Production Performance of Permian Basin Wells & Potential for Improving Oil Recovery

Ozan Uzun
PhD Candidate, Petroleum Engineering

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COLORADO SCHOOL OF MINES
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Drivers and Motivation

- **Permian Basin** is the most prolific oil and gas producing geologic basins in the United Sates—spanning West Texas and Southeastern New Mexico. It has produced more than 33.4 Bbbl of oil and 118 Tcf of natural gas during a 100-year period (EIA 2018).
- The decline in oil recovery and ever-increasing water production require new solutions.
- Classical waterflooding in unconventional reservoirs is not plausible because of the small pore throat dimension casing very low permeabilities of the mudstone matrix. Two practical alternative are: (1) cyclic gas injection and (2) cyclic injection of special surface-active aqueous solutions which have shown great promise.
- Plan is to provide background material and two procedures to improve oil recovery in the Permian Basin tight formations such as the Wolfcamp.

Project Plan

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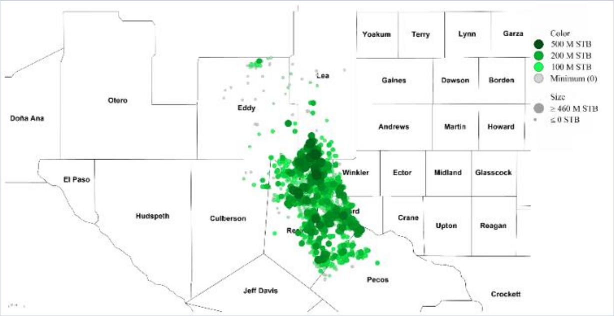
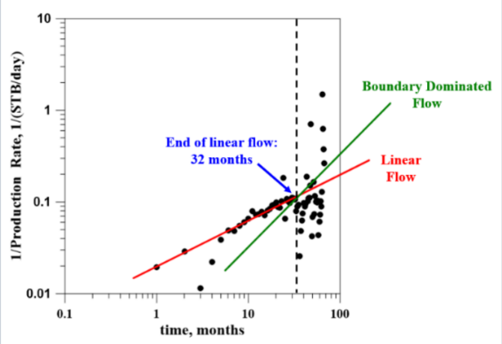
Phase 1:

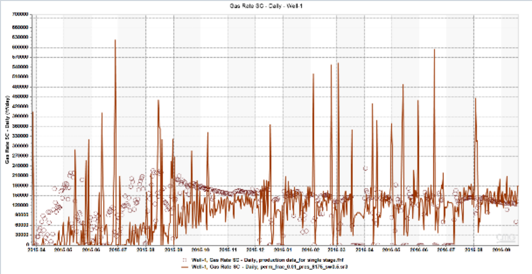
- Determine production characteristics of Delaware Basin wells
- Plan for several innovative EOR experiments

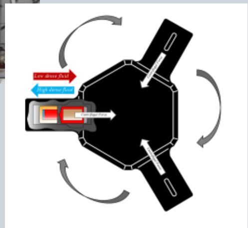




Phase 2:

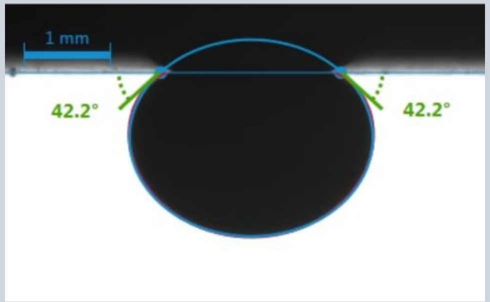
- Build an appropriate numerical model to forecast future performance
- Prepare for the EOR experiments



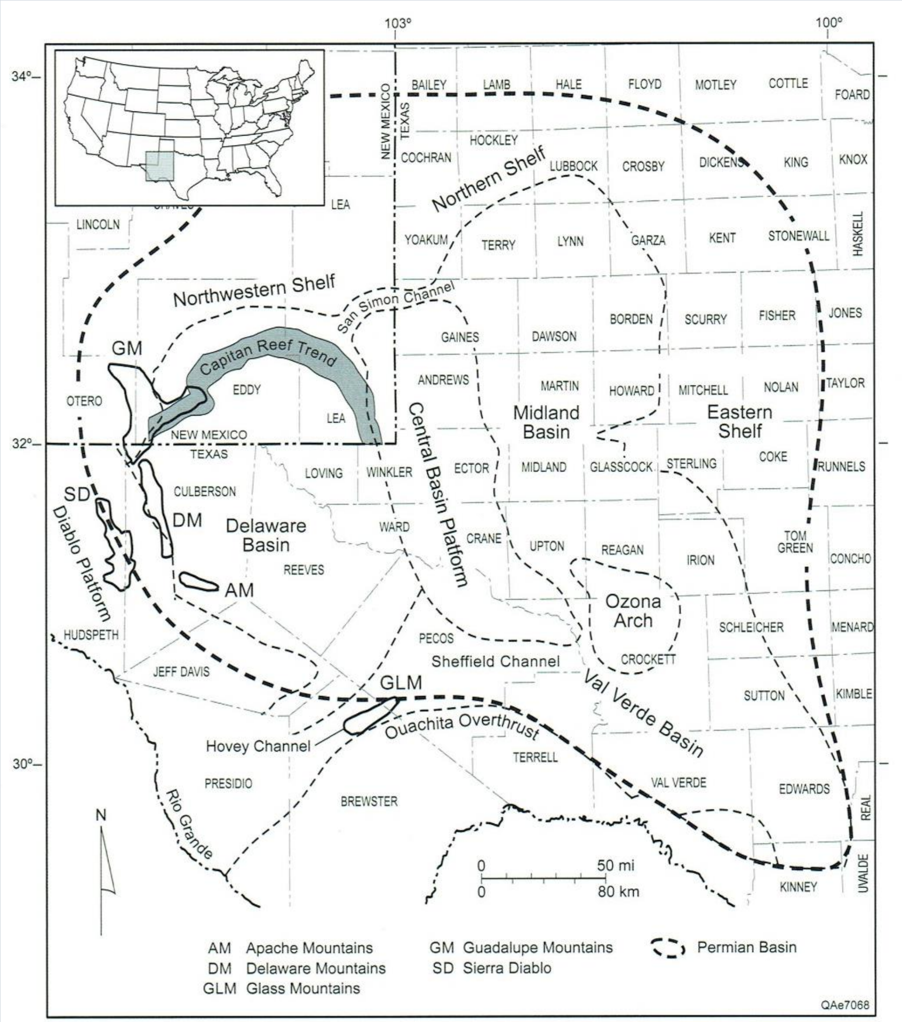


Phase 3:

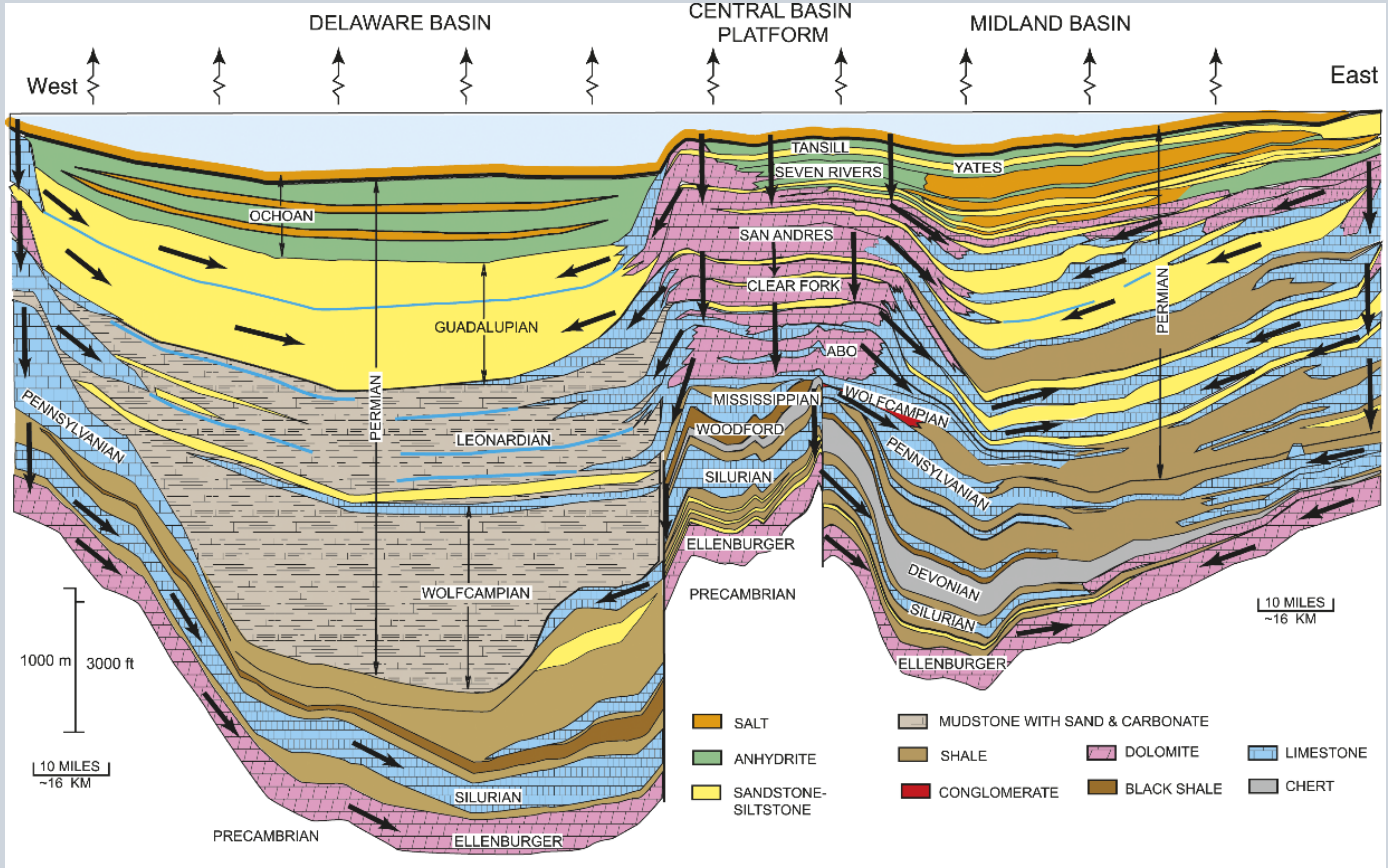
- Conduct EOR experiments
- Characterize field performance using numerical model (history match production data)



Permian Geology



(Ruppel 2019)

