.
2. Neural network synthetic log production
3. Multimineral petrophysical analysis (MMPA).

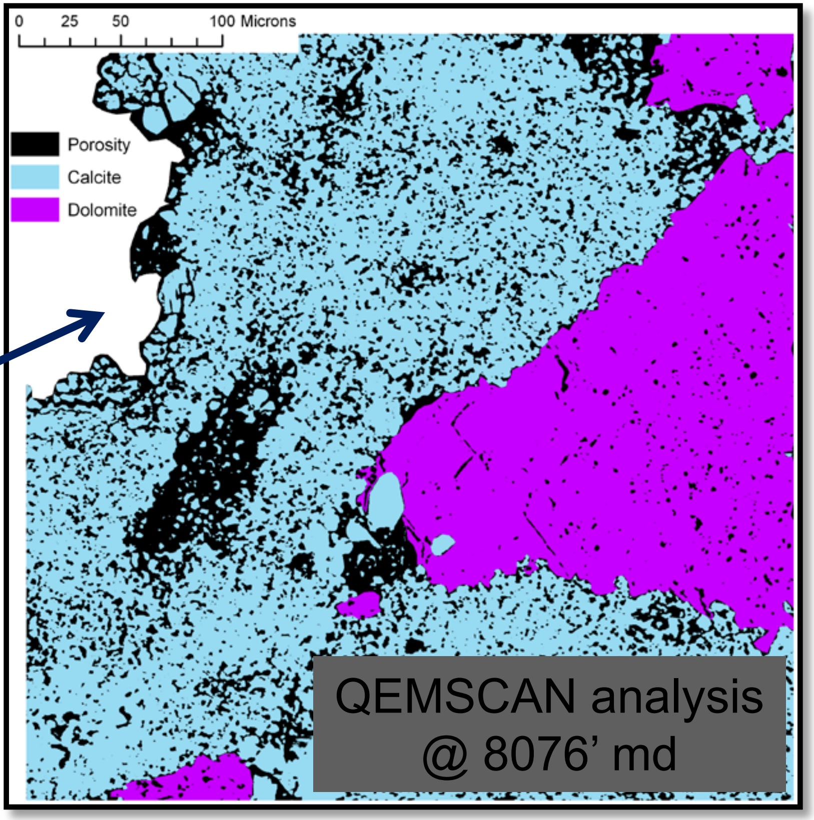
Why do a MMPA? Is this really important?

1. Vintage logs indicated no anhydrite although cuttings suggested otherwise.
2. Gives a better basis for determining formation wettability.
3. Lithology in combination with tectonics control fracture propagation.

