Southwest Regional Partnership on Carbon Sequestration (SWP)

DE-FC26-05NT42591

PHASE III DEMONSTRATION: FARNSWORTH UNIT

ROBERT BALCH[1]

BRIAN MCPHERSON[2]

[1]NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY

[2]UNIVERSITY OF UTAH

2020 Carbon Storage Project Review Meeting
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ACKNOWLEDGMENTS

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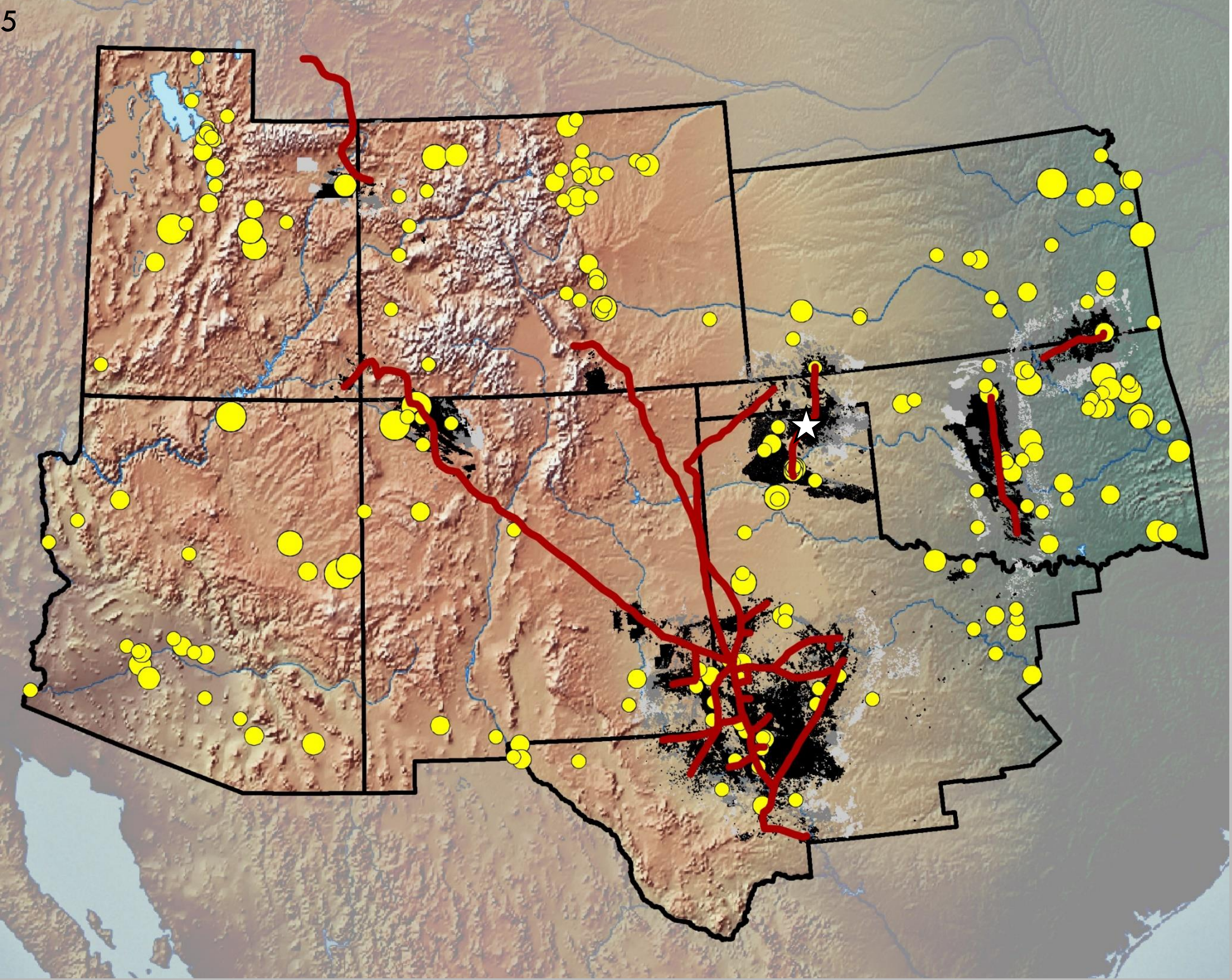
The presenters gratefully acknowledge the contributions of more than 50 SWP scientists and engineers, working at New Mexico Tech, the University of Utah, the University of Missouri, Los Alamos National Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories.

OUTLINE

- Introduction to the SWP
- Status of Milestones
- Effort divided into four groups
  - Characterization effort and lessons learned
    - 2019-2020 Accomplishments
  - Simulation effort and lessons learned
    - 2019-2020 Accomplishments
  - MVA effort and lessons learned
    - 2019-2020 Accomplishments
  - Risk Assessment effort and lessons learned
    - 2019-2020 Accomplishments

THE SOUTHWEST PARTNERSHIP AND FARNSWORTH UNIT



AREA COVERED BY THE SWP

Anthropogenic Supply:
500-600,000
Metric tons
CO_2/year supply

Legend

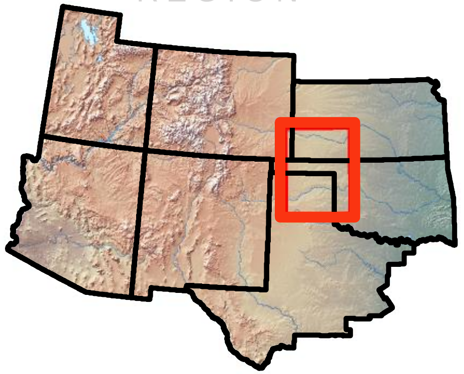
- Utiilization & Storage
- Carbon Capture
- Transportation
- Oil Fields

Other CO_2 Sources

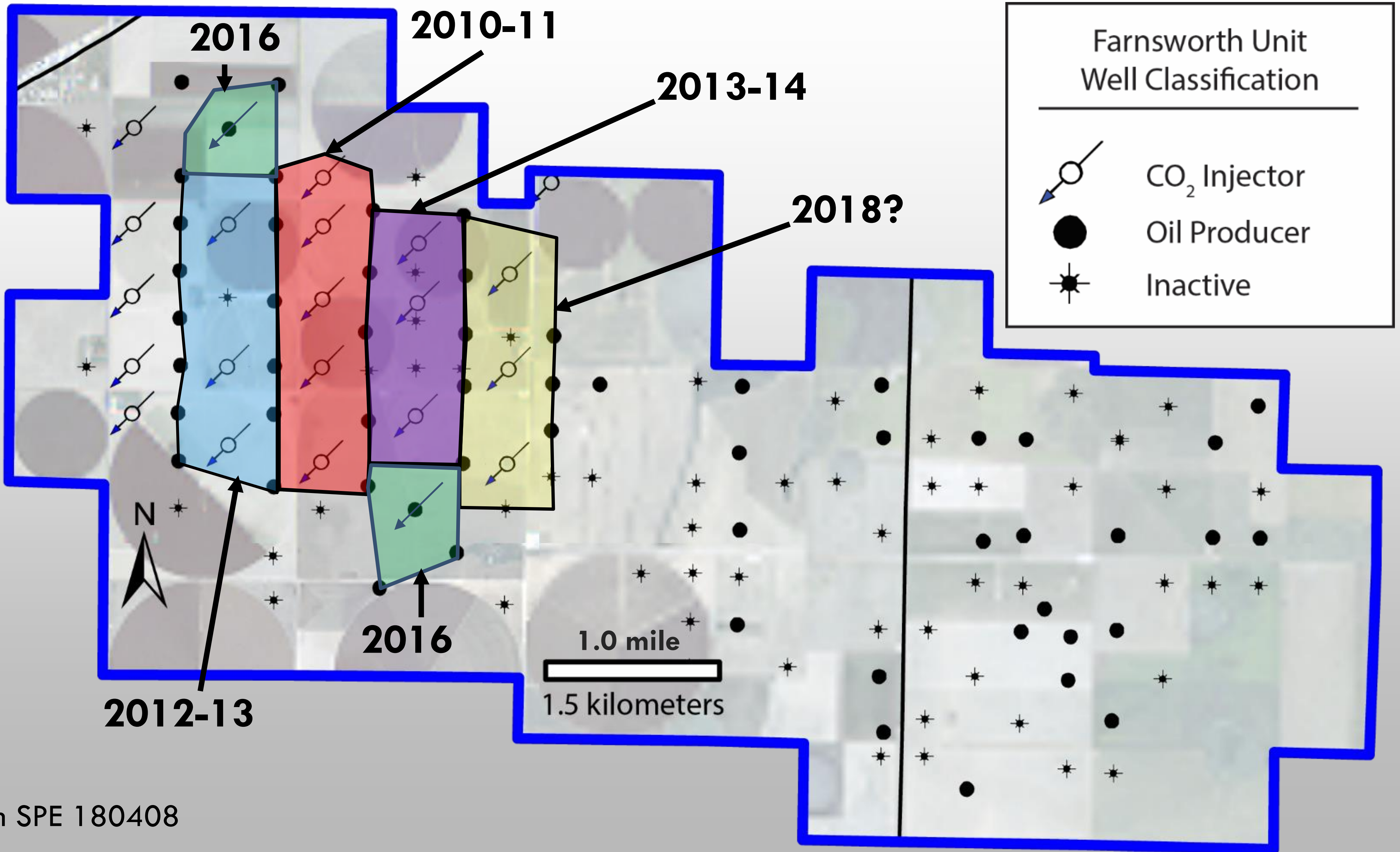
- 0.1 to 0.7 MT/yr
- 0.7 to 1.8 MT/yr
- 1.8 to 4 MT/yr
- 4 to 10 MT/yr
- 10 to 20 MT/yr

Farnsworth Unit

SOUTHWEST CARBON PARTNERSHIP REGION



ACTIVE AND CURRENTLY PLANNED CO_2 PATTERNS



Detailed in SPE 180408

SOUTHWEST PARTNERSHIP: TIMELINE

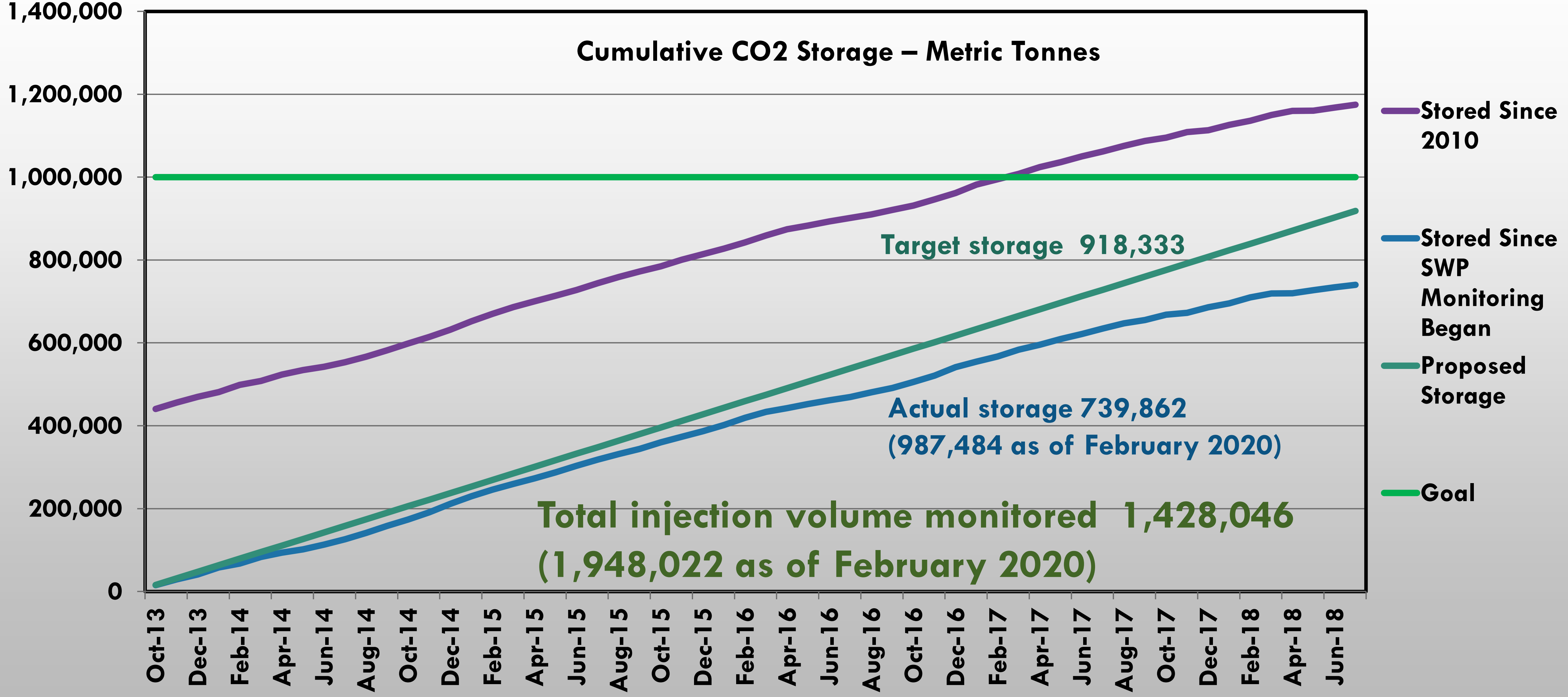
- Phase I – regional sources and sinks,
    - ID Phase II studies
- Phase II – pilot scale studies
    - ID Phase III study site
- Phase III Budget Period 3 – Large Scale demonstration
    - Pre-injection
    - Injection
- Phase III Budget Period 4 – "Post-Injection"