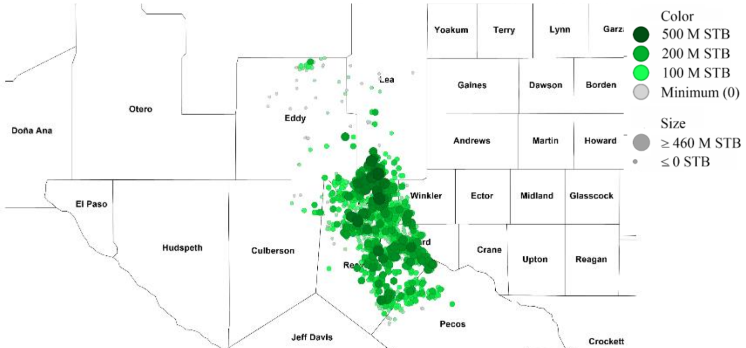


(Saller and Stueber, 2018)

Production Trends

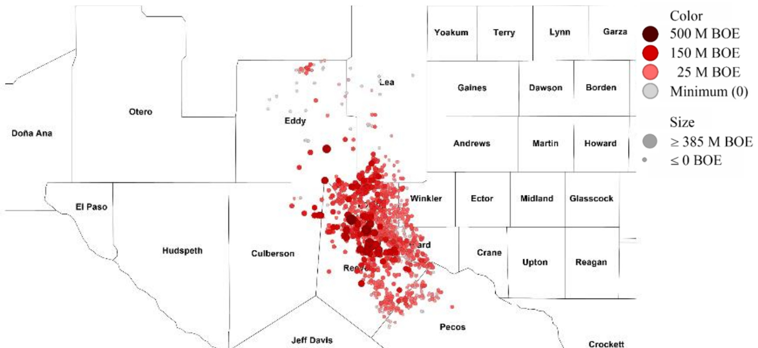
Performance of Oil Wells

12 Months



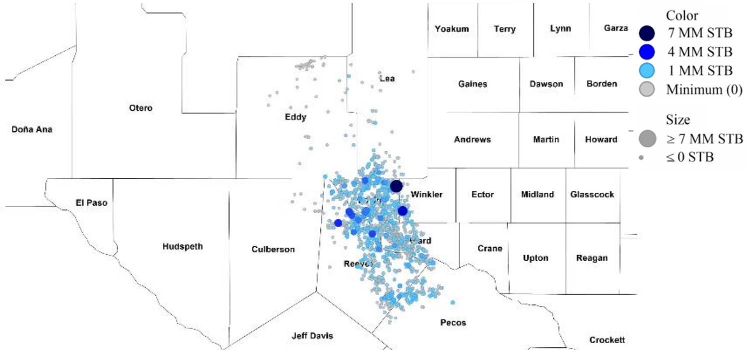
OIL

12 Months



GAS

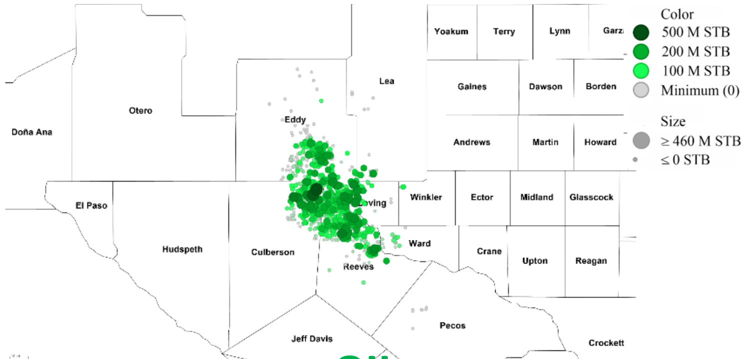
12 Months



WATER

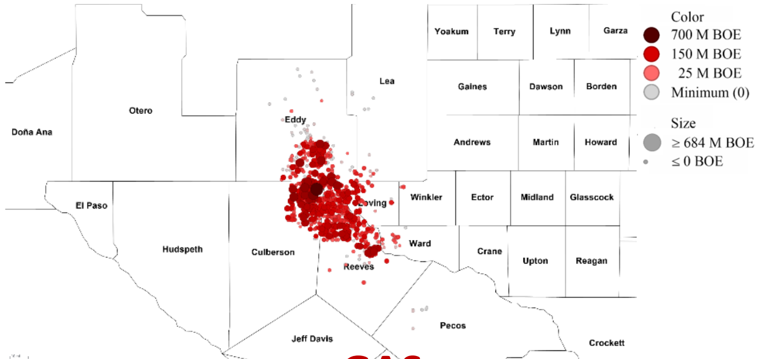
Performance of Gas Wells

12 Months



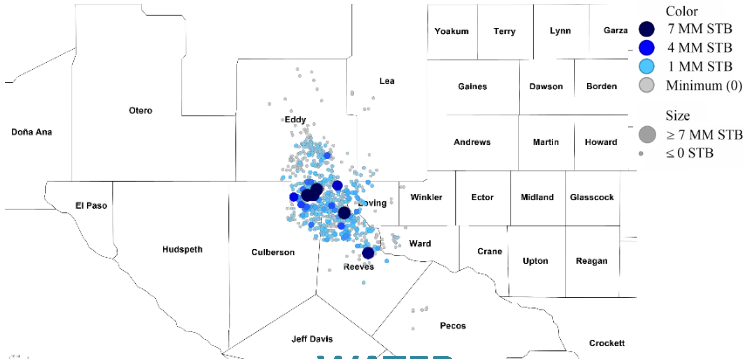
OIL

12 Months



GAS

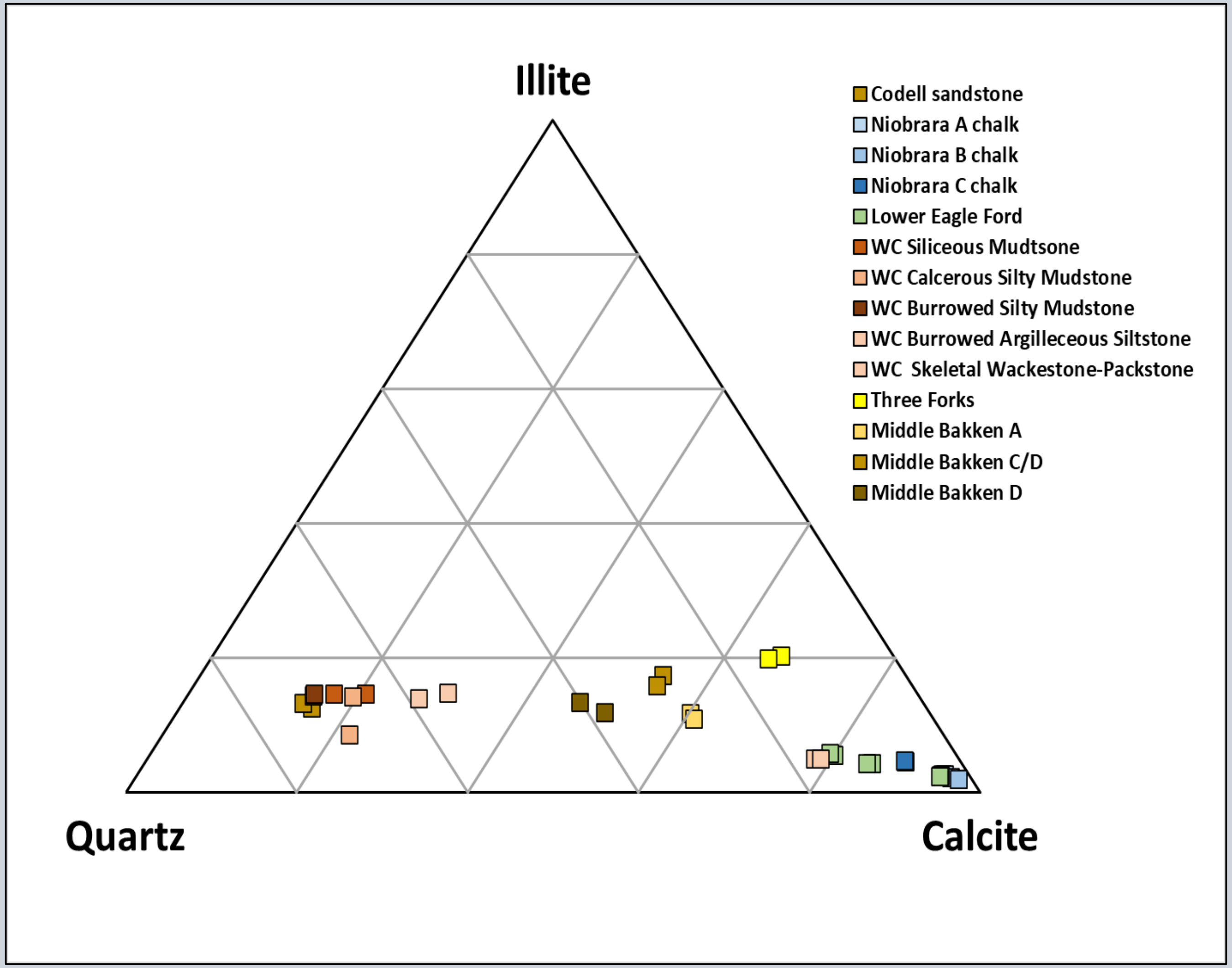
12 Months

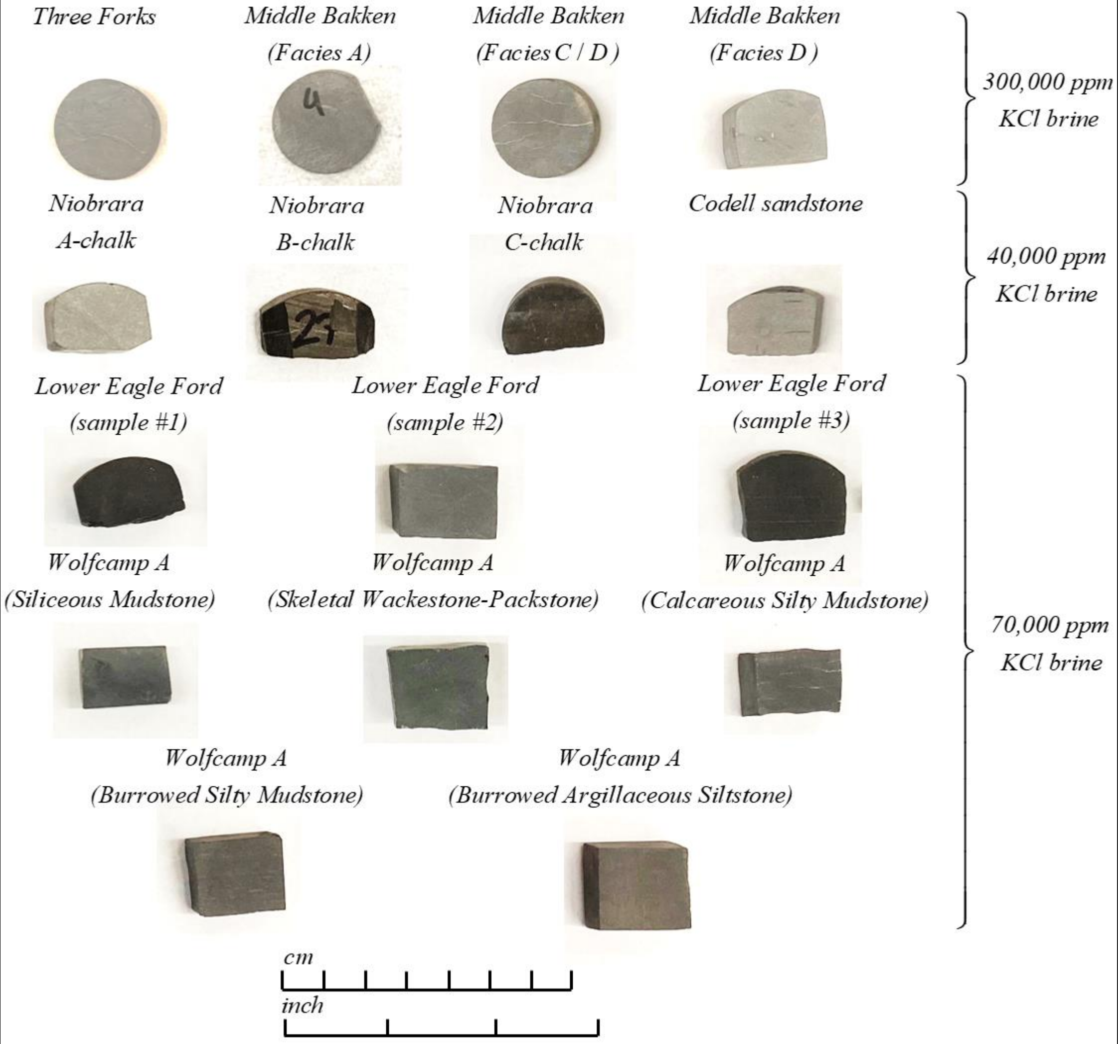


WATER

(Source: Enverus 2022)

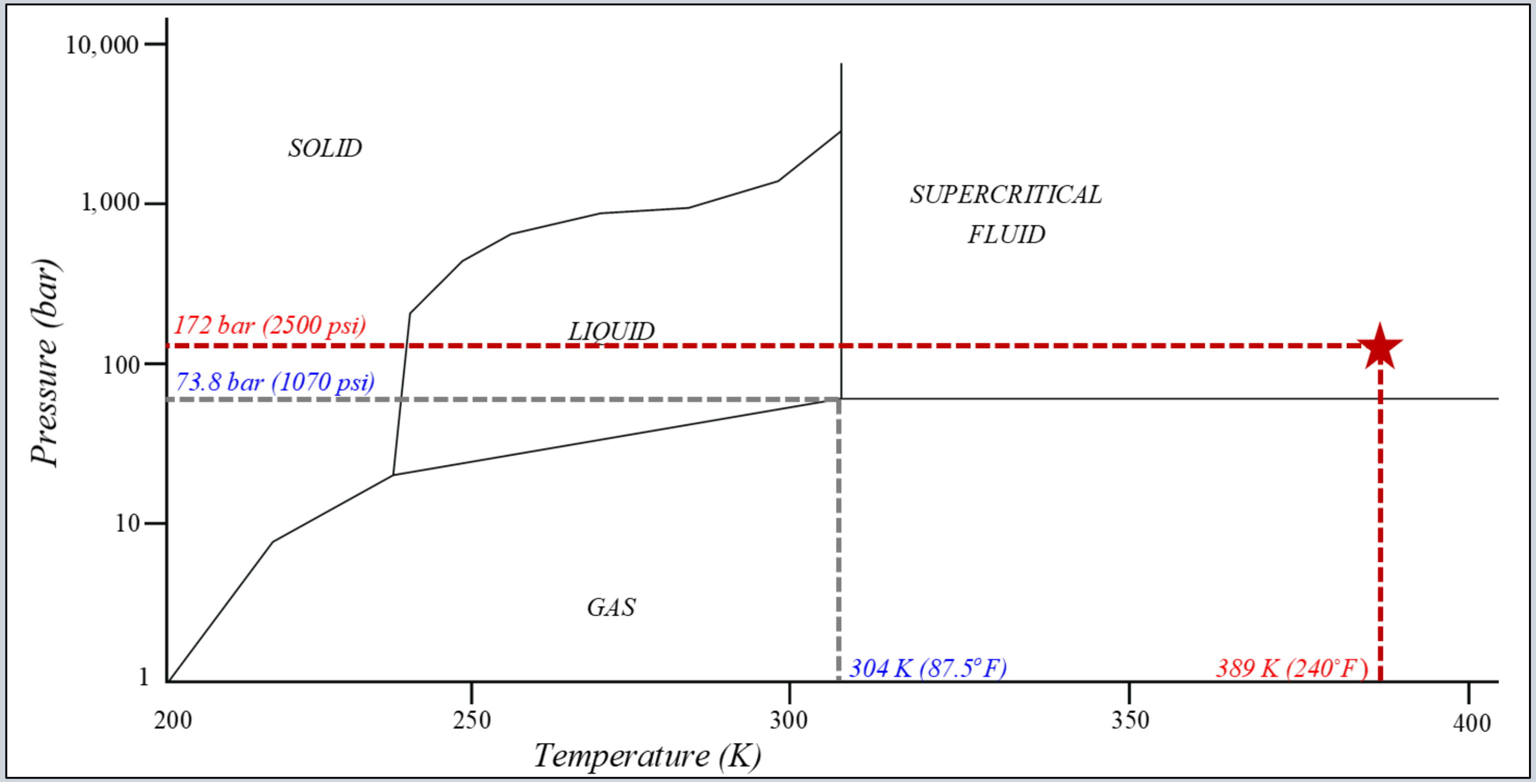
Samples Used for Experiments





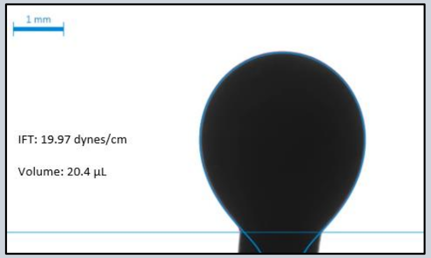