EERC
Energy & Environmental Research Center

Matrix Modeling Workflow

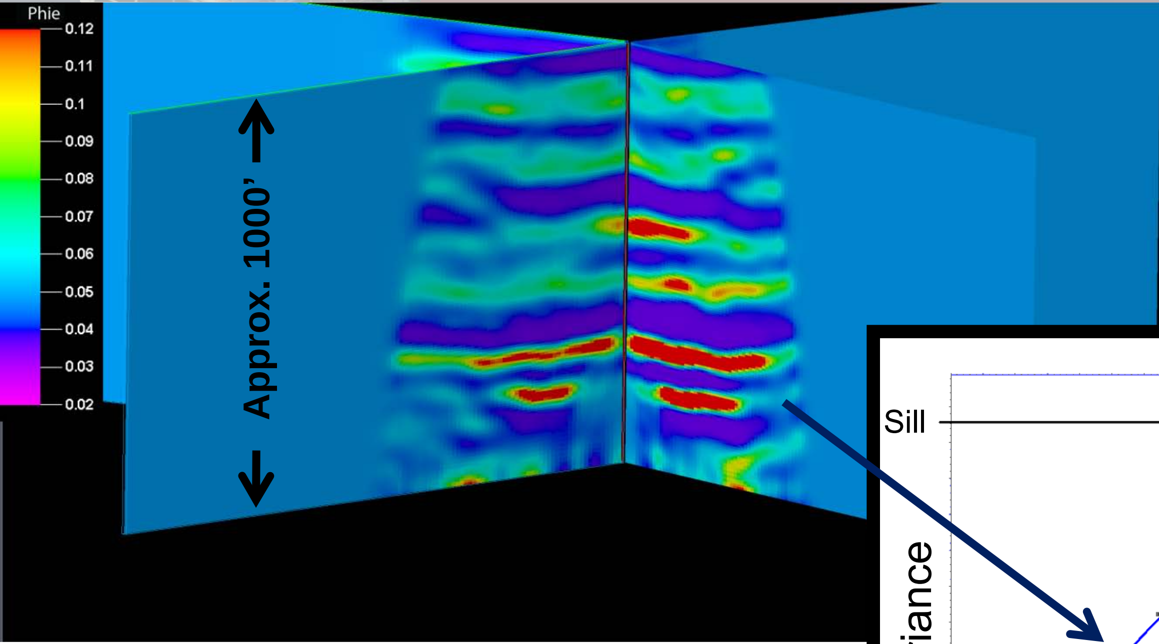




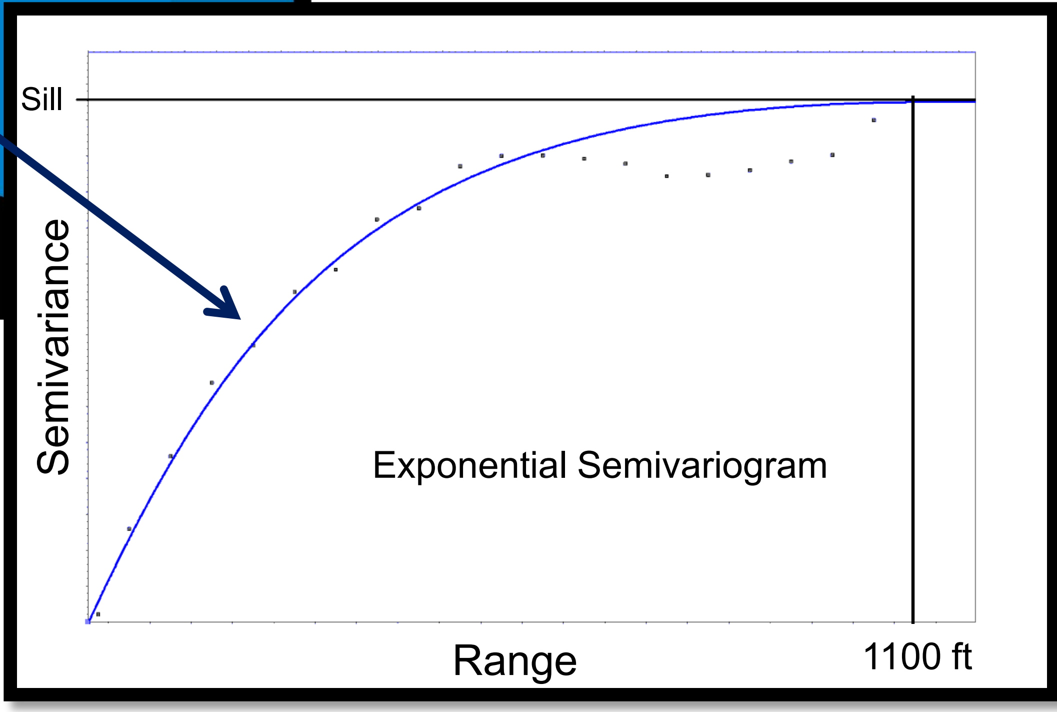
- This graph helps illustrate and verify the relationship between microfacies, effective porosity, and permeability to water.
- Microporosity is defined as pores less than 0.5 μm in diameter.
- S_{wi} cutoffs were used to form the different microfacies.

EERC Energy & Environmental Research Center

Matrix Modeling Workflow

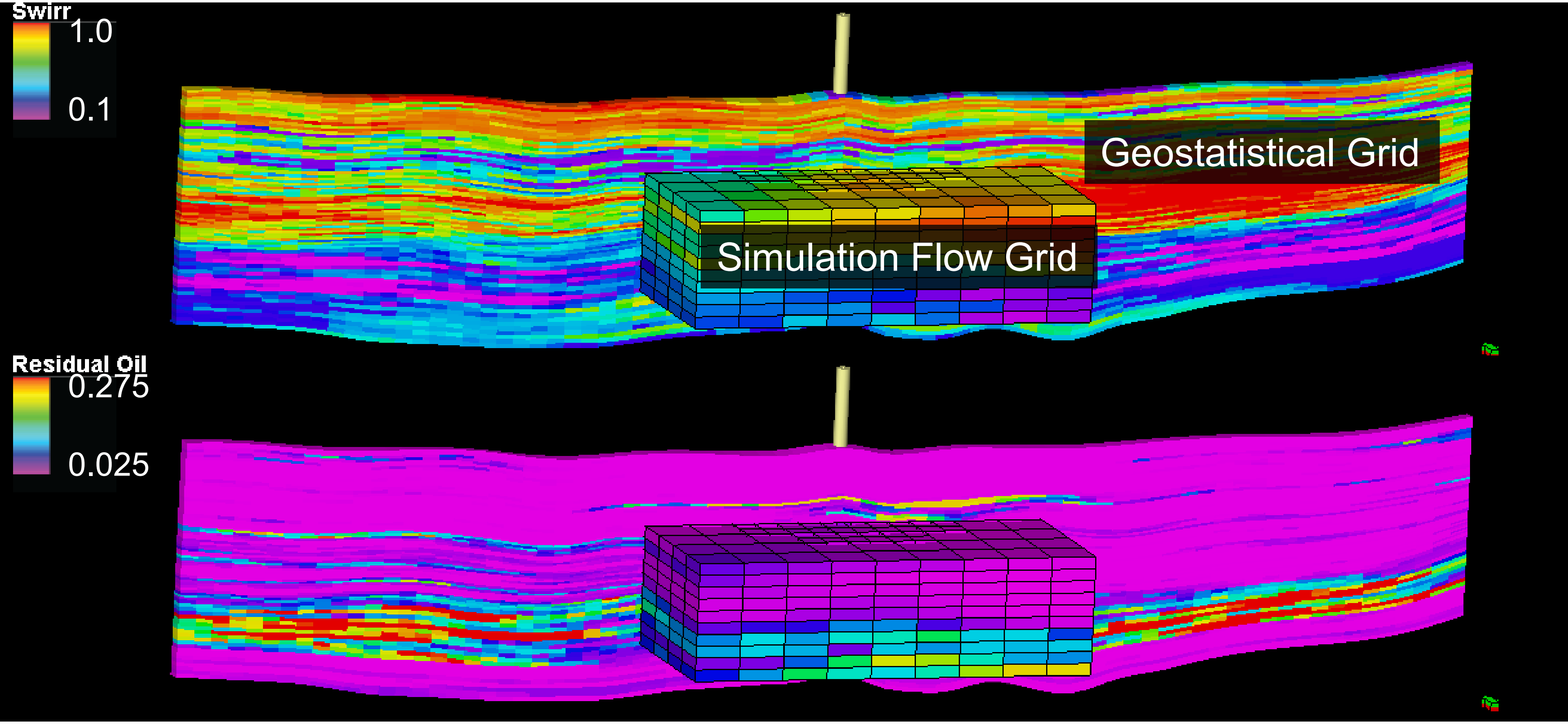


- VSP inversions to effective porosity and absolute acoustic impedance (AAI).