STATUS OF MILESTONES – END OF "INJECTION"

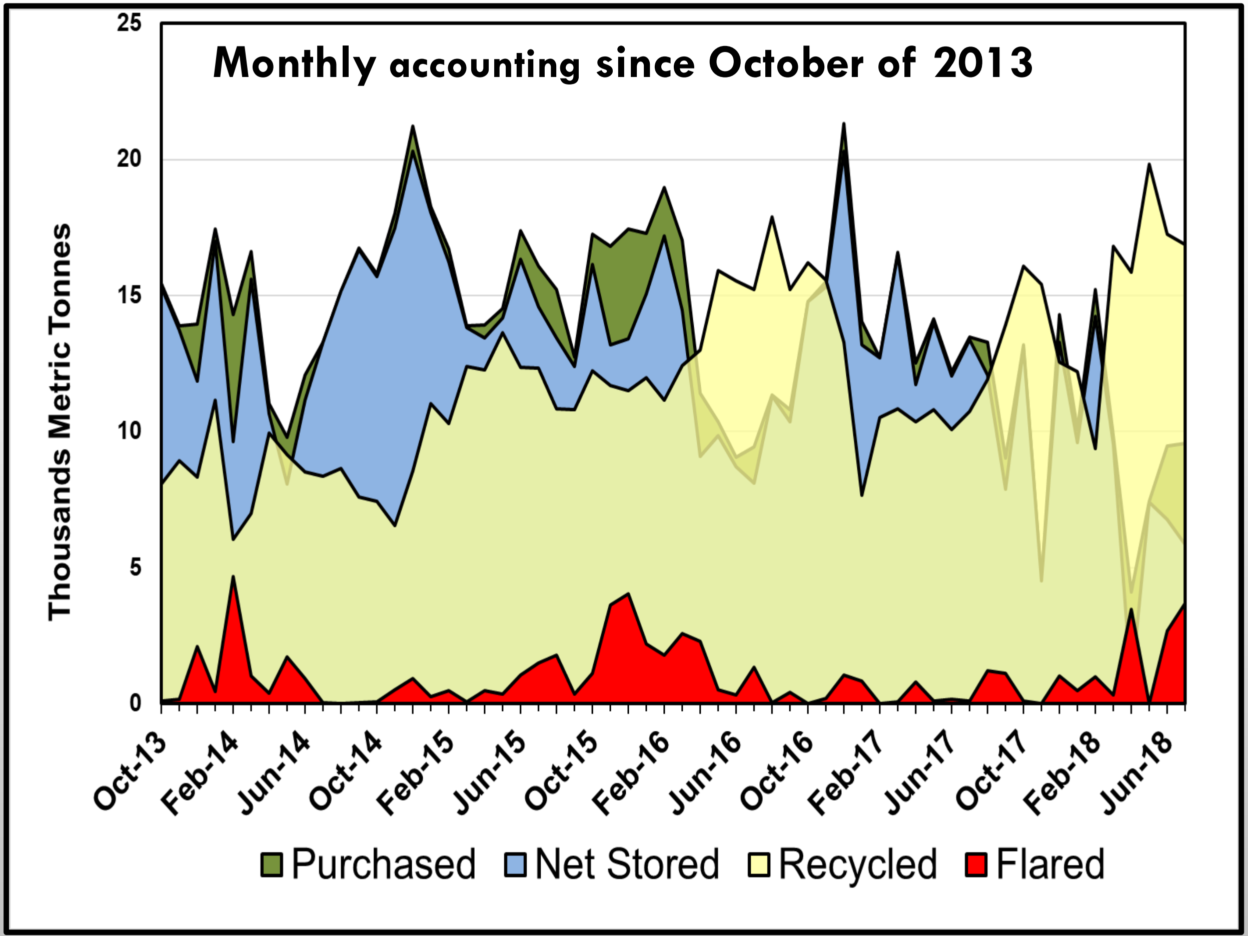
CRITICAL MILESTONES – 25

TECHNICAL MILESTONES – 73

SOUTHWEST PARTNERSHIP: CO_2 STORAGE

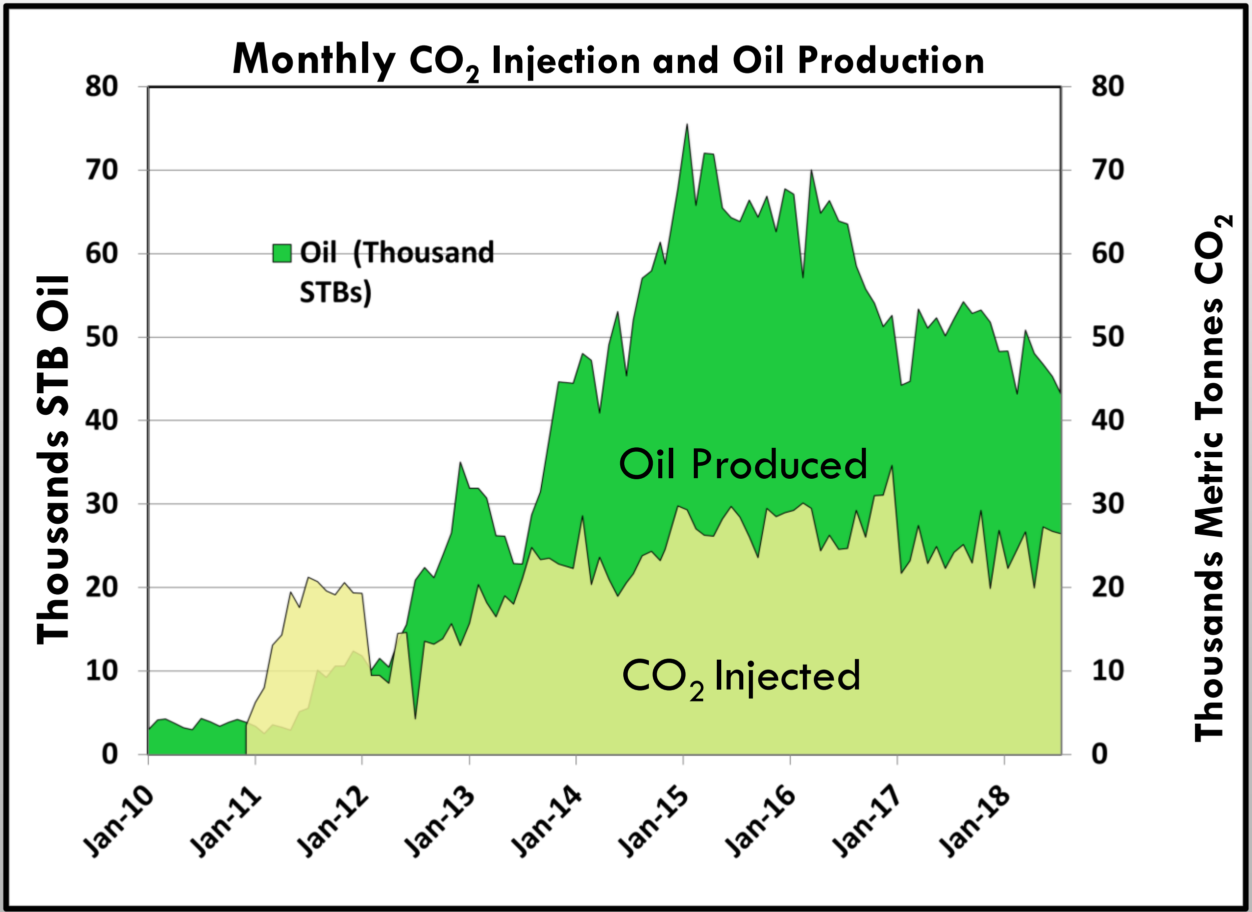


ACCOUNTING - CO_2 AND INCREMENTAL PRODUCTION



- 739,863 tonnes stored since October 2013
- 688,183 tonnes recycled since October 2013
- 1,180,379 tonnes stored since November 2010
- **92.7% of purchased CO_2 still in the system**

- Average monthly oil rate increased from ~3,500 to ~65,000 BBL's in first 4 years of CO_2 Flood
- Initial production response within 6 months
- ~3.8 million STB produced during CO2 flood

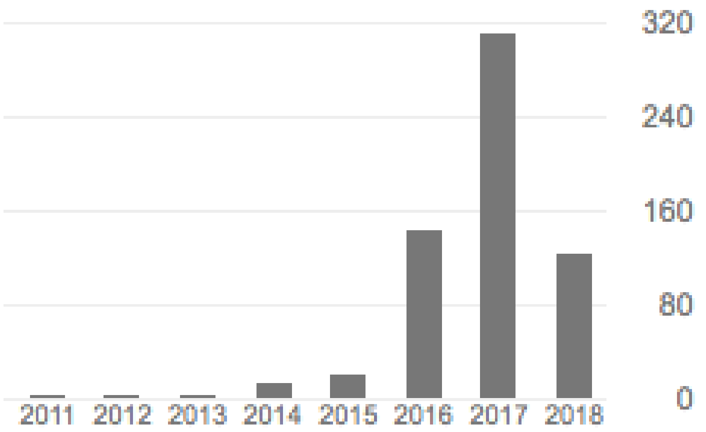


SOUTHWEST PARTNERSHIP: BIBLIOGRAPHY

- >110 publications, major presentations, SPE DL
- Book – 25 Papers covering multiple aspects

Cited by VIEW ALL

	All	Since 2013
Citations	643	616
h-index	14	14
i10-index	16	15



TITLE	CITED BY	YEAR
An integrated framework for optimizing CO2 sequestration and enhanced oil recovery Z Dai, R Middleton, H Viswanathan, J Fessenden-Rahn, J Bauman, ... Environmental Science & Technology Letters 1 (1), 49-54	112	2013
CO2 accounting and risk analysis for CO2 sequestration at enhanced oil recovery sites Z Dai, H Viswanathan, R Middleton, F Pan, W Ampomah, C Yang, W Jia, ... Environmental science & technology 50 (14), 7546-7554	64	2016
Evaluation of CO2 storage mechanisms in CO2 enhanced oil recovery sites: Application to Morrow sandstone reservoir W Ampomah, R Balch, M Cather, D Rose-Coss, Z Dai, J Heath, T Dewers, ... Energy & Fuels 30 (10), 8545-8555	51	2016
Uncertainty analysis of carbon sequestration in an active CO 2-EOR field F Pan, BJ McPherson, Z Dai, W Jia, SY Lee, W Ampomah, H Viswanathan, ... International Journal of Greenhouse Gas Control 51, 18-28	38	2016
Uncertainty quantification for CO2 sequestration and enhanced oil recovery Z Dai, H Viswanathan, J Fessenden-Rahn, R Middleton, F Pan, W Jia, ... Energy Procedia 63, 7685-7693	36	2014
Co-optimization of CO2-EOR and storage processes in mature oil reservoirs W Ampomah, RS Balch, RB Grigg, B McPherson, RA Will, SY Lee, Z Dai, ... Greenhouse Gases: Science and Technology 7 (1), 128-142	31	2017
Potential chemical impacts of CO 2 leakage on underground source of drinking water assessed by quantitative risk analysis T Xiao, B McPherson, F Pan, R Esser, W Jia, A Bordelon, D Bacon International Journal of Greenhouse Gas Control 50, 305-316	22	2016
Optimum design of CO 2 storage and oil recovery under geological uncertainty W Ampomah, RS Balch, M Cather, R Will, D Gunda, Z Dai, MR Soltanian Applied Energy 195, 80-92	21	2017
Analysis of upscaling algorithms in heterogeneous reservoirs with different recovery processes W Ampomah, RS Balch, RB Grigg SPE Production and Operations Symposium	20	2015
Numerical simulation of carbon dioxide injection in the western section of the Farnsworth Unit MD White, BJ McPherson, RB Grigg, W Ampomah, MS Appold Energy Procedia 63, 7891-7912	20	2014