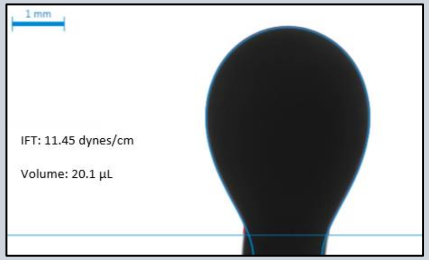
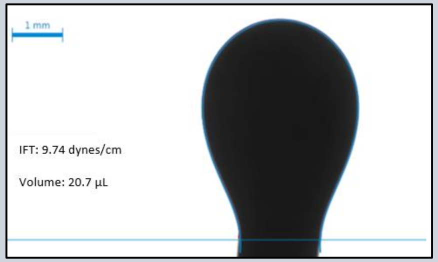
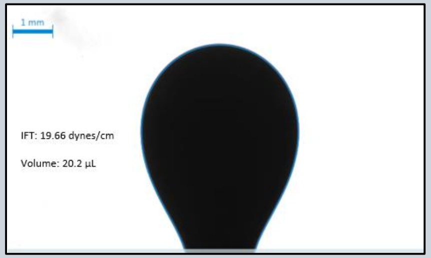
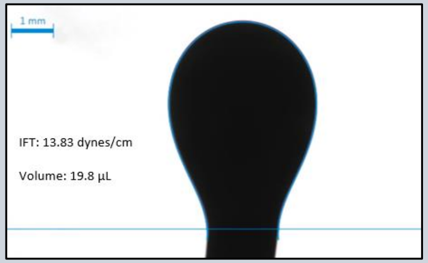
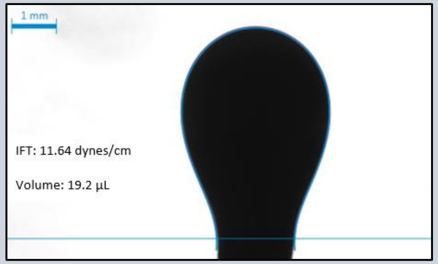
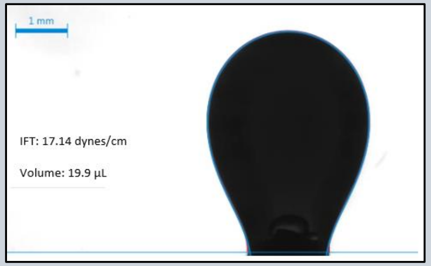
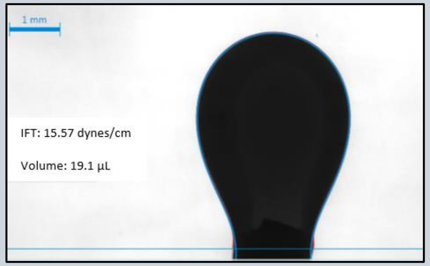
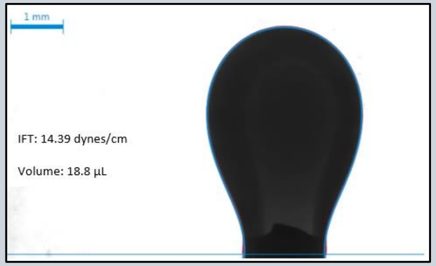
Experimental Procedure

1) Measuring contact angle of **unaged** samples in ambient conditions and reservoir conditions (240^{o}F & 2500 psi).
2) Measuring contact angle of **aged** samples in ambient conditions and reservoir conditions (240^{o}F & 2500 psi).
3) Injecting **CO2** to the cell above supercritical conditions.