- Horizontal semivariogram

Matrix Modeling Workflow

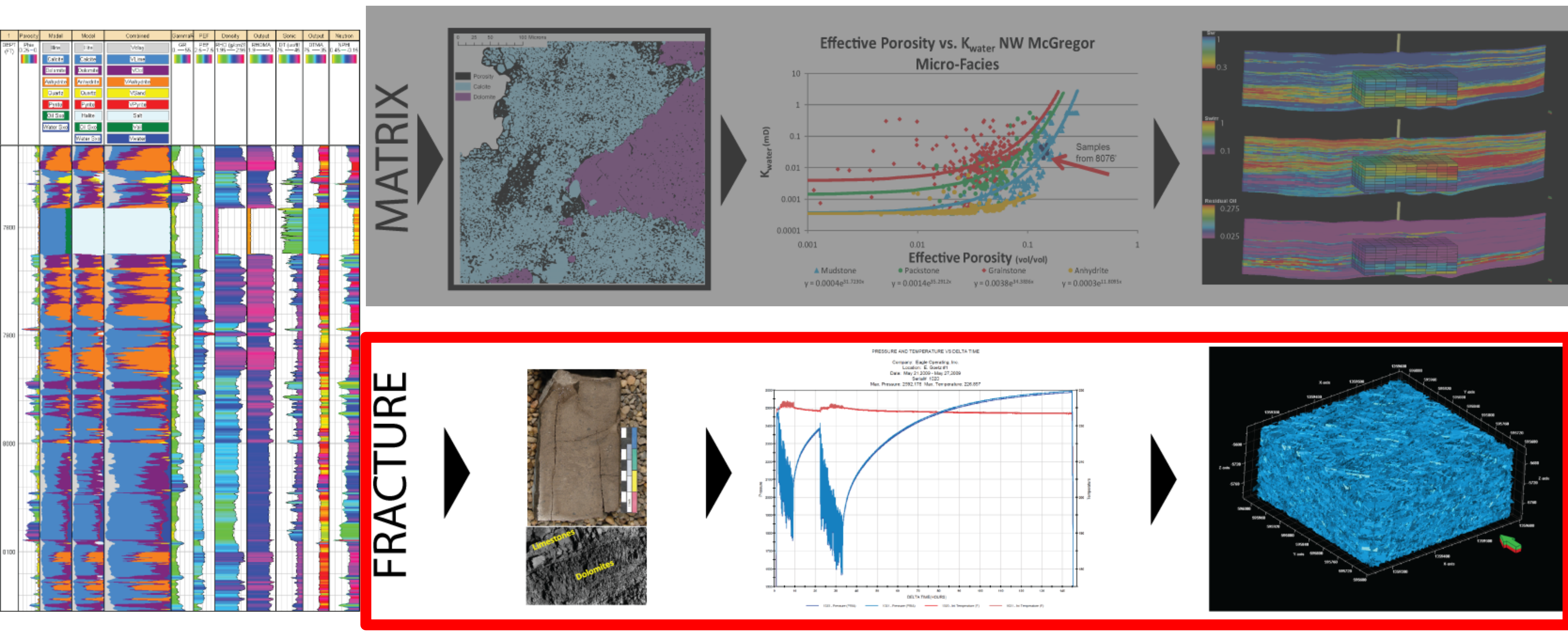


- Matrix modeling used sequential gaussian and indicator cosimulation.
- Upscaled simulation flow grid shown with lowered resolutions.

EERC
Energy & Environmental Research Center

Dual Porosity and Permeability Workflow

Fracture Workflow



Fracture Modeling Workflow

$k_f = k_d^{\,2}/k_m$ **(1)**

k_f =fracture permeability (md)
k_d= Permeability from DST (md)
k_m = Core permeability (md)

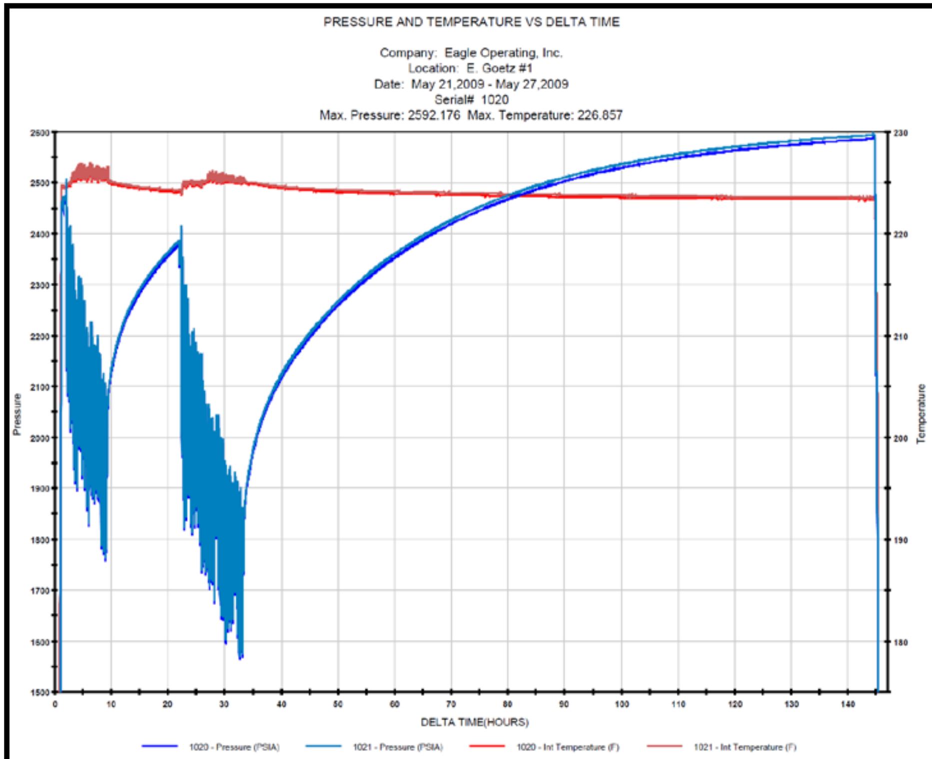
$k_e = k_m + \Phi_f * k_f$

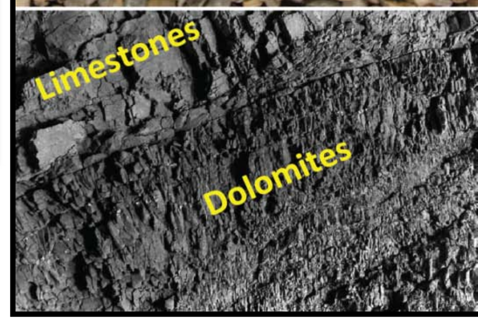
k_e = effective/DST permeability (md)
Φ_f = fracture porosity = W/Z x 100

$k_f = 84.4 \times 10^5 \times W^3/Z$ **(2)**

Z = fracture spacing (cm)
W = fracture width (cm)