SWP CHARACTERIZATION EFFORTS AND LESSONS LEARNED

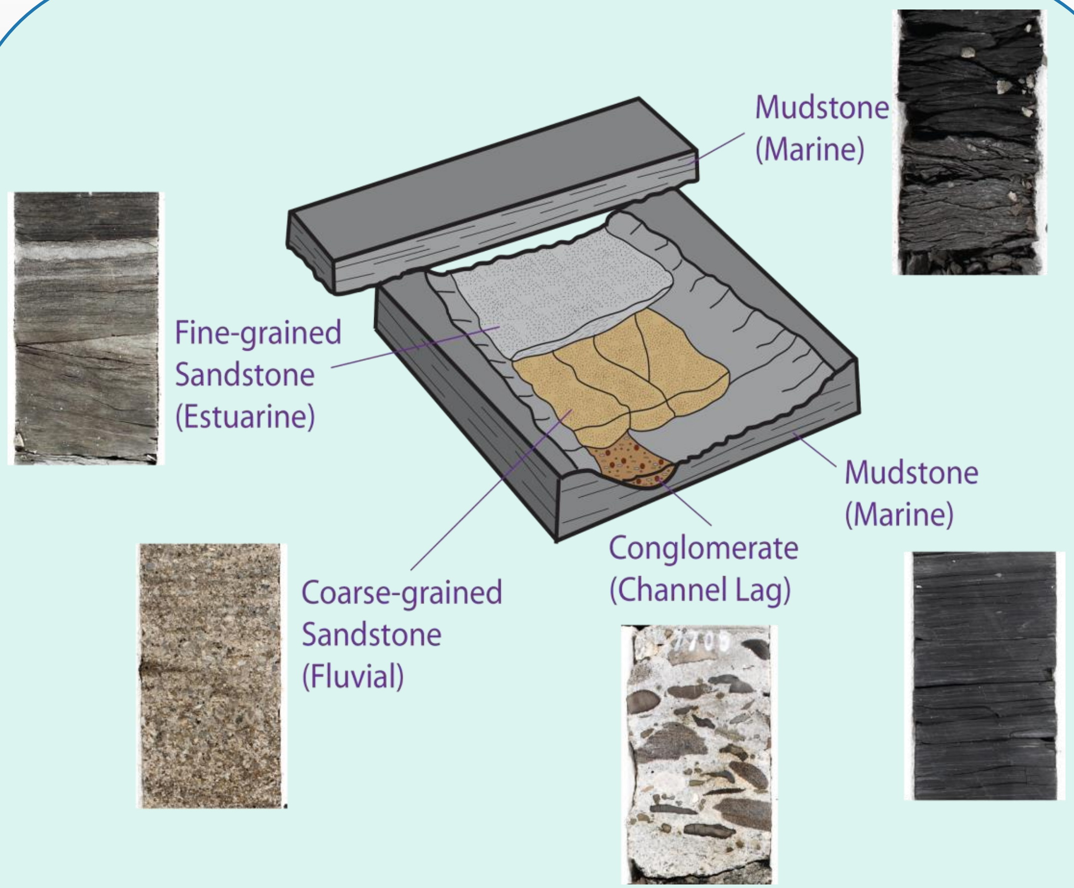
CHARACTERIZATION –GEOLOGICAL UNDERSTANDING

- Goal: Reservoir & caprock description – depositional setting, reservoir architecture, lithologies, fracture potential, geomechanical properties
- Tools: Cores & core analyses, thin section, microprobe, log & seismic data, geomechanical, borehole image logs, CT scanning

CHARACTERIZATION –GEOLOGICAL UNDERSTANDING

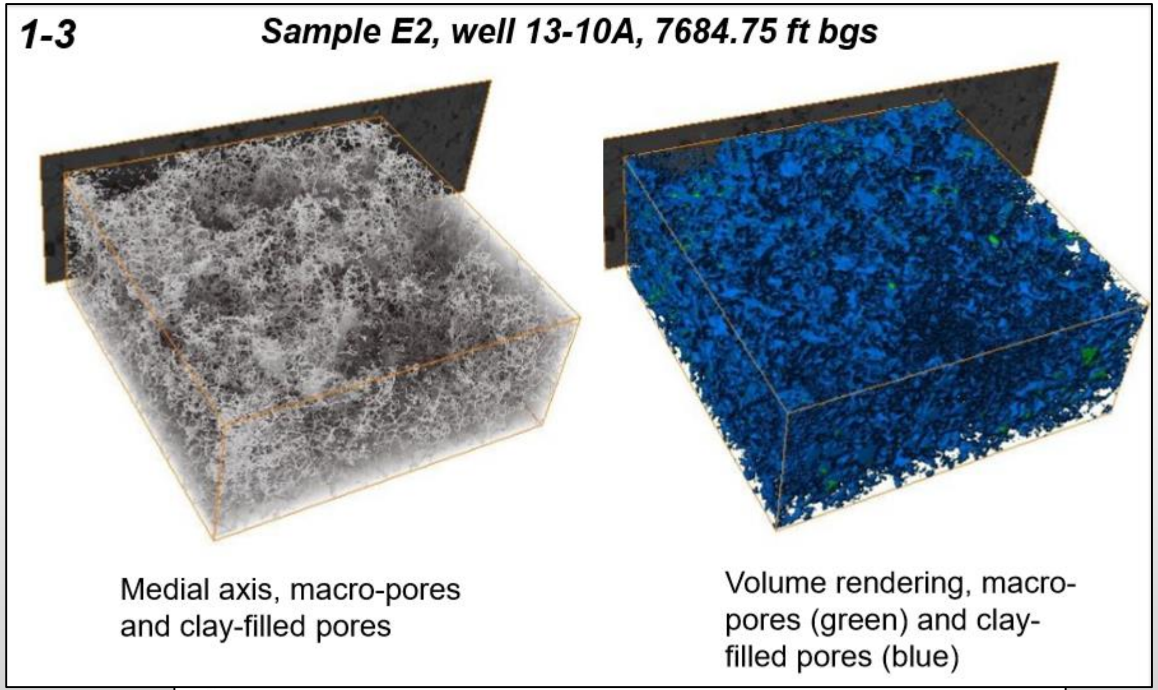
- Findings:
  - Incised valley model fits well, reservoir can be divided into lithofacies based on core descriptions
  - Lithofacies provide a record of marine transgressive/regressive sequences that have effects on reservoir diagenesis
  - Reservoir can also be characterized by Hydraulic Flow Units (HFU) determined from porosity and permeability data using Winland R35 approach, these have different pore structure and interconnectivity
  - Caprock is a sequence of interbedded mudstones/shales and diagenetic limestones
- Better understanding of fluid/rock interactions, relative permeability data

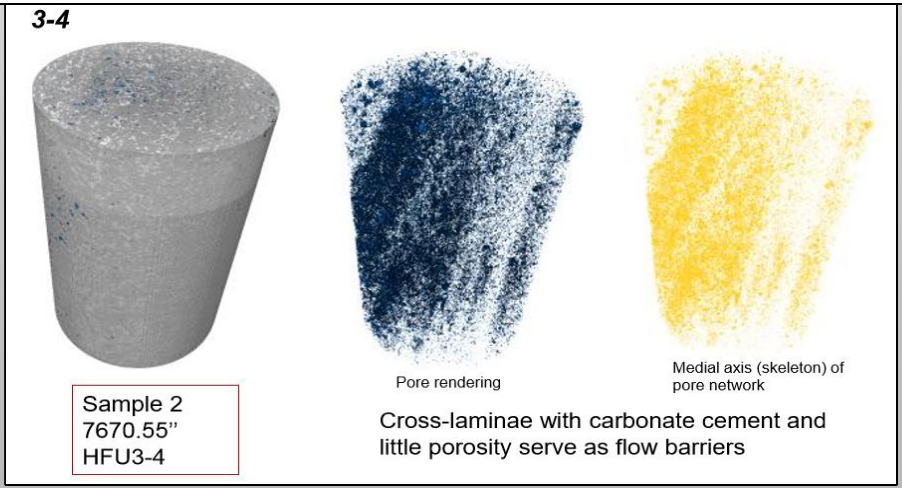
CHARACTERIZATION OF GEOLOGY AT MULTIPLE SCALES



Facies model – reservoir scale

MicroCT Imaging – pore scale, can differentiate between HFUs defined by R35 method

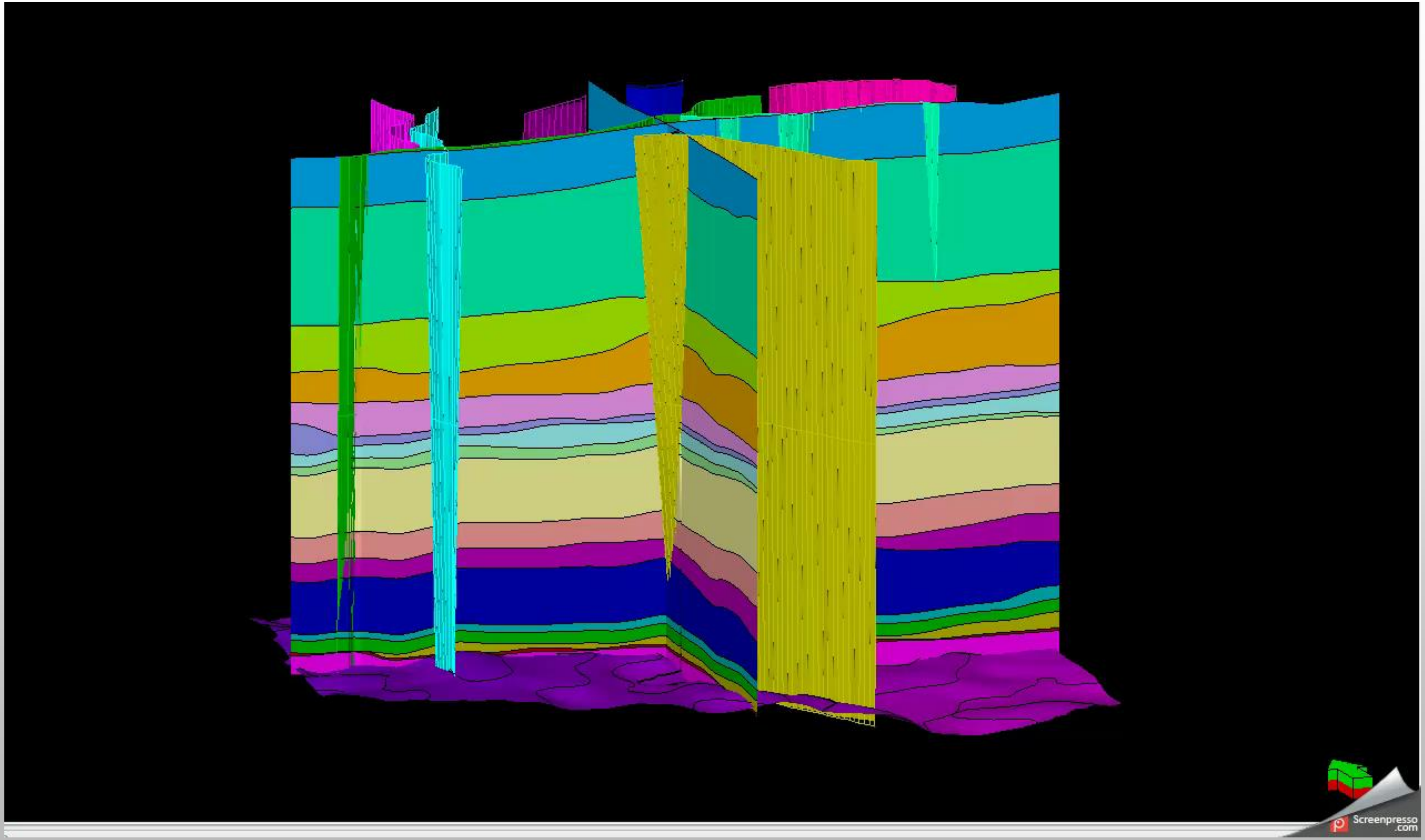




CHARACTERIZATION USING SEISMIC DATA

- Goal - characterizing reservoir architecture & facies distribution, mapping any faults, fractures, or structural features that could influence plume movement or reservoir integrity
- Tools – well logs, 3D surface seismic, 3D VSP's, cross-well tomography
- Findings- A geologic model was generated using all available seismic and well log information available. Geologic information and fault-like features interpreted from 3D seismic were included into this model. (See animation). The reservoir does exhibit heterogeneity. Features that may be faults but are still open to interpretation were noted in seismic data, and there is variation in reservoir thickness and structure across the Farnsworth field
- Geological model updated annually > propagated to simulation model