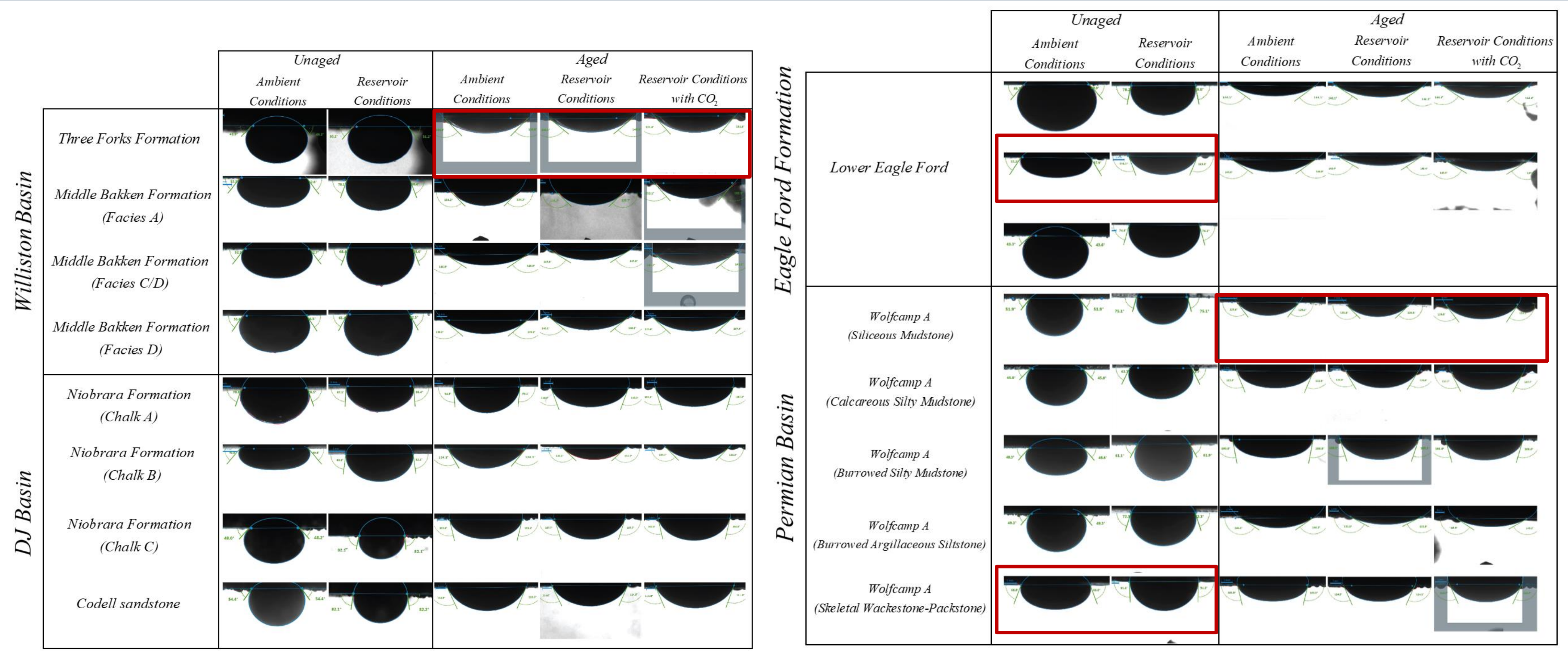


(Modified from Budisa and Schulze-Makuch 2014)

Experiment Results

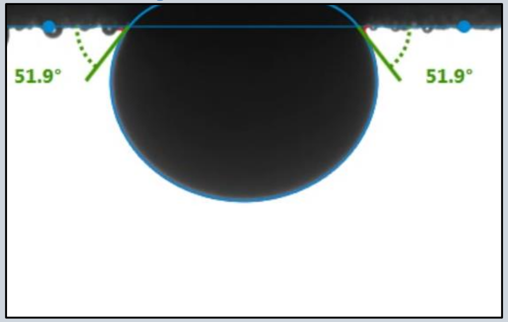
	Ambient Conditions	Reservoir Conditions	Reservoir Conditions with CO_2
DJ Basin	 IFT=19.97 dynes/cm	 IFT=11.45 dynes/cm	 IFT=9.74 dynes/cm
Eagle Ford and Wolfcamp	 IFT=19.66 dynes/cm	 IFT=13.83 dynes/cm	 IFT=11.64 dynes/cm
Williston Basin	 IFT=17.14 dynes/cm	 IFT=15.57 dynes/cm	 IFT=14.39 dynes/cm

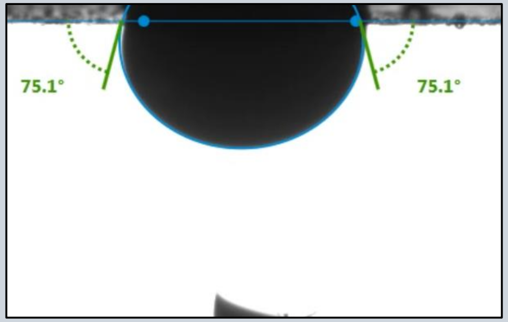
Experiment Results



Effect of Temperature & Pressure

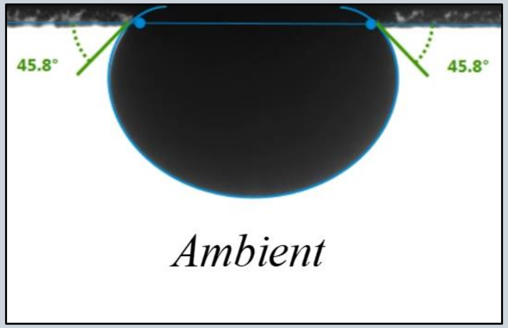
Temperature

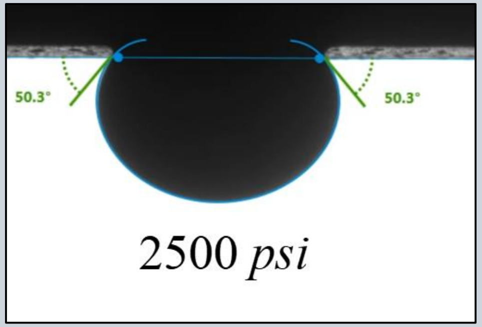




- Rapid increase (<3 hrs)
- Permanent
- Change varies (5-54 º)

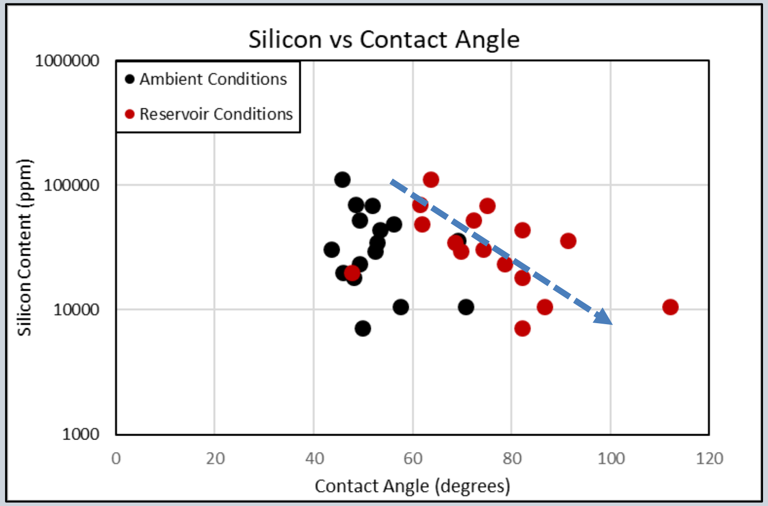
Pressure

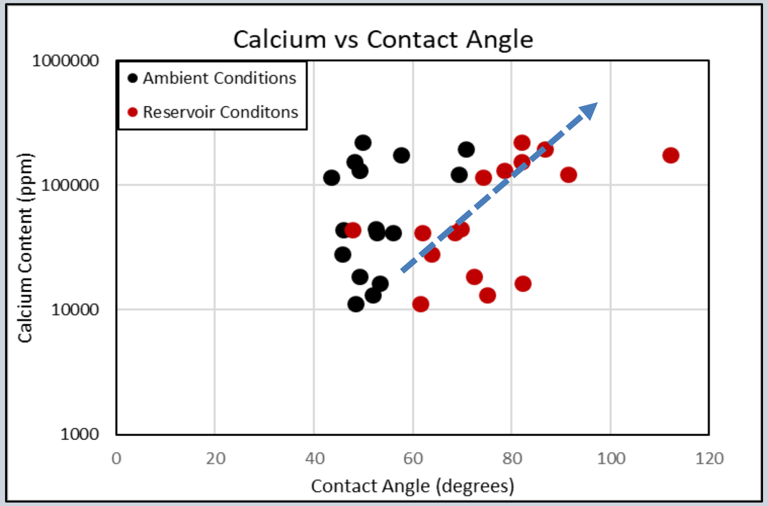


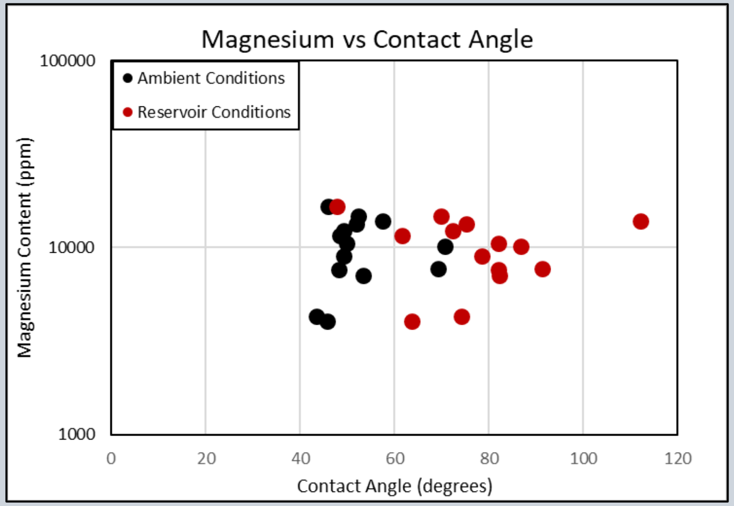


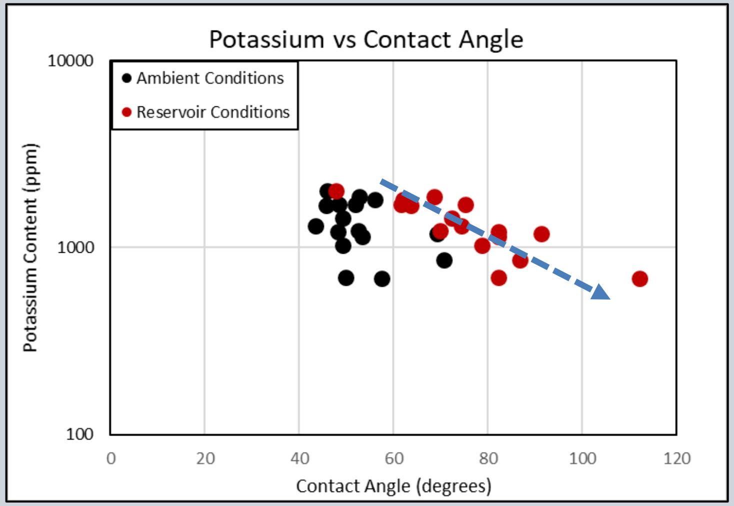
- Immediate increase
- Temporary
- Change is same on all samples (~4.5º)