Z is measured by documenting fractures in core

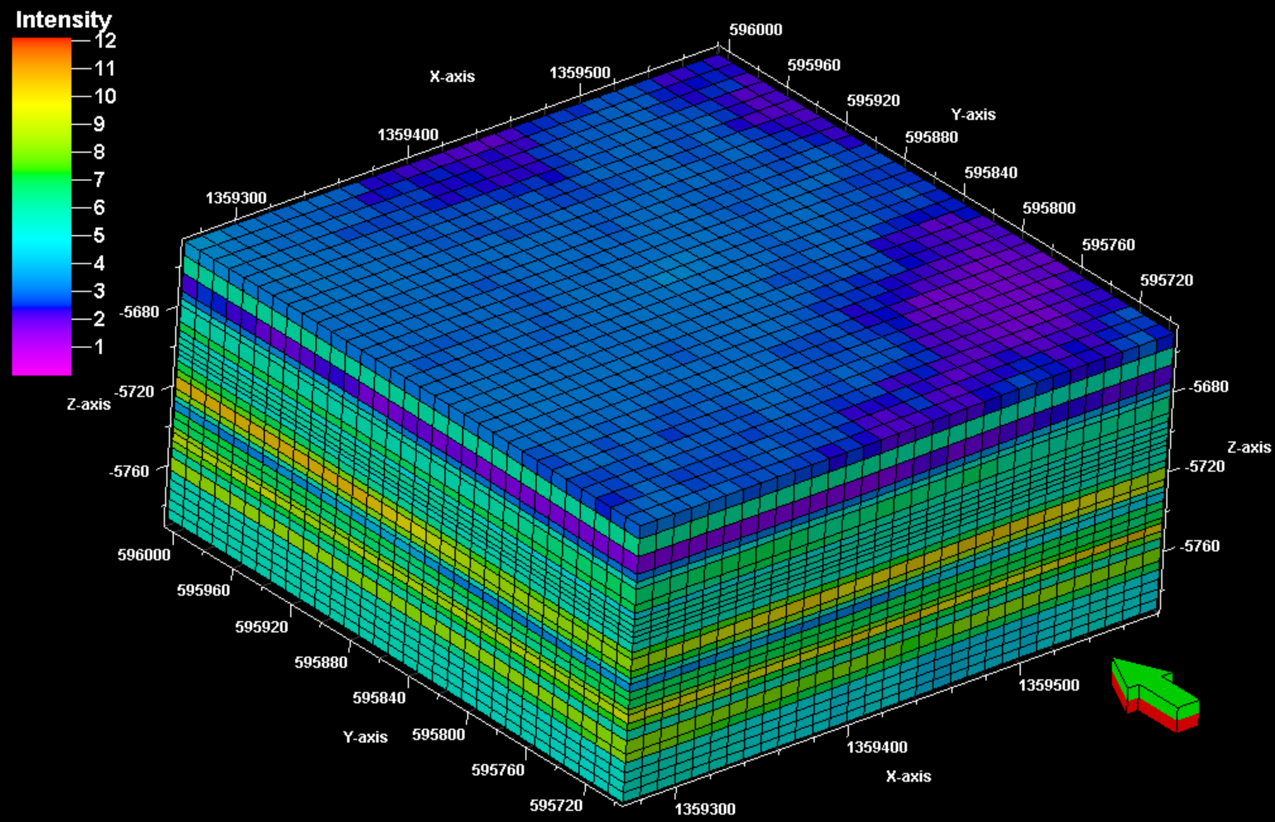




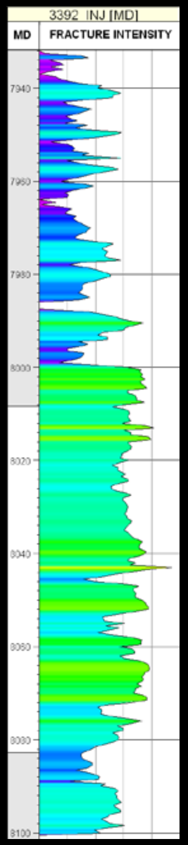
- Fractures propagate differently according to lithology.
- This concept was used to model fractures.