CHARACTERIZATION: SEISMIC DATA



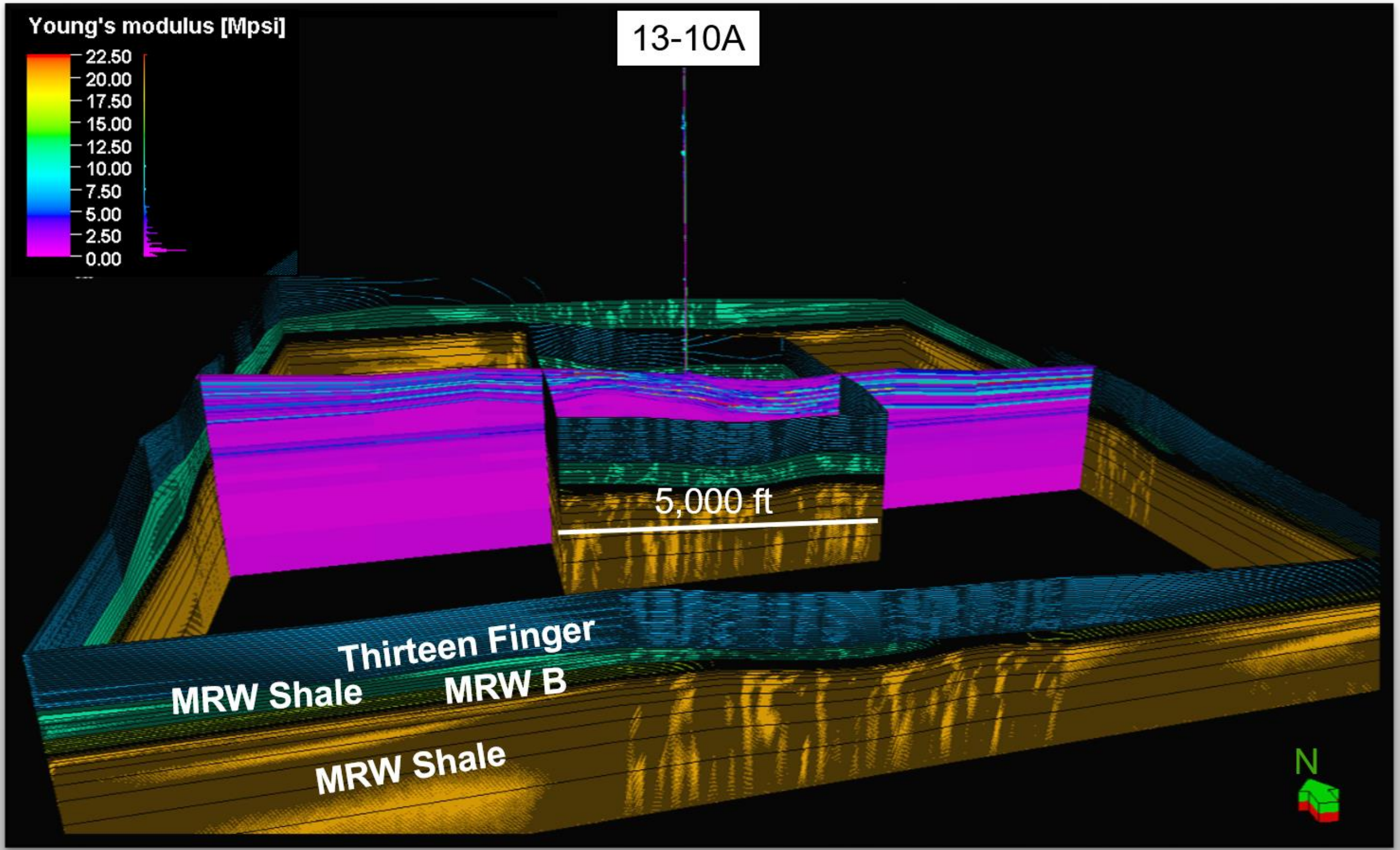
Annually updated Geological model

Planar features may be faults, fractures, and/or facies changes, paleovalley walls – remains to be determined

CHARACTERIZATION: MECHANICAL EARTH MODEL

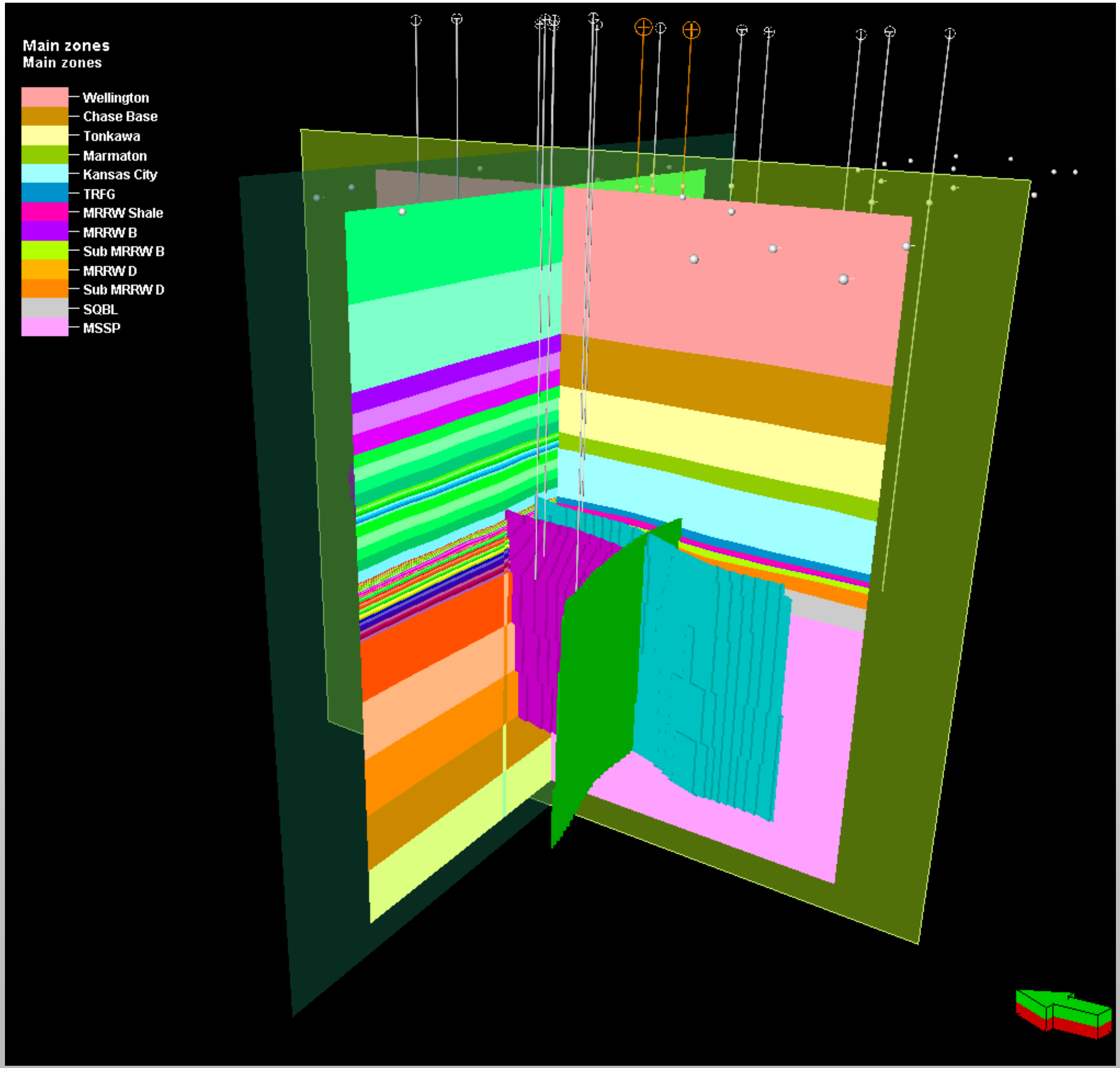
- Goal: Create a mechanical earth model that could be used to model rock behavior under a variety of scenarios
- Tools: Well logs, mechanical tests, geophysical studies
- Results: A small scale (5000 ft. by 5000 ft.) mechanical earth model centered on 13-10A. Utilized 1D geomechanical model generated by Schlumberger at 13-10A from sonic logs and post stack 3D seismic inversion to calculate geomechanical properties

Small-scale MEM Young's modulus



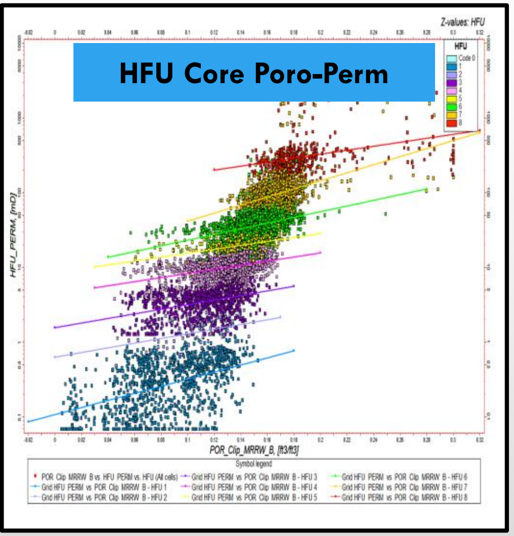
GEOLOGICAL MODEL UPDATE – 2020

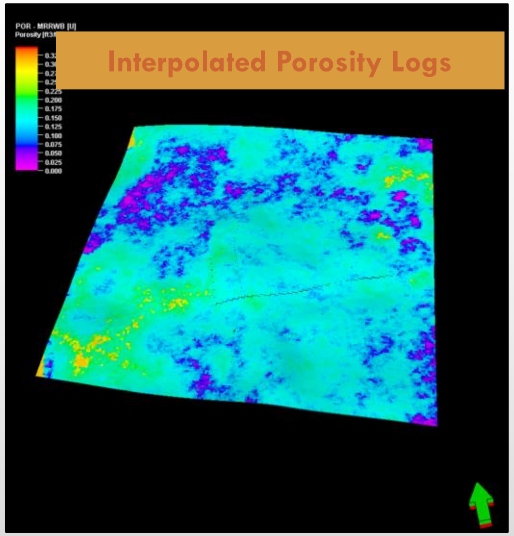
- Rotated to conform with principal stress direction (18/108 deg)
- Extends from Wellington to 10,000’ depth (Mississippian)
- Includes 3 previously mapped faults
- 14 horizons, 13 zones.
- 189x179x106. ~ 3.6 million cells.
- Cells size 100’ x 100’ x variable from 3’ (Morrow B) to 1,100’ (Wellington).
- Less stratification shallow, more stratification sub Morrow B formations.
- Structure/Strat interpreted from depth imaged seismic data.
- Properties interpolated with elastic inversion.