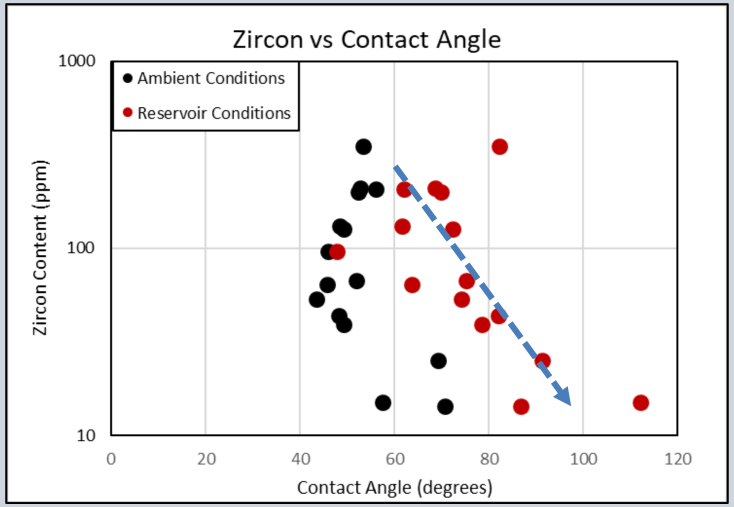
Effect of Mineralogy on Contact Angle Changes (Unaged Cores)



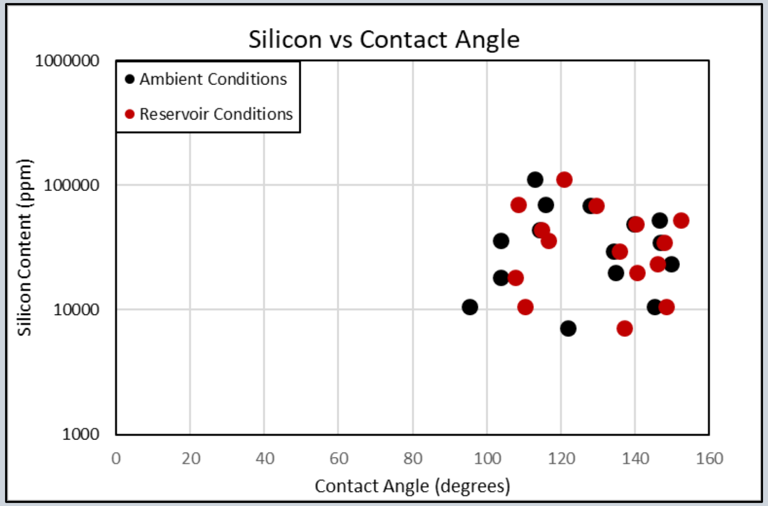


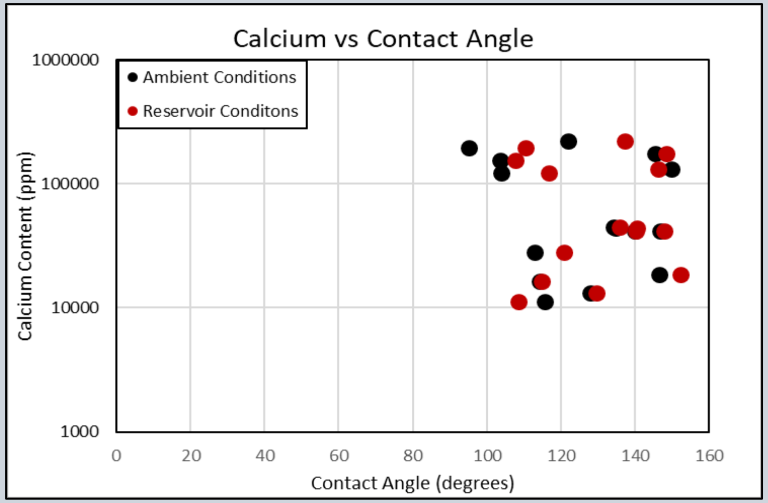


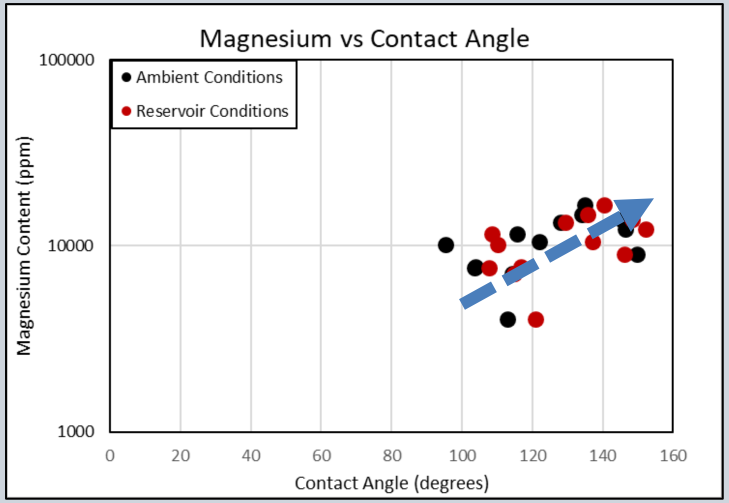


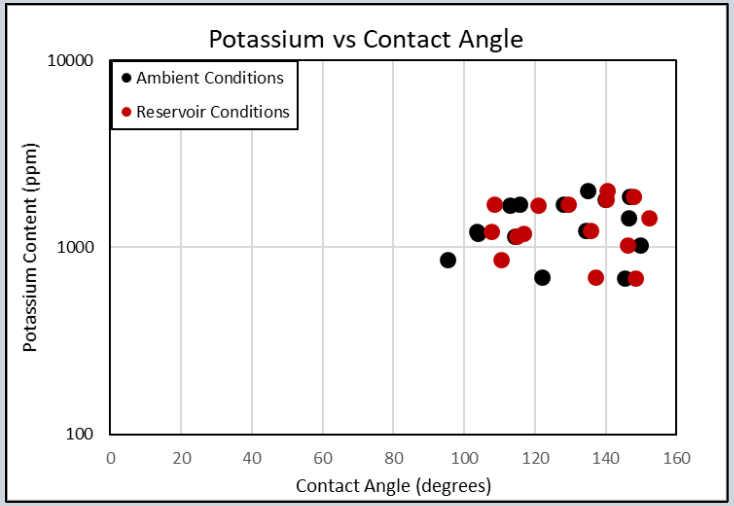


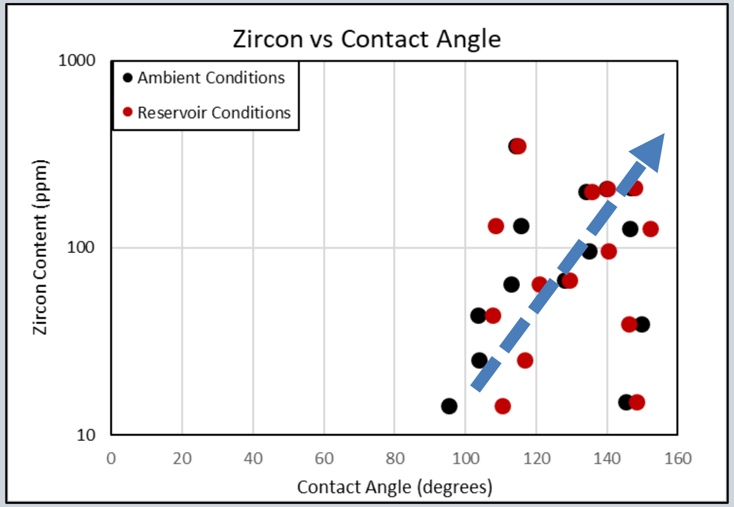
Effect of Mineralogy on Contact Angle Changes (Aged Cores)