EERC
Energy & Environmental Research Center

Fracture Modeling Workflow

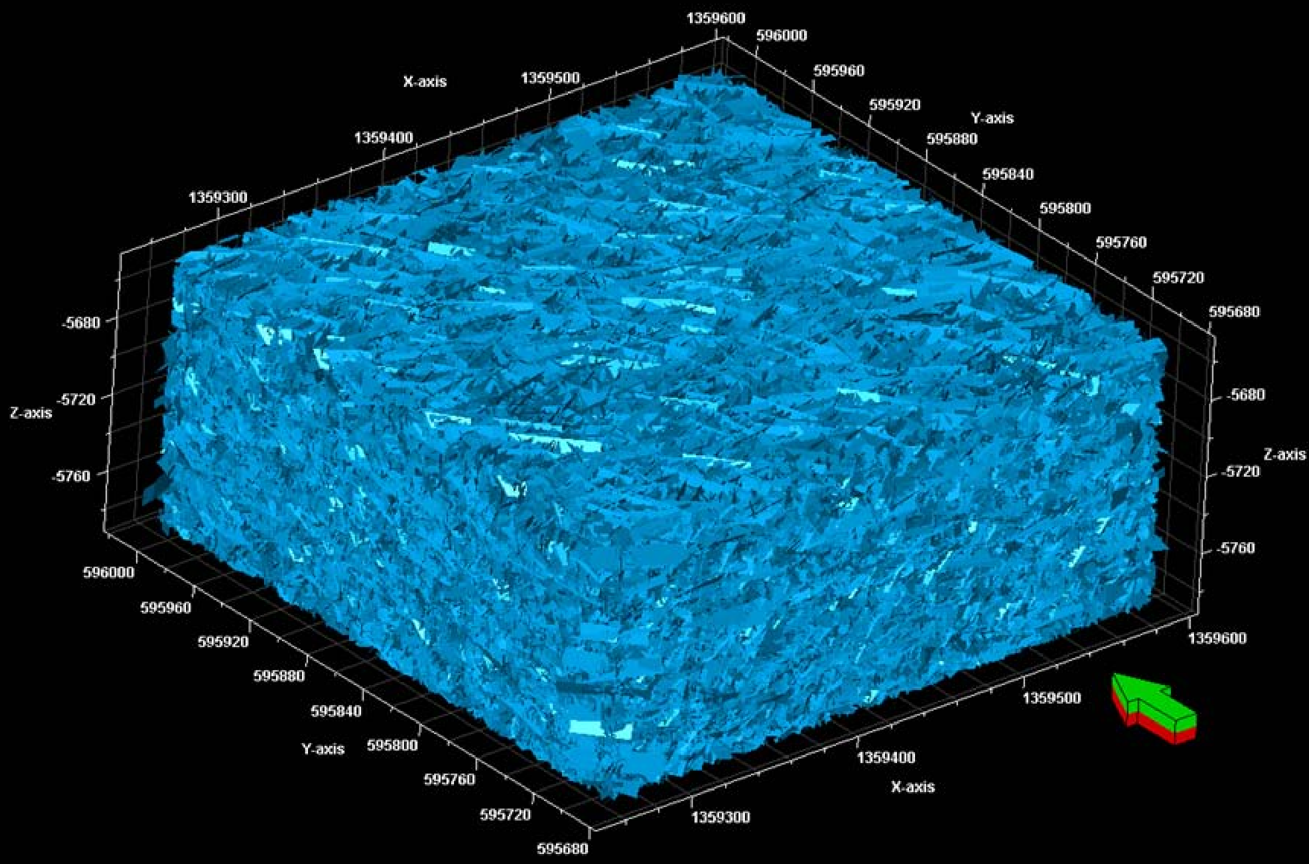


Fracture Intensity Grid



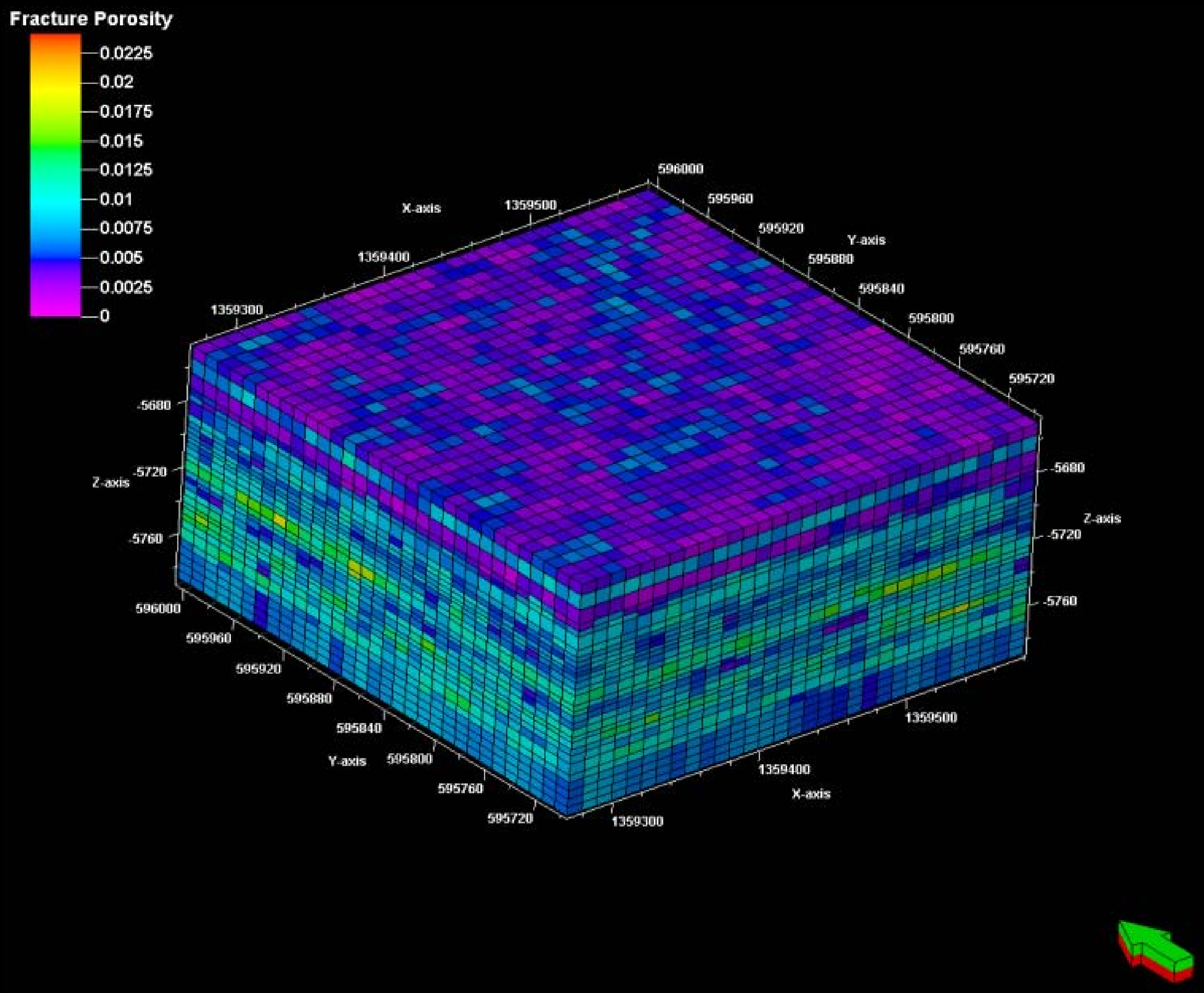
Synthetic Fracture Intensity Log

Fracture Modeling Workflow



Discrete Fracture Network

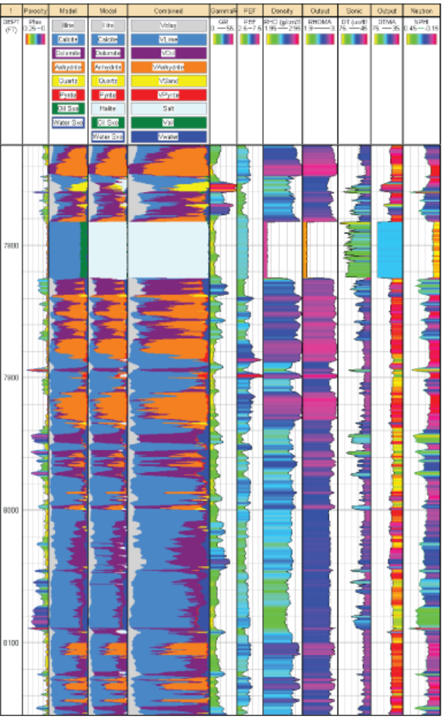
Fracture Modeling Workflow



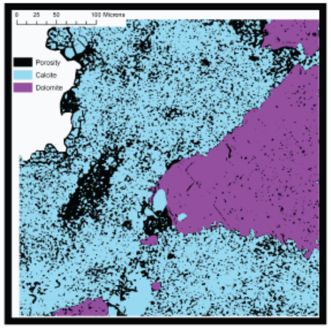