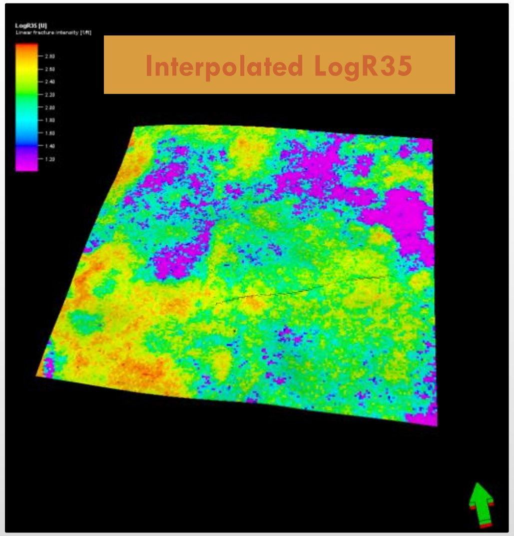


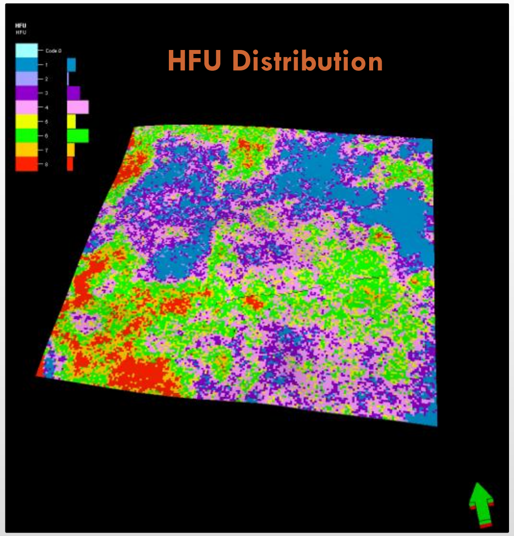
GEOMODEL PROPERTY INTERPOLATION: FORMATION DEPENDENT METHODOLOGY

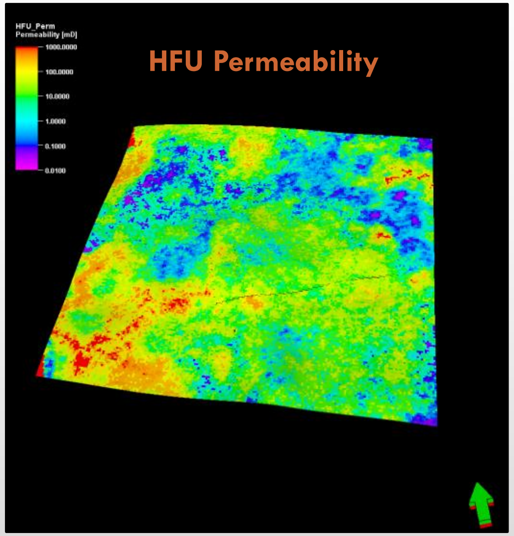
Morrow B Formation



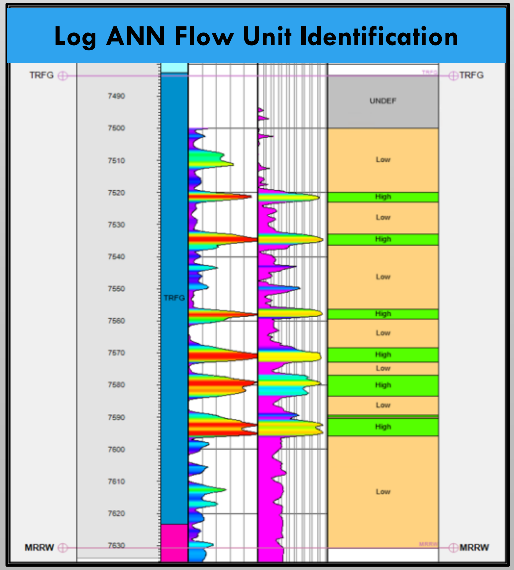


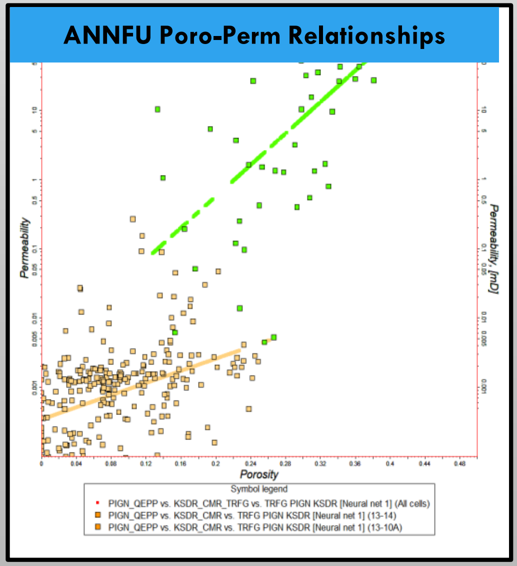


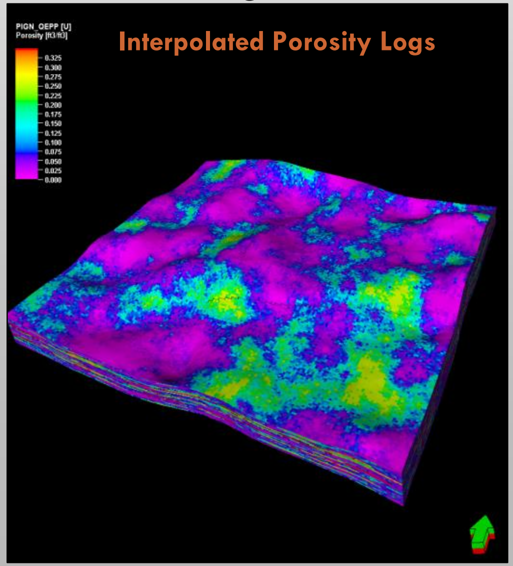


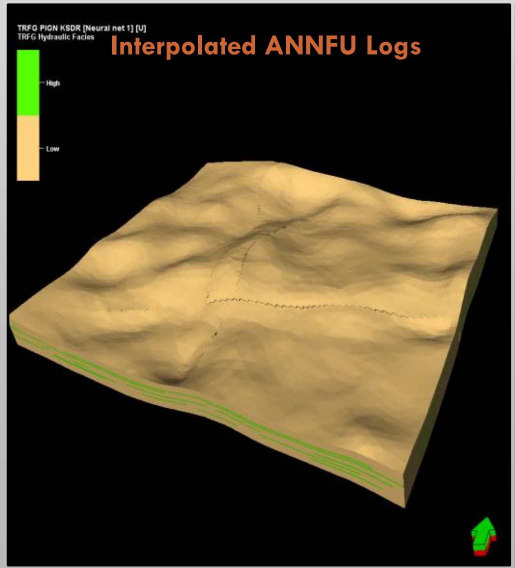


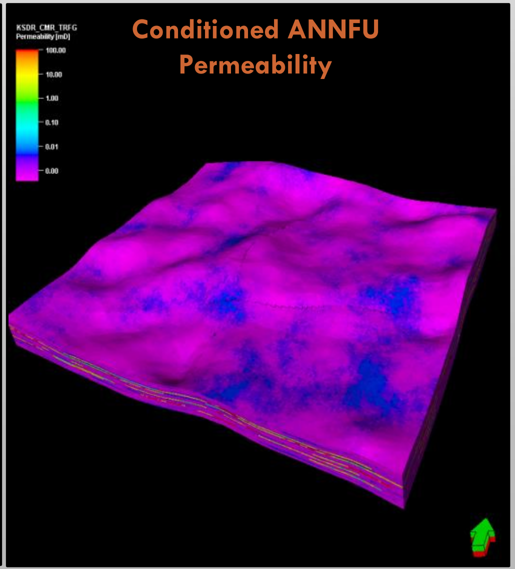
Thirteen Finger Formation





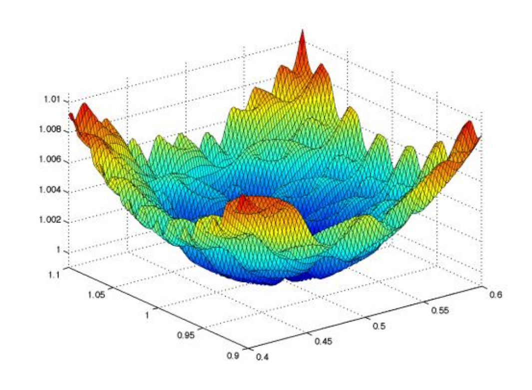






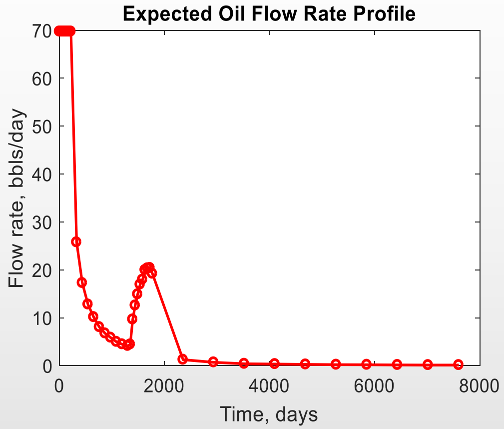
MACHINE-LEARNING (ML) ASSISTED HISTORY MATCHING WORKFLOW

Global Optimizer

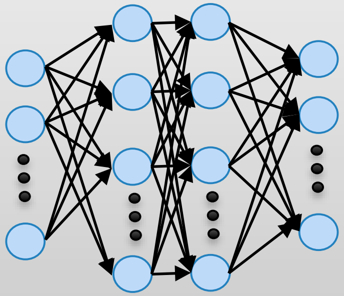


Tune the reservoir model

Historical data



A machine-learning proxy



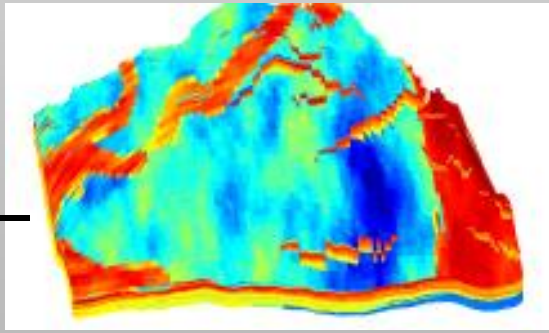
Updated reservoir properties

Save the Results

No

Yes

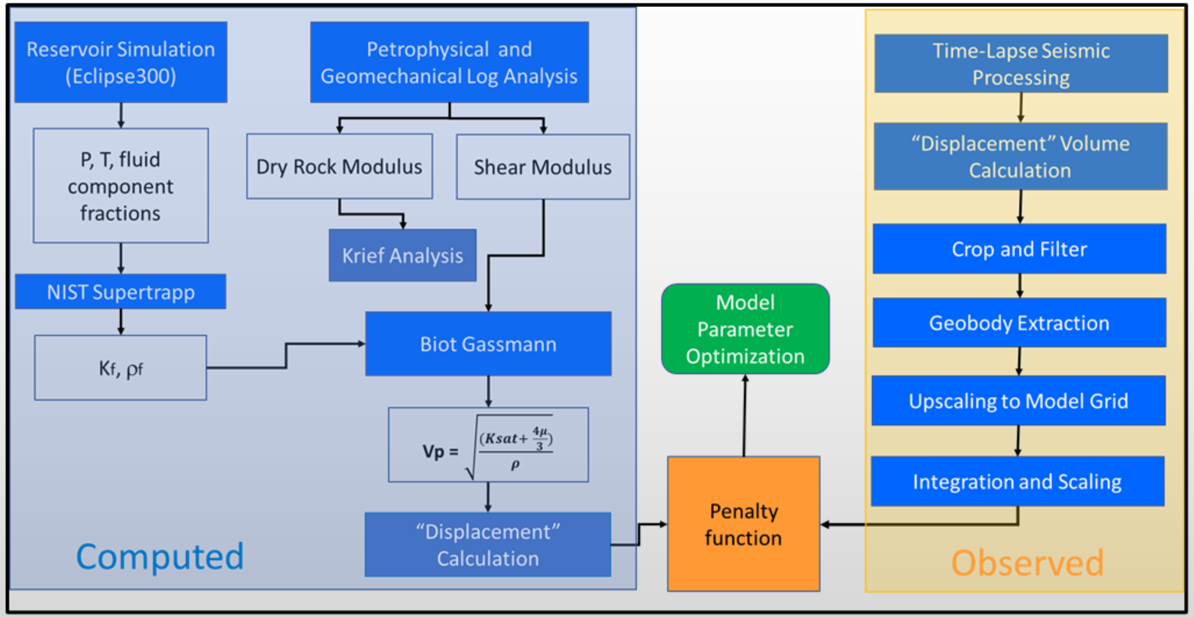
Good match?



High-fidelity numerical model

TIME-LAPSE SEISMIC INTEGRATION

Integration Scheme



Fluid Substitution

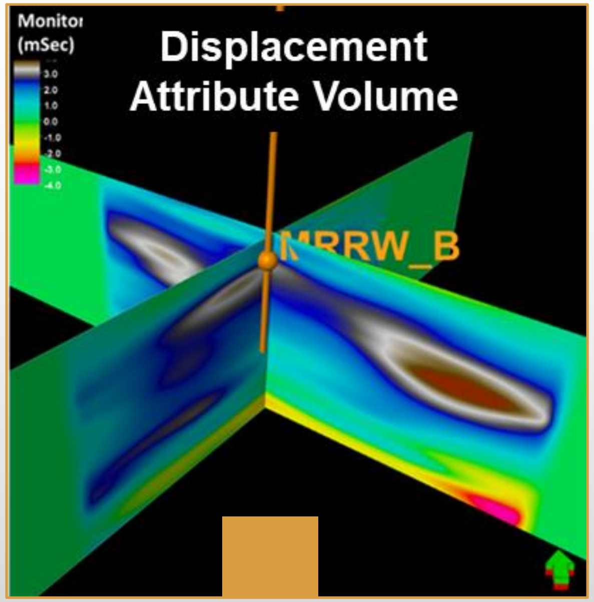
$$K_{sat} = K_{dry} + \frac{\left[1 - \frac{K_{dry}}{K_s}\right]^2}{\frac{\emptyset}{K_f} + \frac{(1-\emptyset)}{K_s} - \frac{K_{dry}}{K_s^2}}$$

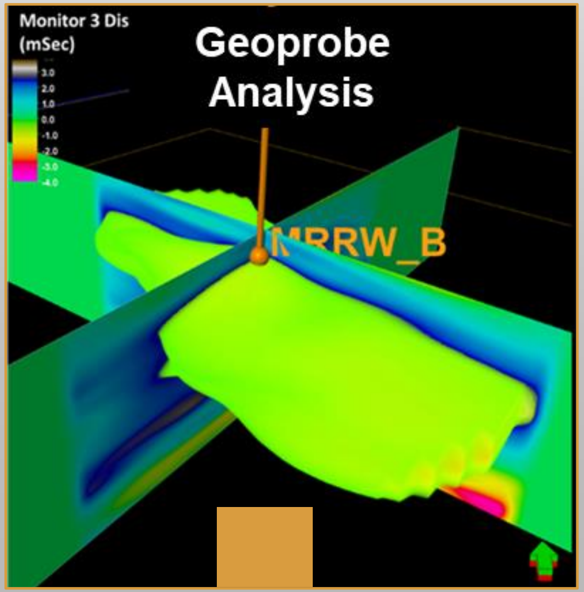
$$K_{sat} = K_{dry} + K_{pore}$$

$$K_{pore} = \frac{\left[1 - \frac{K_{dry}}{K_s}\right]^2}{\frac{\emptyset}{K_f} + \frac{(1-\emptyset)}{K_s} - \frac{K_{dry}}{K_s^2}}$$

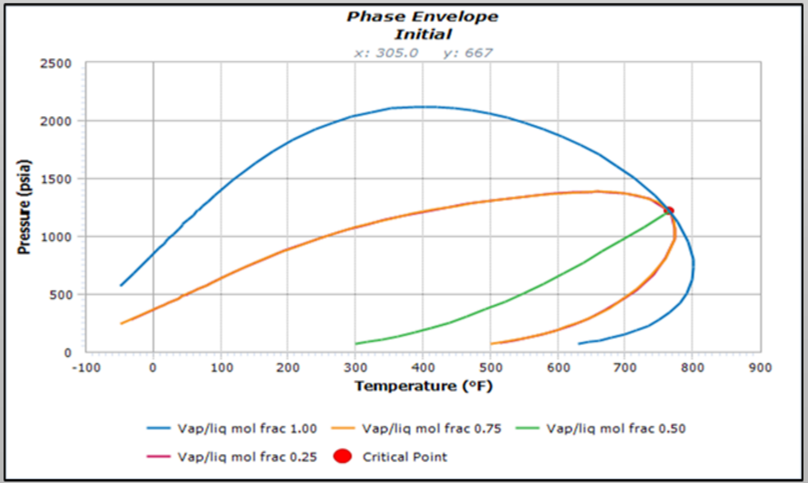
$$K_{sat} = K_{dry} + \frac{\alpha^2}{\frac{\emptyset}{K_f} - \frac{(\alpha-\emptyset)}{K_s}}$$