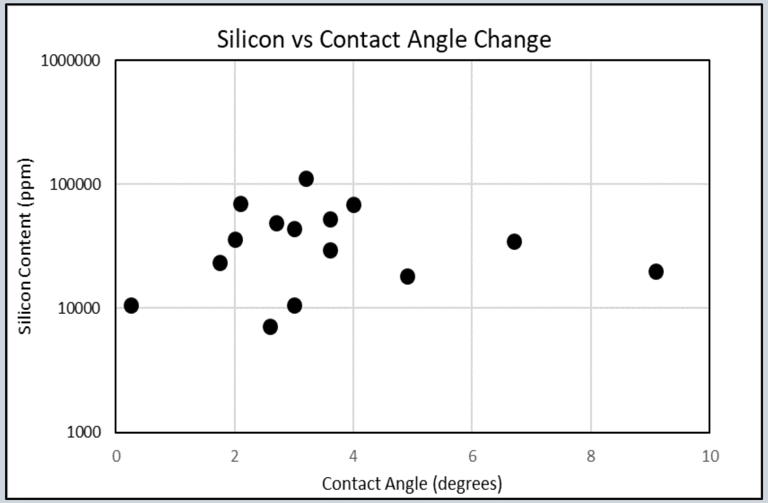


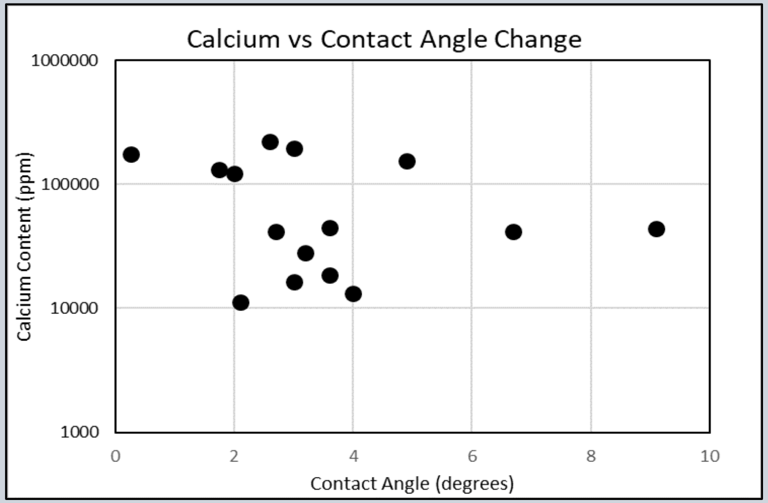


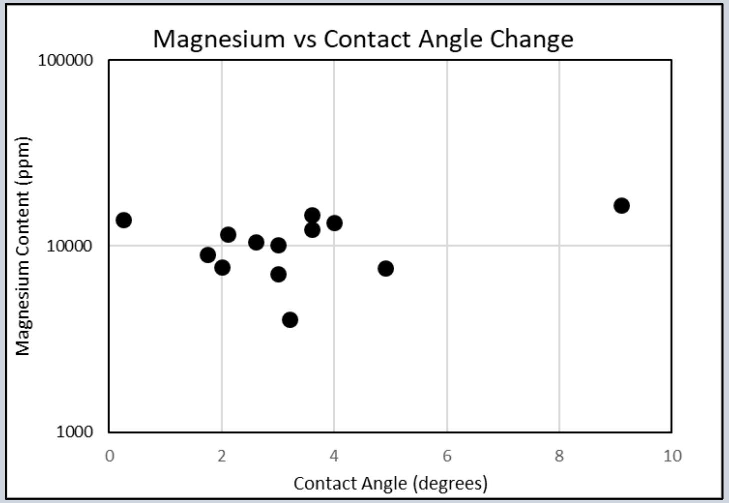


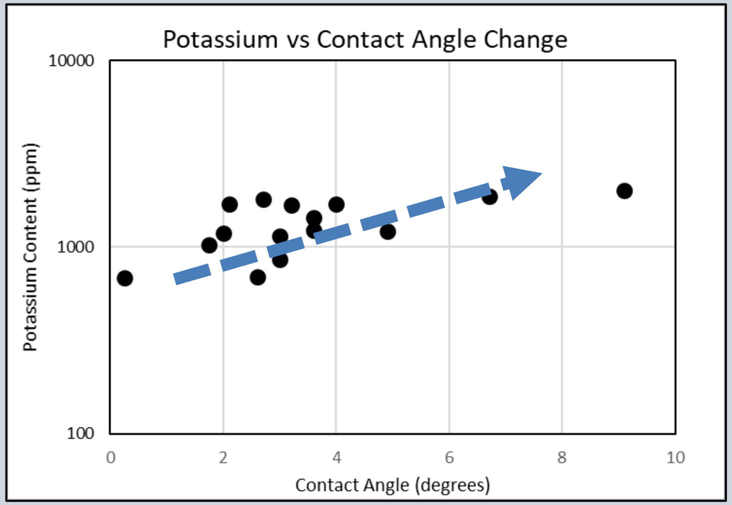


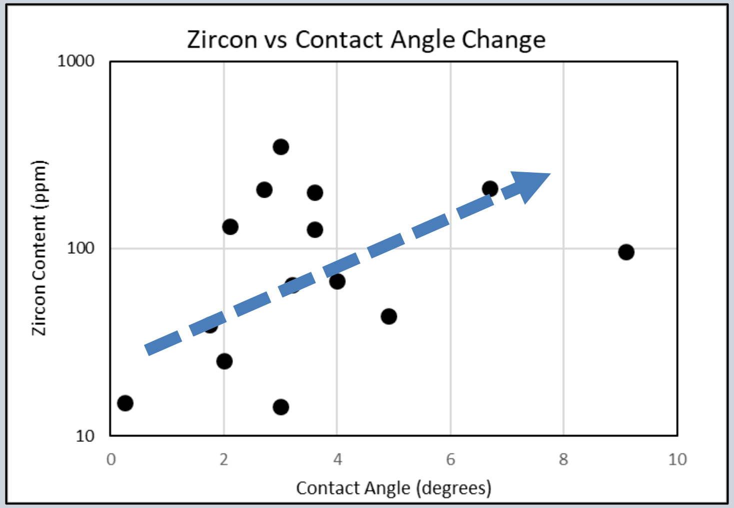
Effect of Mineralogy on Contact Angle Changes (Aged Cores with CO2)







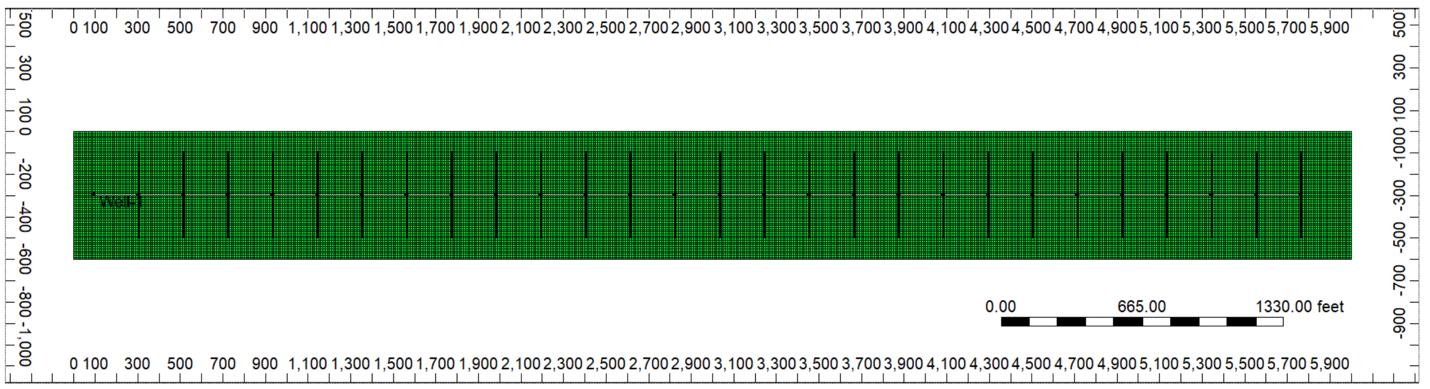


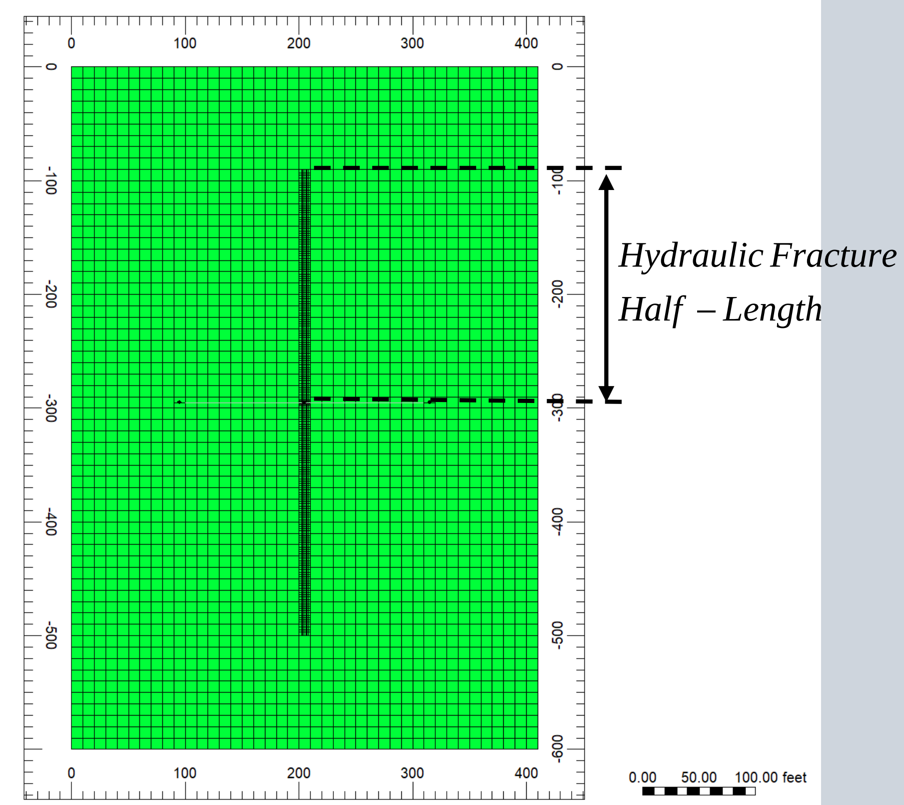


CMG-GEM Numerical Model
Reservoir Properties & Numerical Grid Structure

- Gross thickness: 600 ft
- Initial res pressure: 8175 psia
- Reservoir temp:181.5 °F

- Porosity: 0.06
- Matrix permeability: 0.0003 mD
- Matrix pore compressibility: 1×10^{-5} $psia^{-1}$