Fracture Porosity

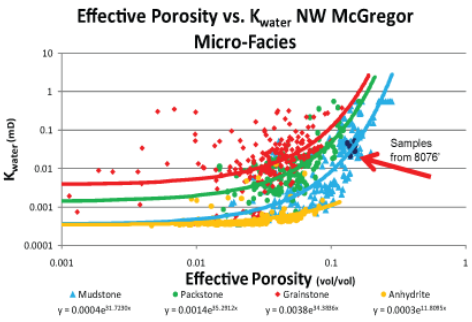
Dual Porosity and Permeability Workflow

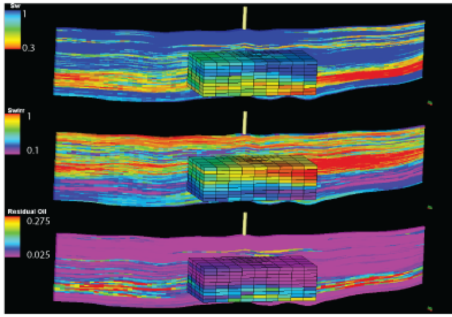
Dynamic Simulation



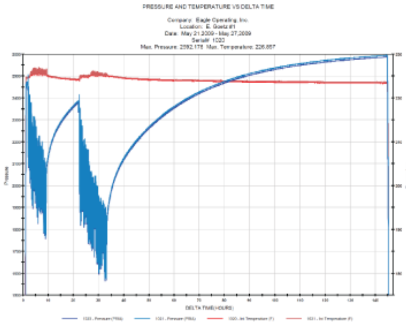
MATRIX

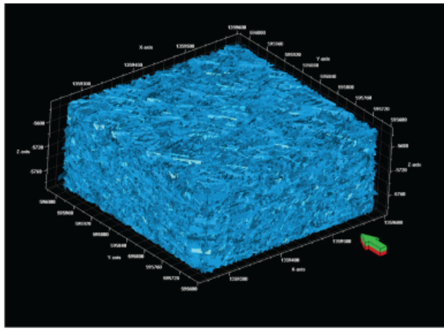




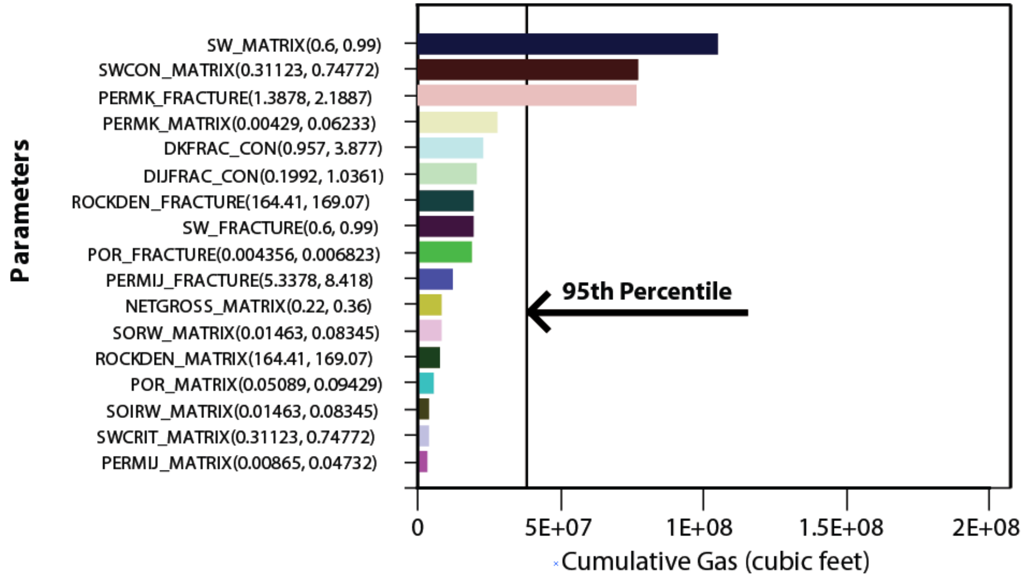


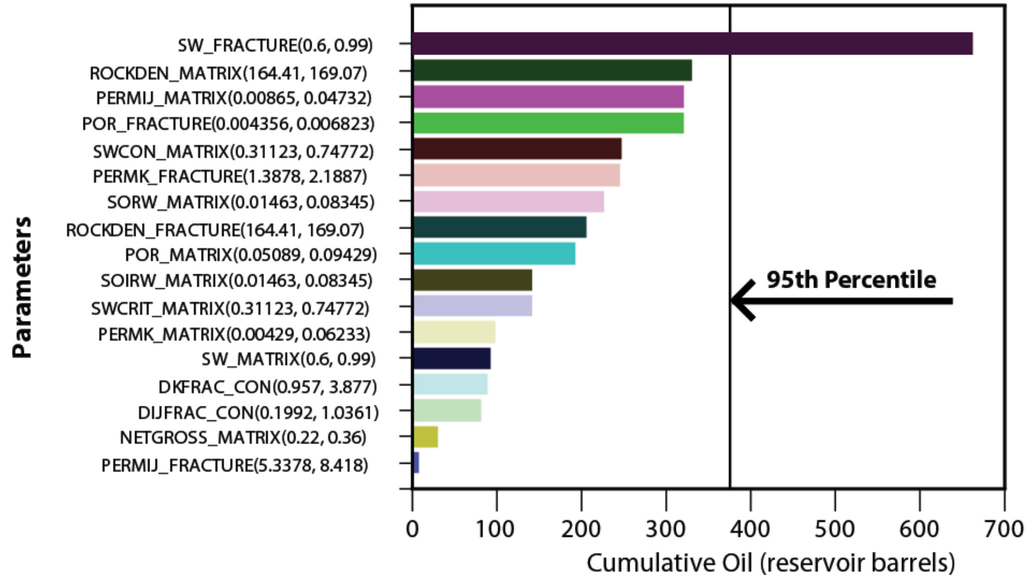
FRACTURE