Time Lapse Attribute Analysis

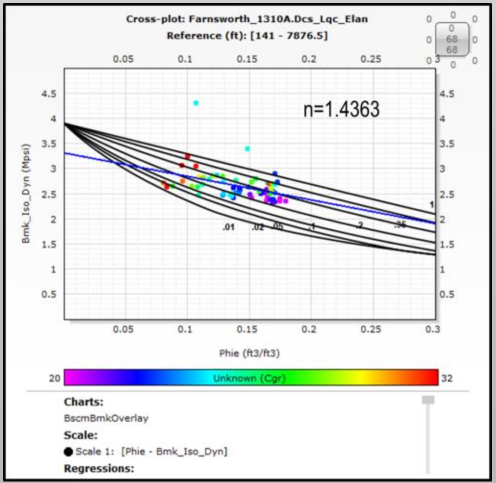




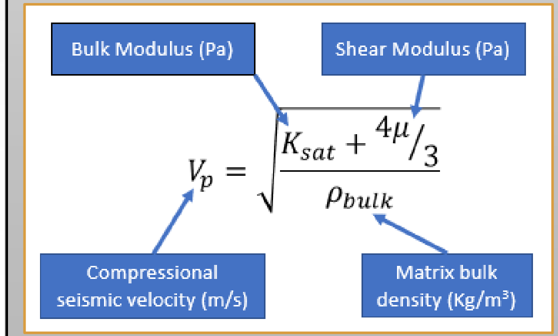
Fluid Studies/EOS



Petrophysics/Rock Physics

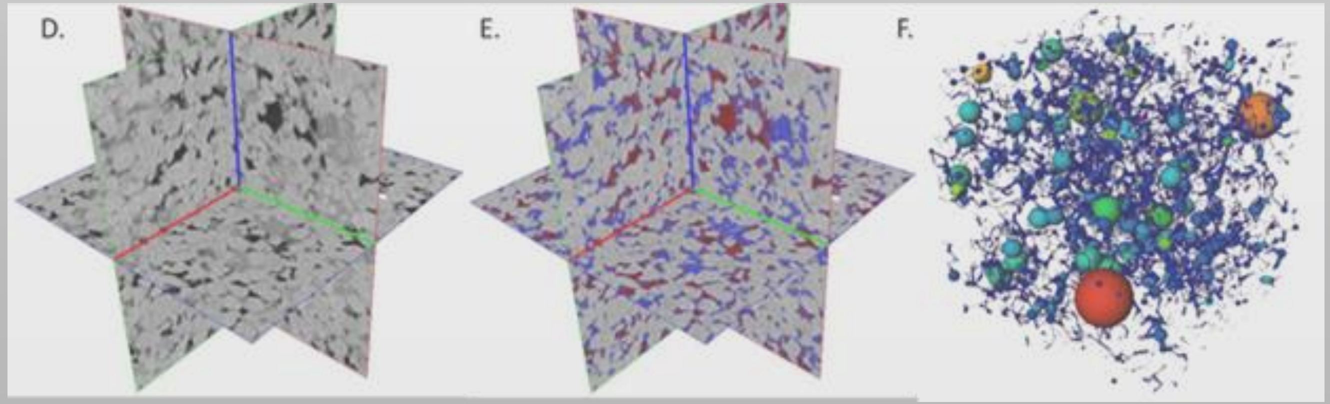


Elastic Media Modeling



CHARACTERIZATION MAJOR FINDINGS: FLUID/ROCK INTERACTIONS

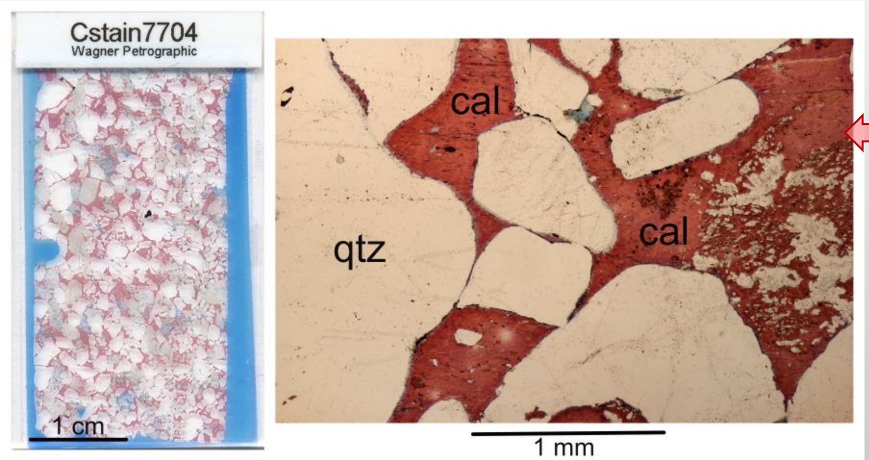
- The heterogeneity of the reservoir was classified into five hydraulic flow units based on pore scale investigations. Two flow units were investigated for fluid/rock interaction studies.
- Flow-through experiments were conducted at reservoir pressure and temperature to better understand implications associated with mechanical property changes that arise from CO_2-rich fluid-rock interaction following CO_2 injection into the subsurface.
- We found that chemo-mechanical degradation is highly controlled by the cement texture and composition, as well as the burial history of the rock.



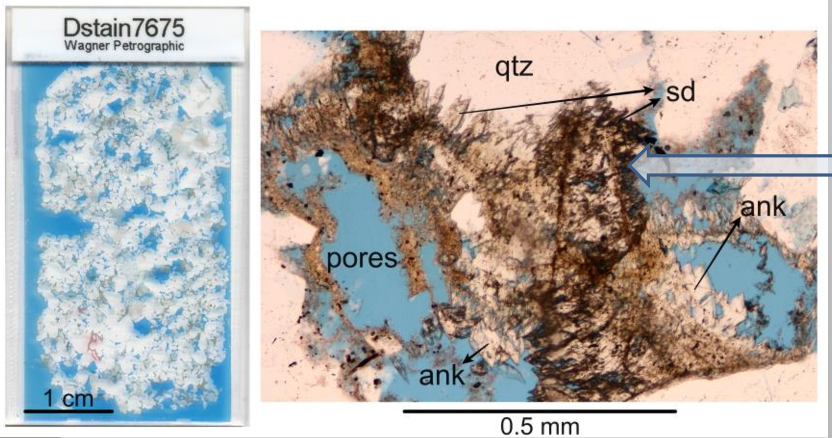
Tomographic images of one flow unit showing images and pore networks built from those images, sphere size scaled to pore size.

CHARACTERIZATION MAJOR FINDINGS: FLUID/ROCK INTERACTIONS

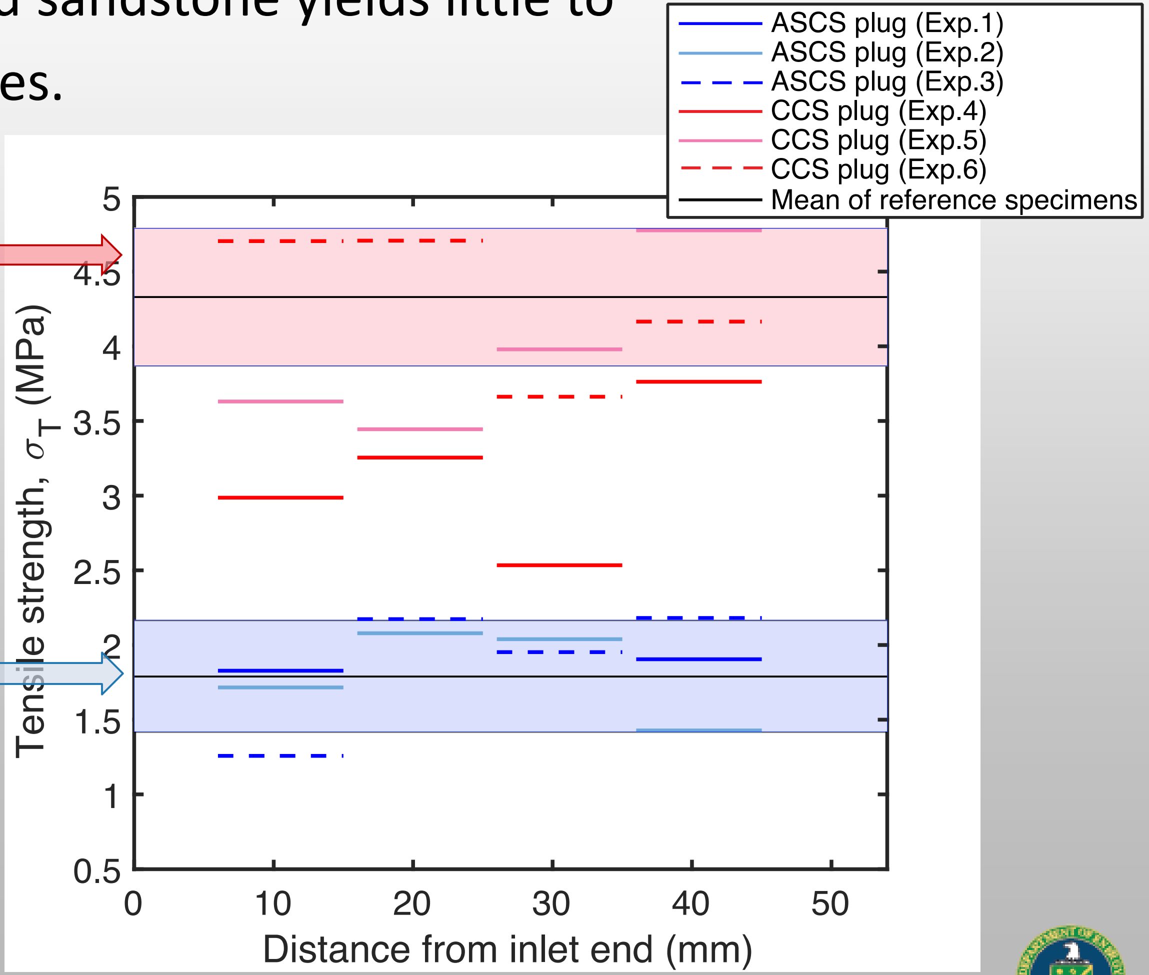
- CO_2-induced dissolution in disseminated ankerite-siderite-cemented sandstone yields little change in permeability and mechanical properties.
- CO_2-induced dissolution in poikilotopic calcite-cemented sandstone yields little to significant permeability and mechanical property changes.



Calcite cement



Ankerite/siderite cement



SWP MVA EFFORTS AND LESSONS LEARNED

The MVA technologies deployed by the SWP are targeted to provide the data necessary to track the location of CO_2 in the study area, including migration, type, quantity and degree of CO_2 trapping. Monitoring data is used to facilitate simulation and risk assessment, particularly with respect to USDWs, the shallow subsurface, and atmosphere.

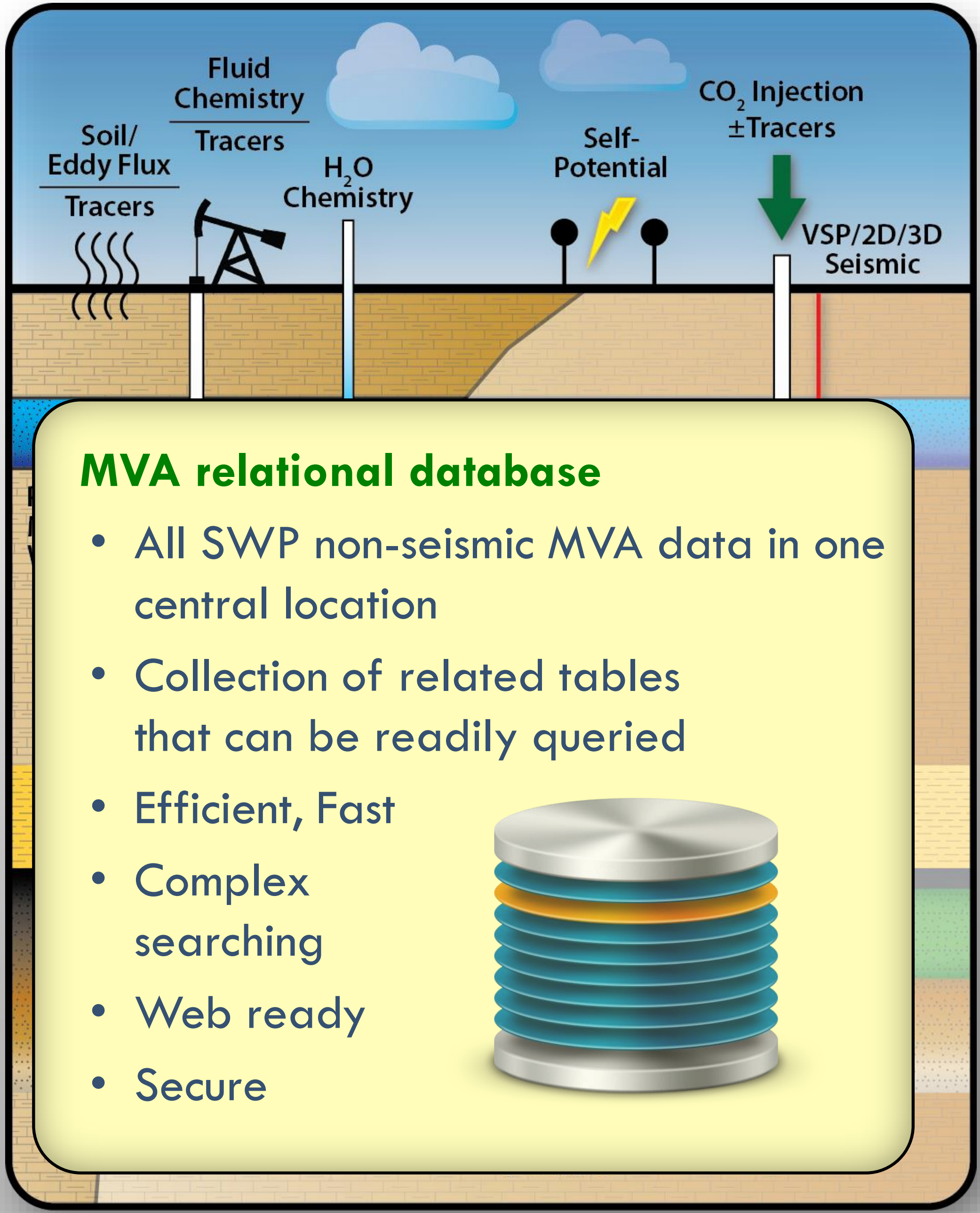
MVA OVERVIEW – TECHNOLOGY

Detecting CO_2 and/or brine outside Reservoir:

- Groundwater chemistry (USDW)
- Soil CO_2 flux
- CO_2 & CH_4 Eddy Covariance
- Aqueous- & Vapor-Phase Tracers
- Self-potential (AIST)
- Distributed Sensor Network (Ok. State)

Tracking CO_2 Migration and Fate:

- *In situ* pressure & temperature
- 2D/3D seismic surveys
- VSP's
- Cross-well seismic
- Passive seismic
- Fluid chemistry (target reservoir)
- Aqueous- & Vapor-Phase Tracers
- Gravity surveys & MagnetoTelluric (AIST)



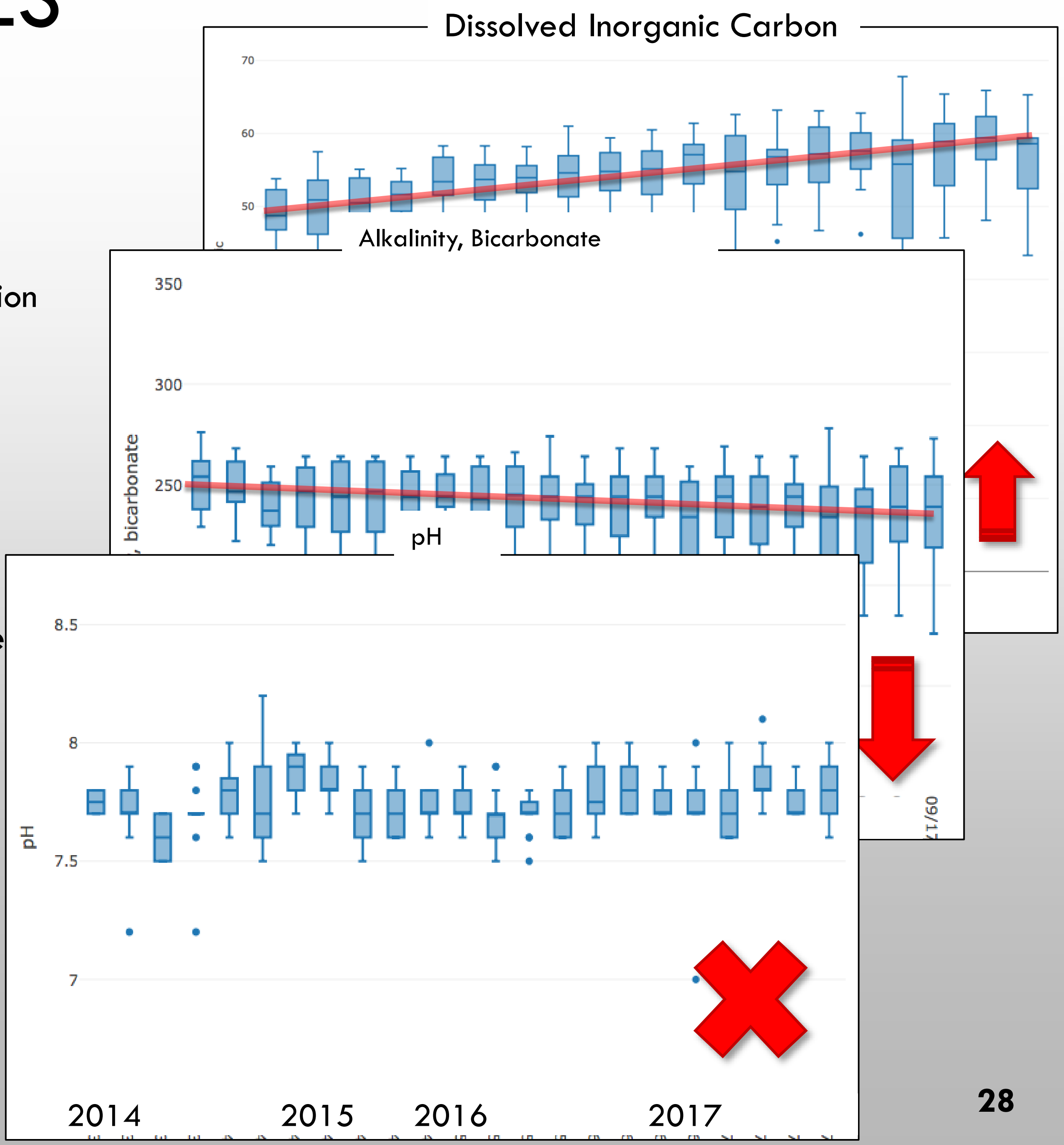
MVA relational database

- All SWP non-seismic MVA data in one central location
- Collection of related tables that can be readily queried
- Efficient, Fast
- Complex searching
- Web ready
- Secure

MVA OVERVIEW – SUCCESSES

USDW Monitoring

- Quarterly sampling of groundwater wells in/around FWU (n≈22) to monitor for brine, hydrocarbon and/or CO_2 leakage from depth.
    - Includes Major Cations/ Anions, pH, Conductivity, Alkalinity, Oxidation and Reduction Potentials (ORP), Inorganic Carbon (IC) and Organic Carbon (OC), Trace Metals and Isotopes (13C,18O, and D).
- Total/Dissolved Inorganic Carbon (DIC) *increasing* "field wide" (>18 USDW wells).
    - DIC (C_T) = $[CO_2] + [HCO_3^-] + [CO_3^{2-}]$
    - **DIC is a measure of CO2 in an aqueous system**
    - **However!** No other indicators of CO_2 leakage yet measure (pH steady, Alkalinity decreasing, ORP increasing)
    - More data needed, but increasing DIC values likely due to regional recharge and/or groundwater contamination from the surface (e.g. fertilizers)
- Technology validates spatial and temporal sampling as a means to monitor USDW for potential leakage

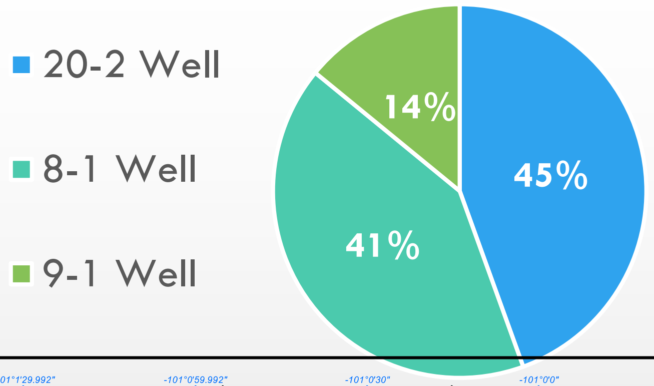


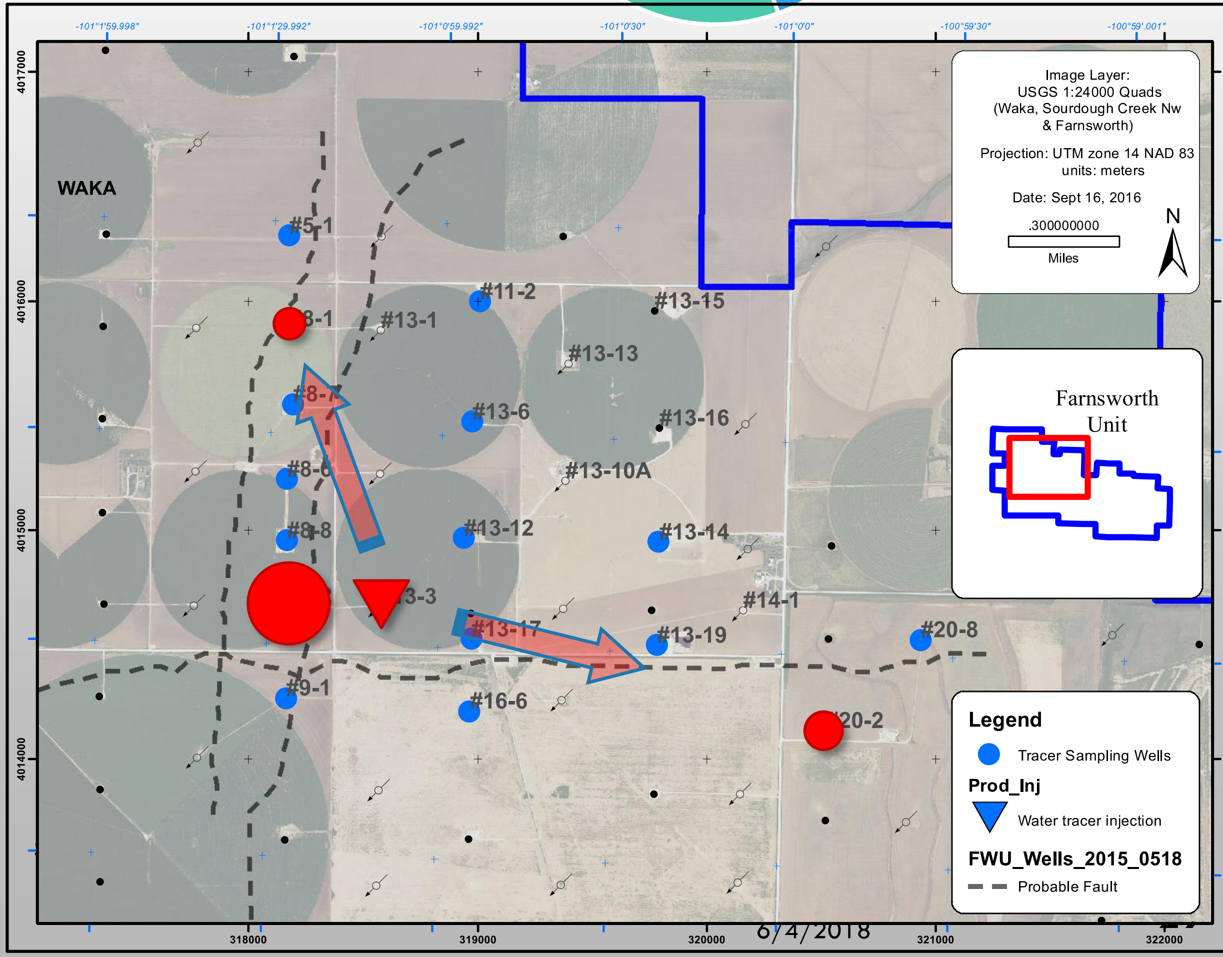
MVA OVERVIEW – SUCCESSES

Reservoir Tracers – Aqueous Phase

- Aqueous-phase tracer slugs (Naphthalene sulfonates) were injected into 5 well patterns to successfully evaluate fluid velocities, interwell connectivity and identify and characterize significant reservoir heterogeneities (faults).
  - The latest injection (FWU #13-3) yielded results indicating significant preferential fluid flow along two adjacent faults <map at right>
  - Relative tracer recovery along (#8-2 and #20-2) and across faults (#9-1) indicate variable transmissive versus sealed characteristics