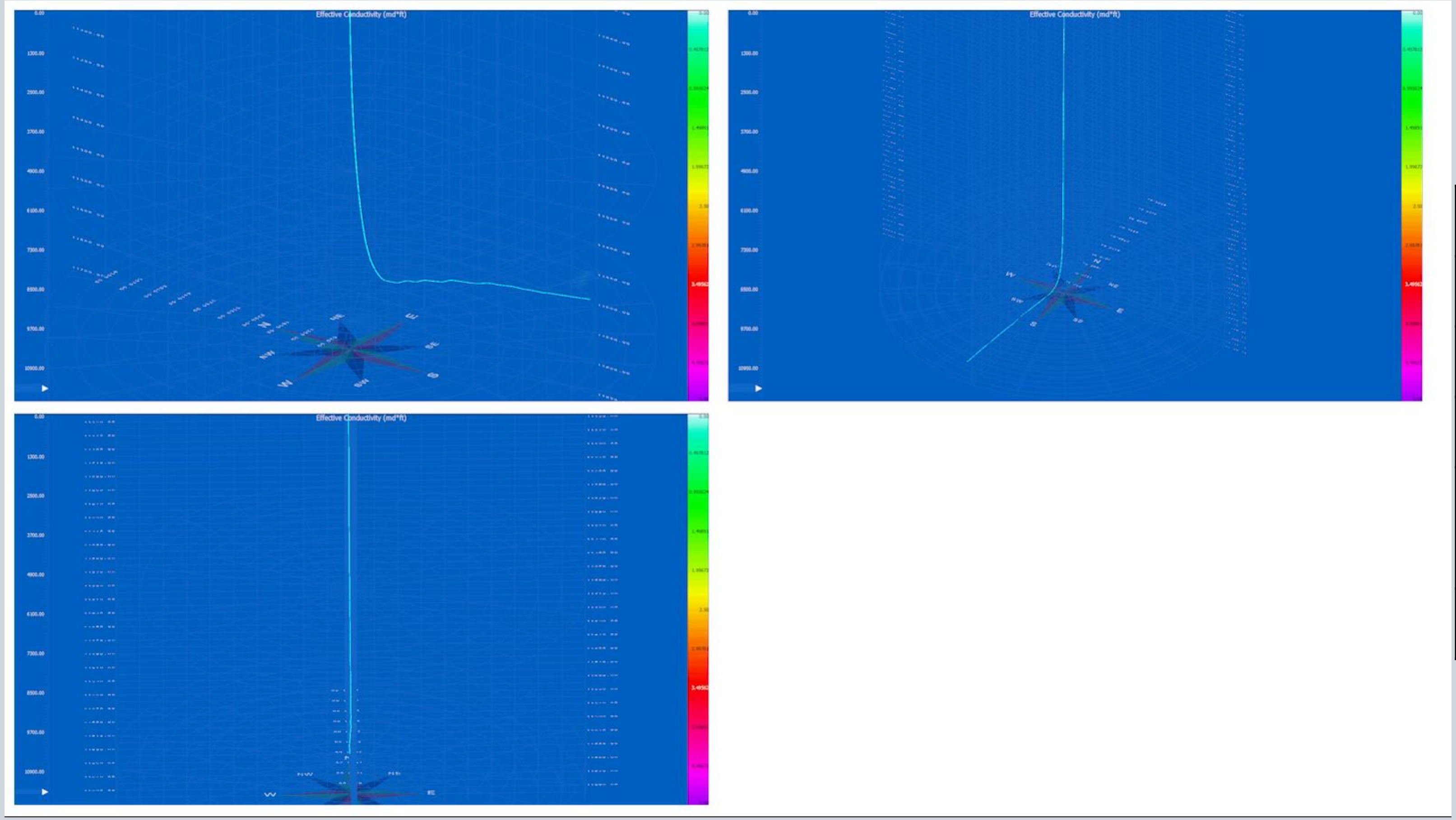


IMAX : 600
JMAX : 60
KMAX : 60

Δx : 10 ft
Δy : 10 ft
Δz : 10 ft

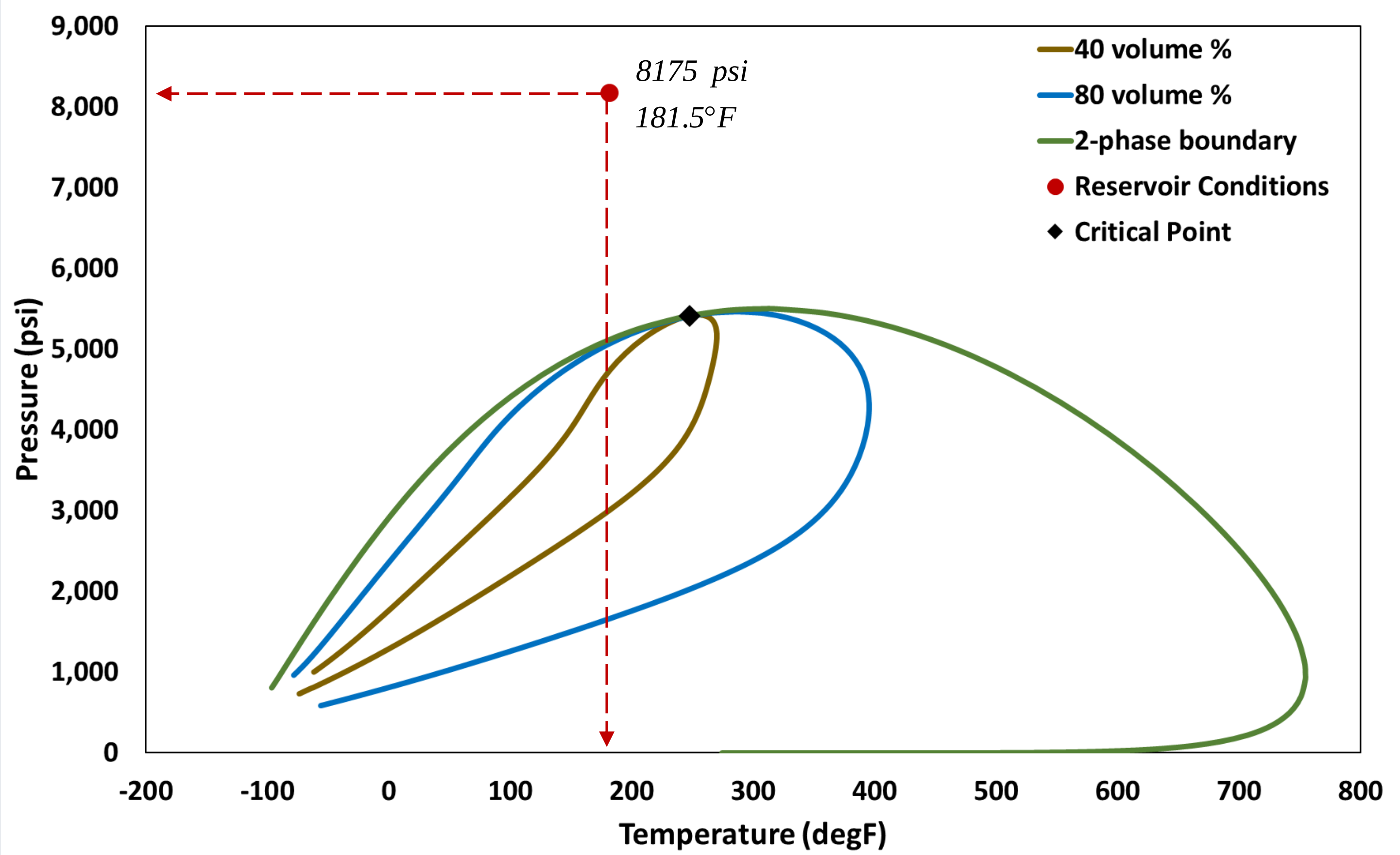
27 HF stages

GOHFER Hydraulic Fracture Model



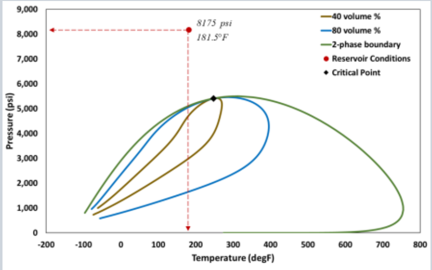
Number of Stages	27
Cluster per stage	4
Stage Length (ft)	212
Cluster Spacing (ft)	52
Total Perforation shot per stage	24
Perforation Diameter (in)	0.54/0.46

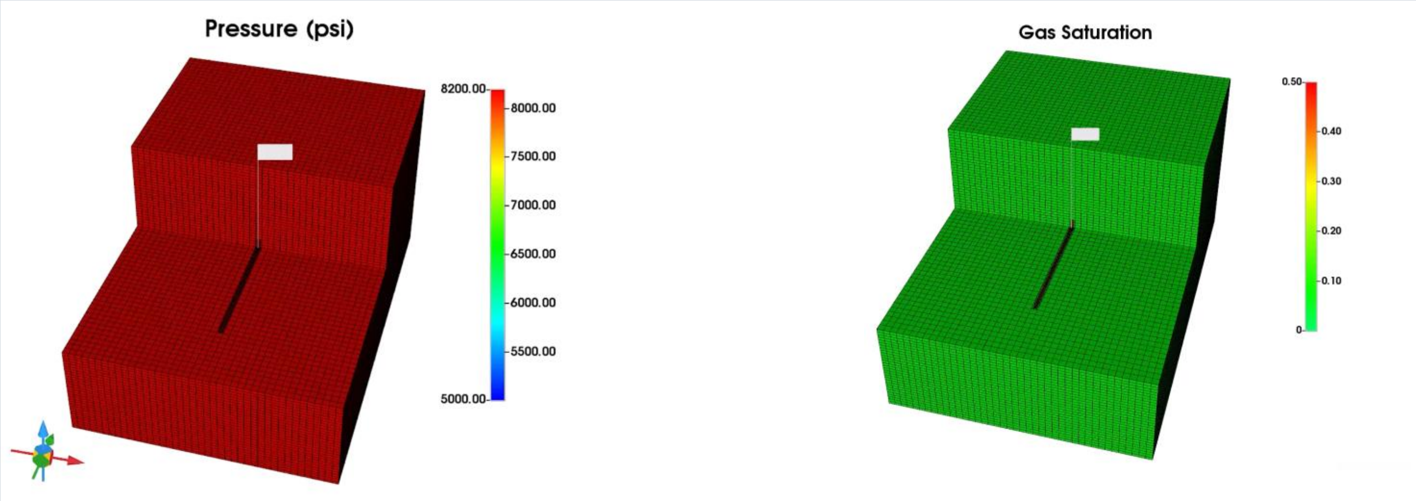
Hydrocarbon Fluid Model

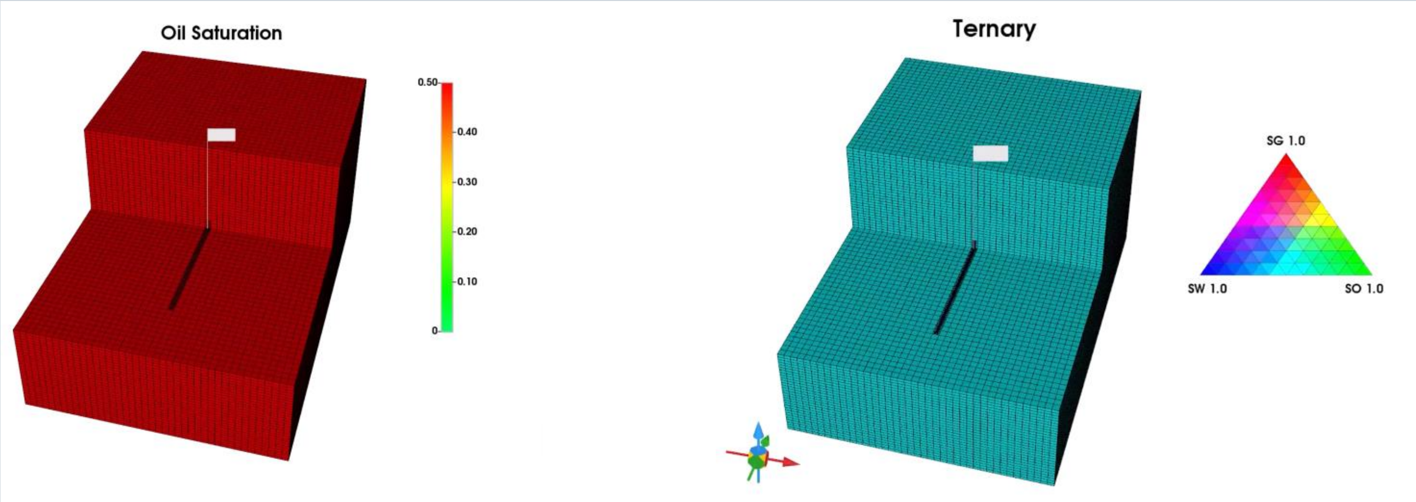


Component	Mole Percent
N_2 to CO_2	0.9
CH_4	67.59
C_2H_6	9.24
C_3H_8	5.51
IC_4 - NC_4	2.79
IC_5 - FC_6	2.31
FC_7 - FC_{10}	5.62
FC_{11} - C_{15}	2.98
FC_{16} - C_{22}	1.69
FC_{23} - C_{30+}	1.35