Sensitivity Analysis





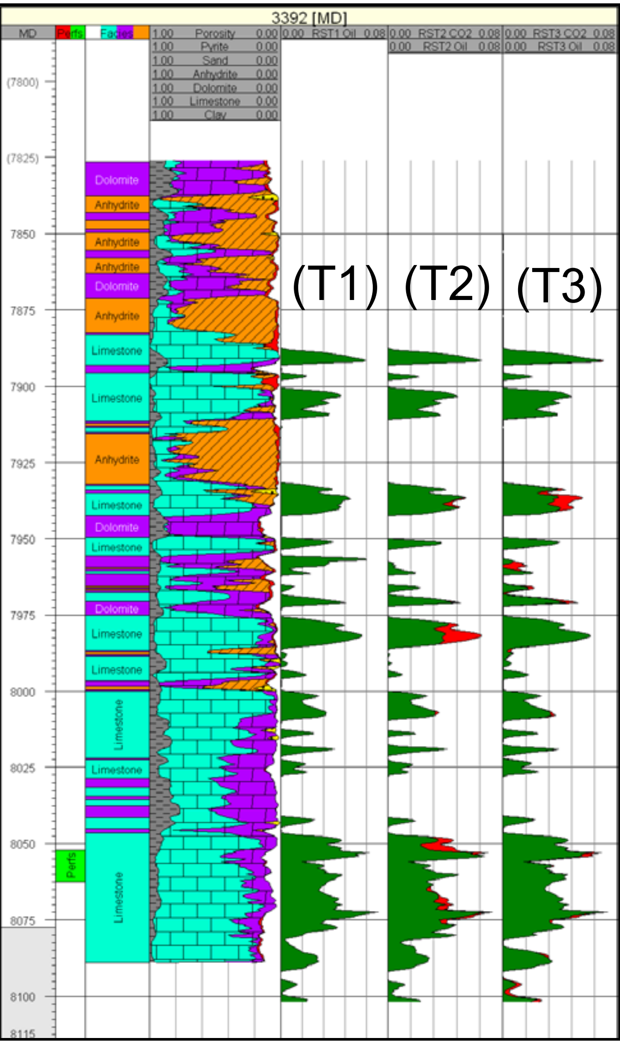
Why do a sensitivity analysis?

- To limit variable petrophysical properties that most affect injection and production.
- Without this, many unnecessary simulation runs may be required to form a history match.

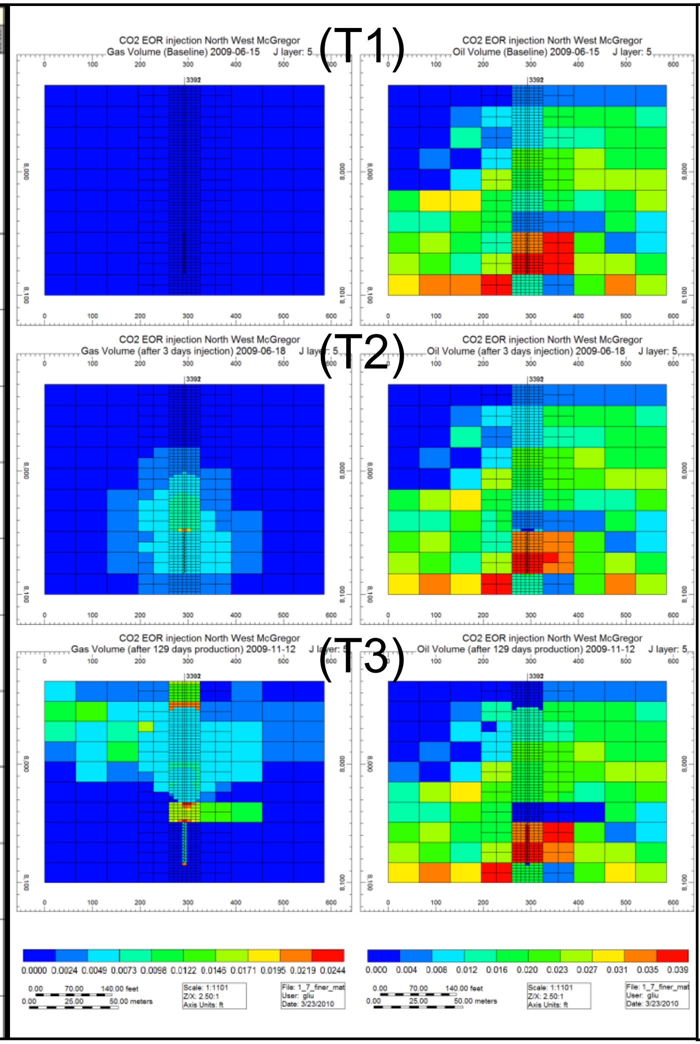
EERC
Energy & Environmental Research Center