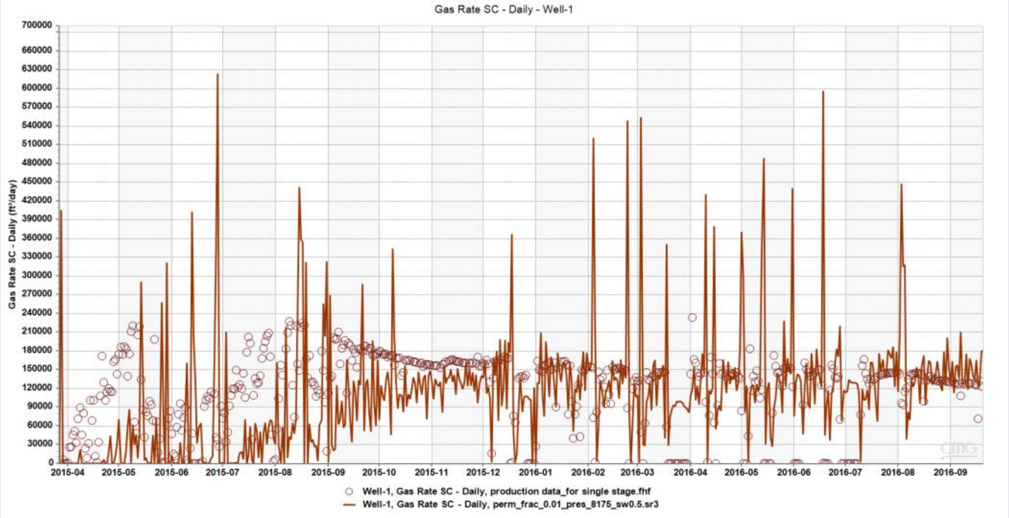
CMG-GEM Numerical Model History Match Results

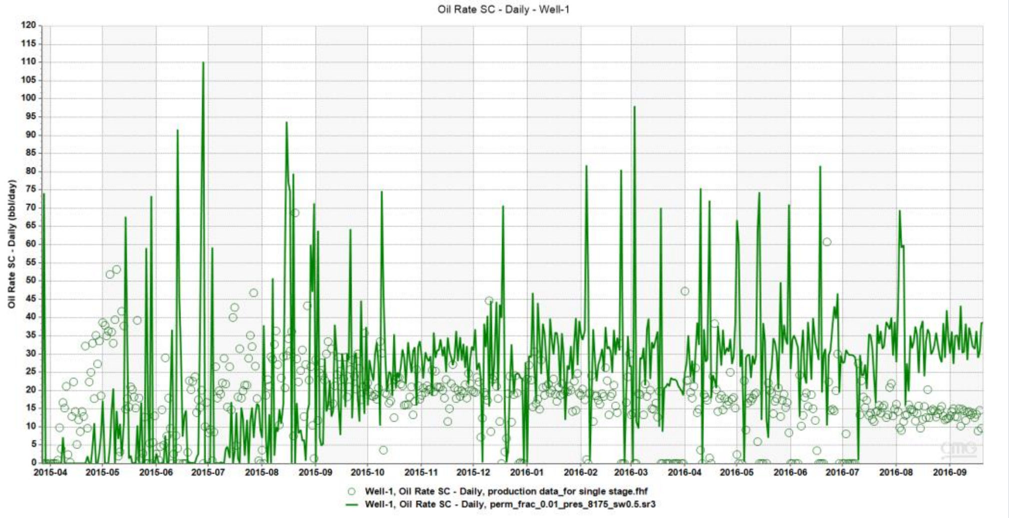


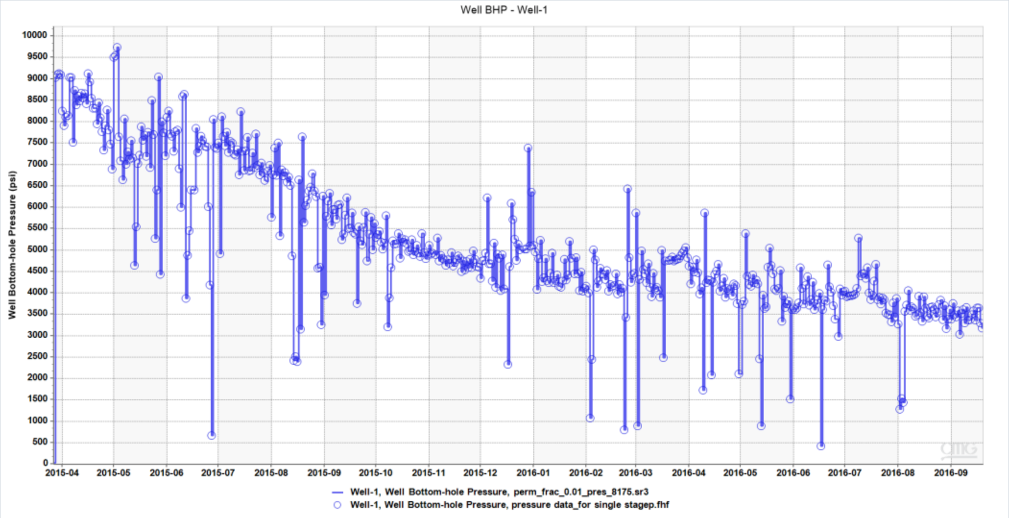




CMG-GEM Numerical Model History Match Results

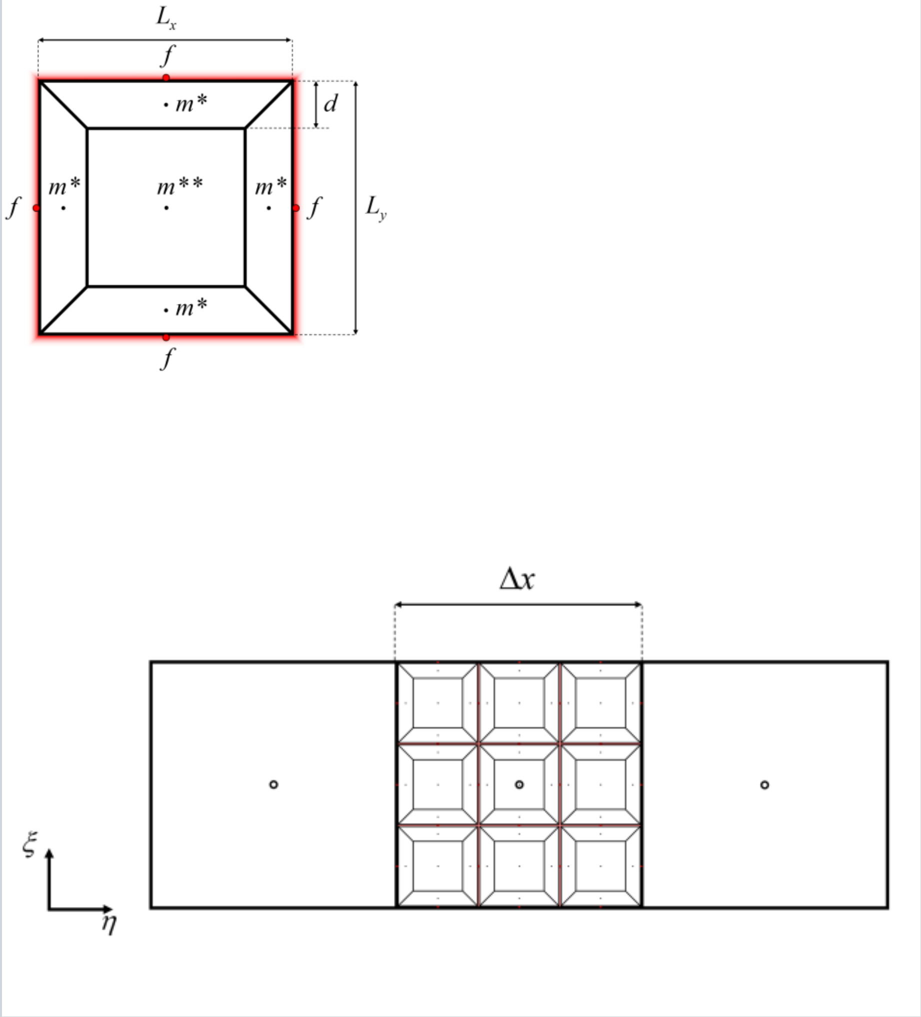






Tuning the numerical model & history matching

Matrix Refinement Numerical Model



Fracture:

$$\nabla.\frac{k_{f,eff}}{\mu}\nabla p_f - \tau + \hat{q} = (\phi c_t)_f \frac{\partial p_f}{\partial t}$$

$$\tau = \sigma_1 \frac{k_m}{\mu}(p_f - p_m)$$

$$\sigma_1 = \frac{4}{d^2}$$

Matrix*:

$$\frac{k_{m^*}}{\mu}\left[\sigma_1(p_f - p_{m^*}) - \sigma_2(p_{m^{**}} - p_{m^*})\right] = (\phi c_t)_m \frac{\partial p_{m^*}}{\partial t}$$

$$\sigma_1 = \frac{4}{d^2}$$

$$\sigma_2 = \frac{2}{d}\left(\frac{1}{L_x - d} + \frac{1}{L_y - d}\right)$$

Matrix**:

$$\frac{k_{m^{**}}}{\mu}\left[\sigma_3(p_{m^*} - p_{m^{**}})\right] = (\phi c_t)_m \frac{\partial p_{m^{**}}}{\partial t}$$

$$\sigma_3 = \frac{4}{(L_x - 2d)(L_x - d)} + \frac{4}{(L_y - 2d)(L_y - d)}$$

where;

c_t=total compressibility(psi^{-1})

d=distance between matrix blocks(ft)

$k_{f,eff}$=effective permeability(mD)

L_x,L_y,L_z=matrix block size(ft)

q=flow rate(ft^3/d)

f=porosity

p_f=fracture pressure(psi)

p_m=matrix pressure(psi)

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