Dynamic Simulation History Matching

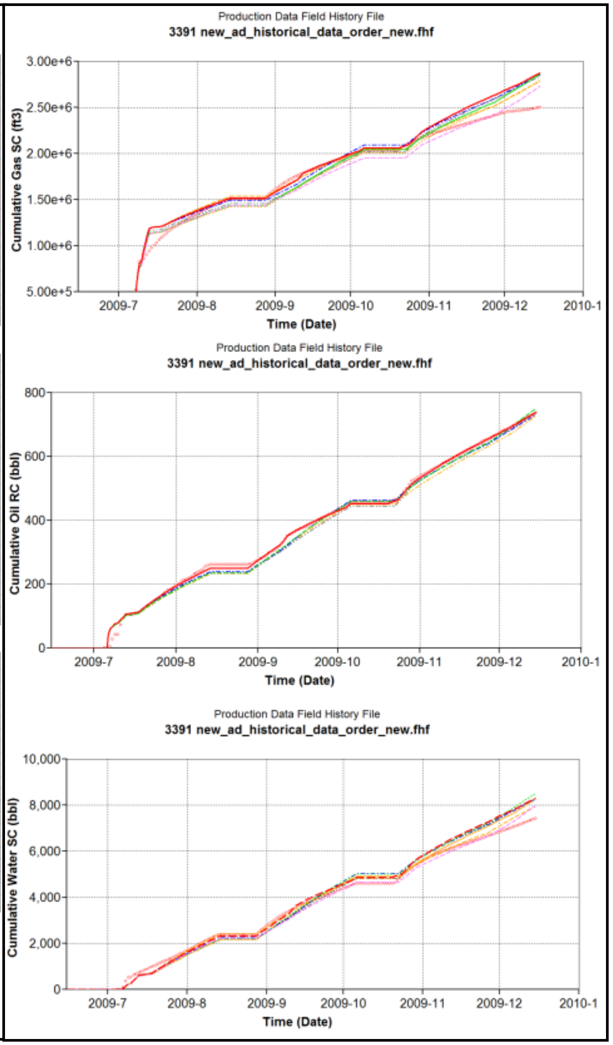
Time-Lapse RST Log



Time-Lapse Simulation Cross Sections of Total Oil and CO_2 Volumes

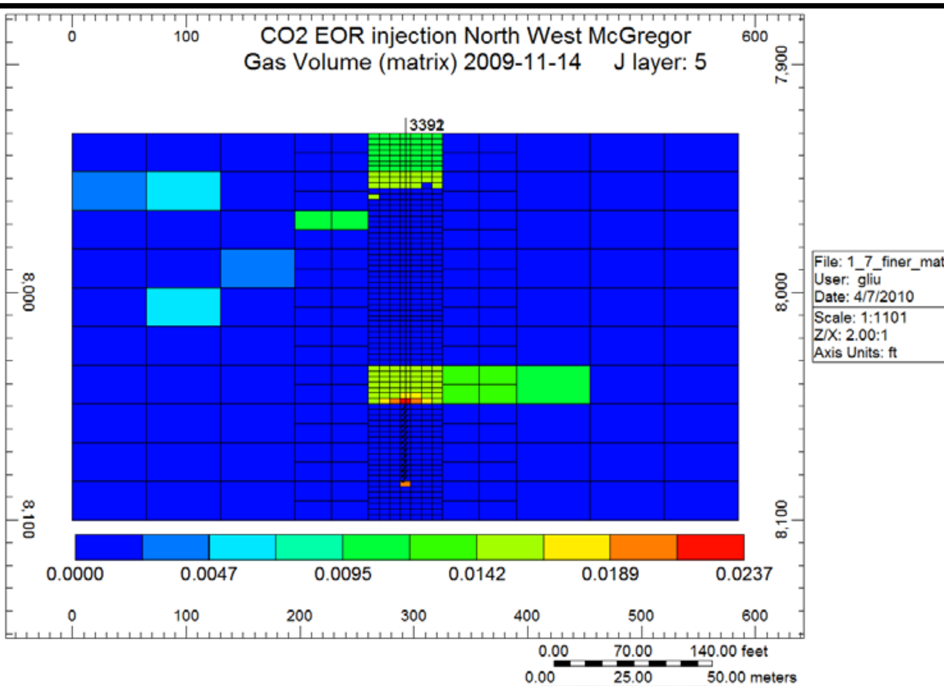


History Match Graphs

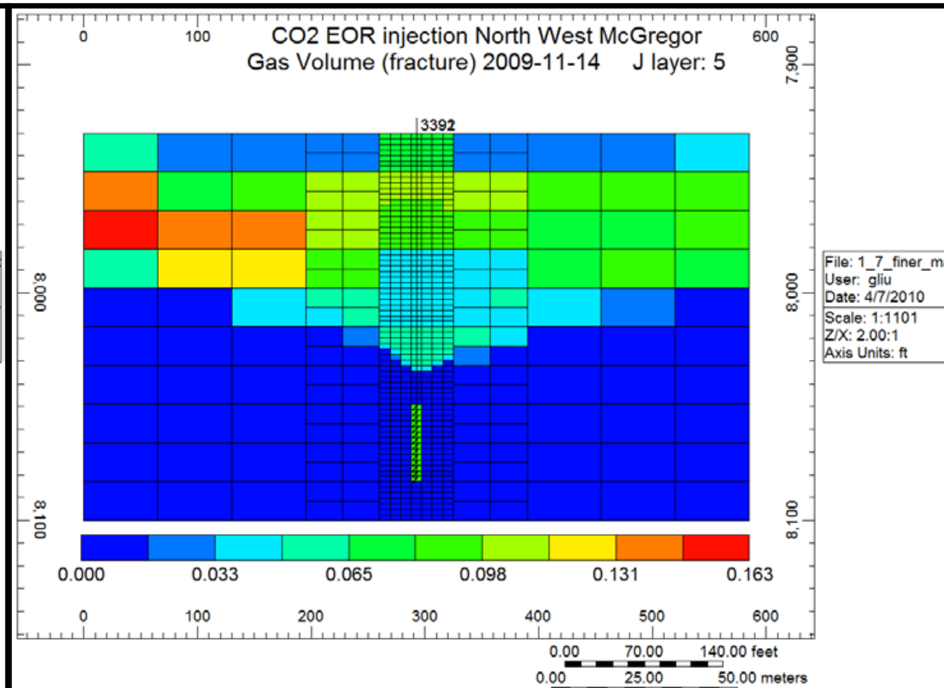


Matrix vs. Fracture CO_2 Saturations

MATRIX



FRACTURE



- CO_2 volumes are apparent In both matrix and fracture pore space.
- Most of the CO_2 is left in the fractures and does not permeate the matrix blocks.

EERC
Energy & Environmental Research Center

Results, Conclusions, Lessons Learned

- Over 6 months, recovery doubled.
- Injectivity was proven at 440 tons in 1.27 days, increasing qualifications for this type of formation in large-scale CO_2 injection projects.
- VSP and RST were determined to be vital and excellent tools for near-wellbore modeling.
- Modeling and history-matching activities gave good support for the overall CO_2 plume extent.
- Not accounting for fractures can lead to erroneous history matches.

Acknowledgments

The authors would like to thank:

Eagle Operating
Computer Modeling Group
Schlumberger
North Dakota Geological Survey
All PCOR Partnership partners
for their support.

Thank You!

Contact Information

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018
Phone: (701) 777-5000
Fax: (701) 777-5181
Web site: www.undeerc.org

Damion Knudsen, dknudsen@undeerc.org, (701) 777-5397
Charles Gorecki, cgorecki@undeerc.org, (701) 777-5355
James Sorensen, jsorensen@undeerc.org, (701) 777-5287
Jordan Bremer, jbremer@undeerc.org, (701) 777-0877
Steve Smith, ssmith@undeerc.org, (701) 777-5108
Edward Steadman, esteadman@undeerc.org, (701) 777-5279
John Harju, jharju@undeerc.org, (701) 777-5157

References

(1) Lucia, F. J. , 2007, Carbonate reservoir characterization, 2d Ed.: Springer Publishing.

(2) Djebbar, T., and Donaldson, E., 2004, Petrophysics, theory and practice of measuring reservoir rock and fluid transport properties, 2d Ed.: Gulf Publishing.