2-NS Relative recovery between FWU wells #8-1, #9-1 and #20-2

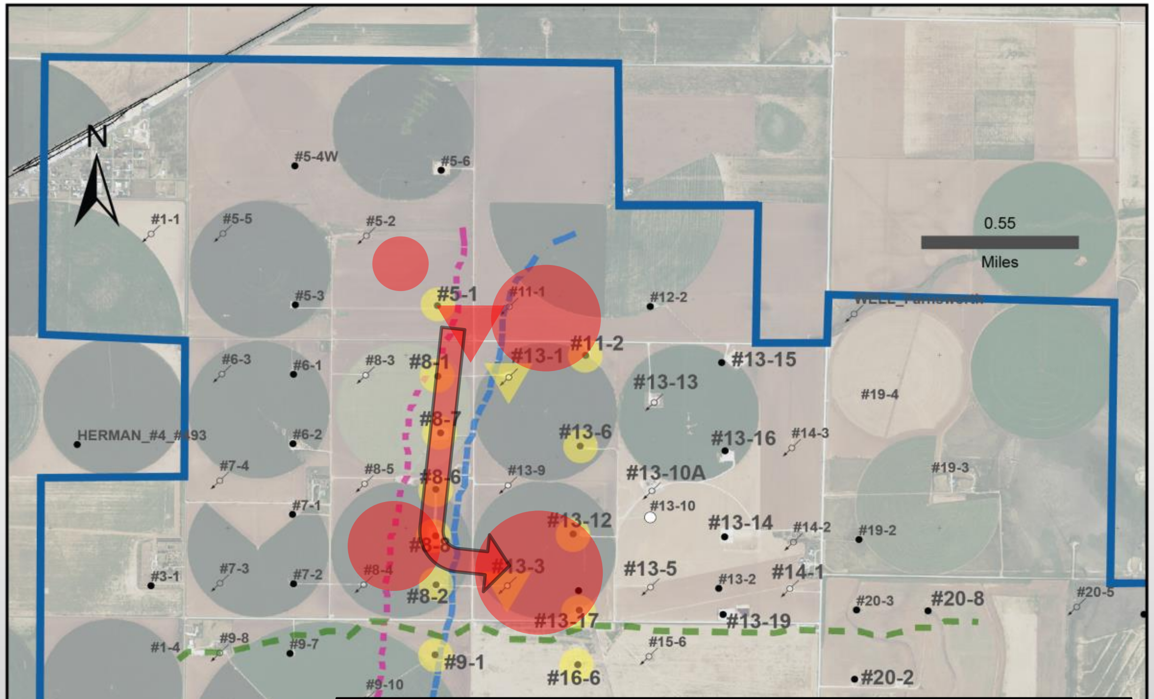


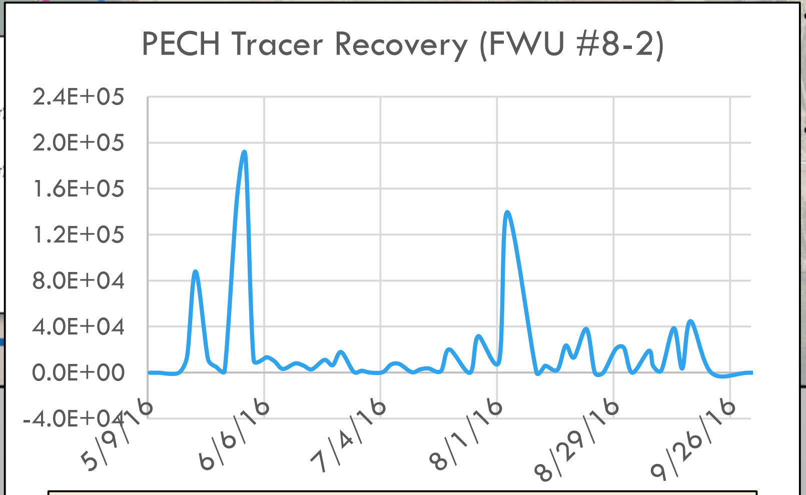


MVA OVERVIEW – MIXED SUCCESSES

Reservoir Tracers – Vapor Phase

- Vapor-phase tracer slugs (Perfluorocarbons) were injected into 4 well patterns in an attempt to assess CO_2 migration in the reservoir.
  - An injection into FWU #13-1 yielded results suggesting preferential fluid flow along two adjacent faults <map at right>
  - However, vapor-phase tracer recovery is not as straightforward (multiple spikes) as the aqueous-phase tracers, leading to uncertainty in analysis.
  - Despite technological advancements made by NMT for the purpose of gas tracer collection, injection and sampling sampling both require specialized equipment and procedures that increase on-site access, effort and costs.





Fluctuating vapor-phase tracer return curve for FWU well #8-2 is indicative of most wells sampled.

GOST: Gas Oil Separation Tank for collection of vapor-phase tracers

MVA MAJOR FINDING: COUPLING OF GEOPHYSICS, MODELING & TRACERS

Geophysical modeling & structural interpretation using 3D reflection seismic

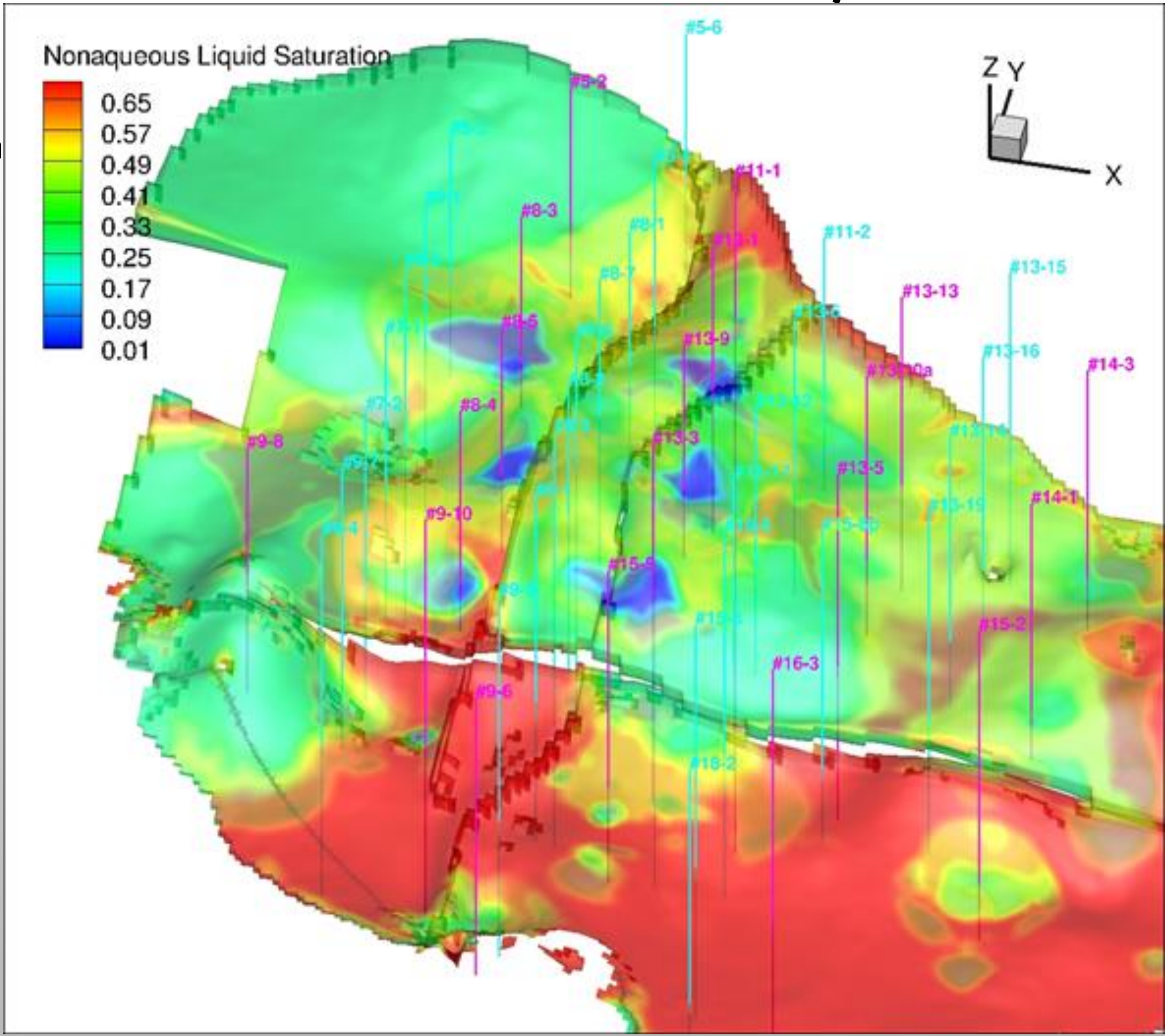
- Seismically resolvable faults/fault-like features interpreted by seismic attributes
- Implies many smaller faults/fractures
- Faults probably act as sealing features rather than seal bypass systems
- Faults affect geologic properties in geomodel

Reservoir Tracers

- Reservoir tracer data yielded useful model development data, including verification of and characterization of faults and transport pathways.

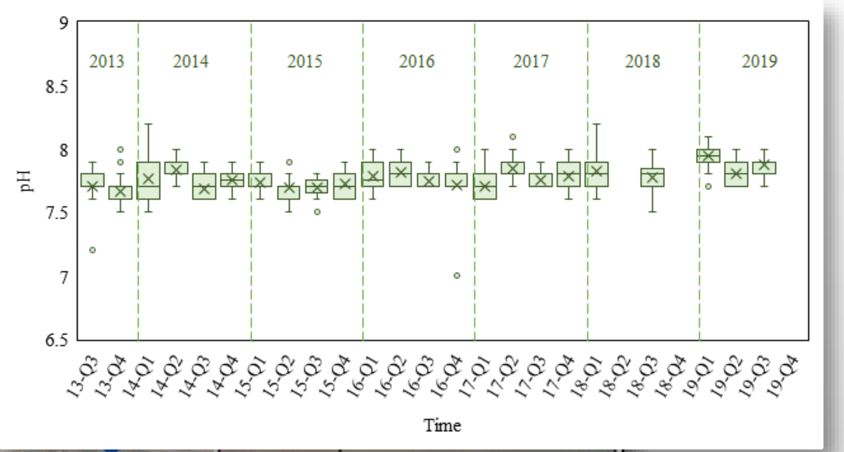
Modeling & Simulation

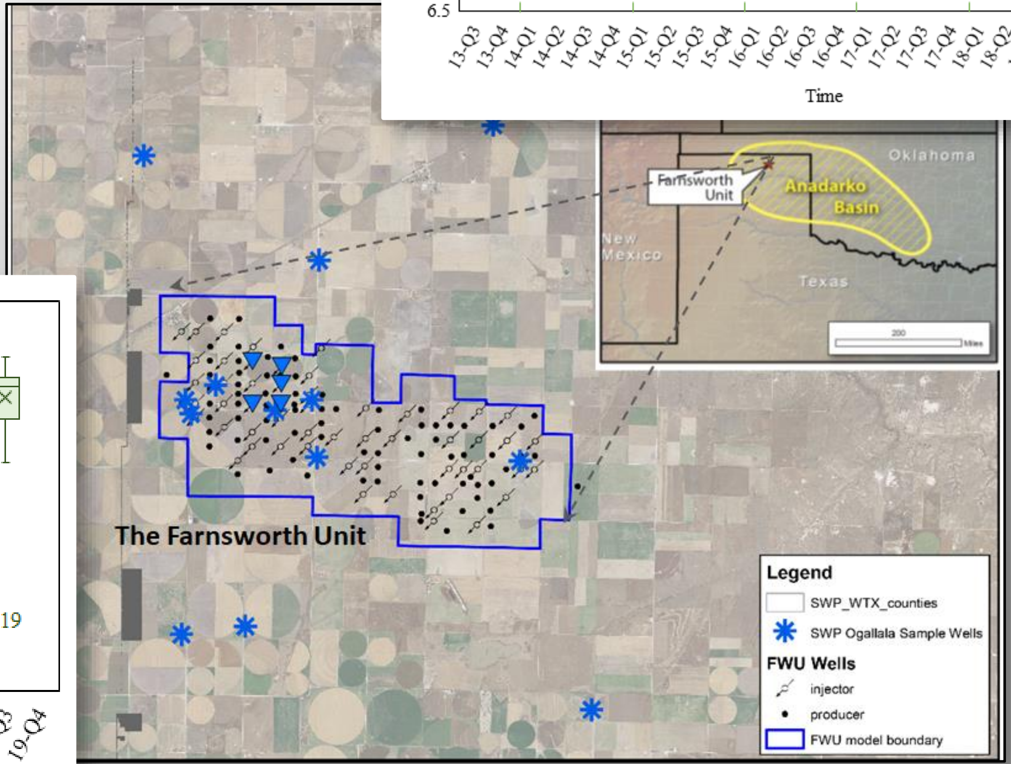
- Numerical simulations of the aqueous-phase tracer injections were able to successfully predict fluid transport in specific well patterns and increased permeabilities along adjacent faults.

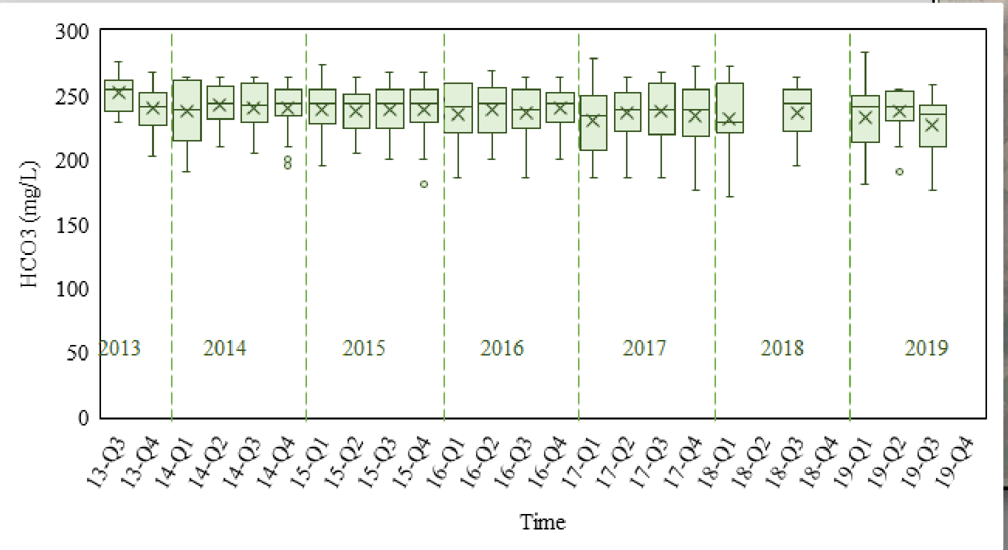


MAJOR ACHIEVEMENTS DURING 2019 - 2020

- **Subtask 6.1 Surface and Near-Surface Monitoring**
  - Completed longitudinal analysis of USDW (Ogallala aquifer) major cation/anion and trace metal concentrations for wells in and around the FWU
  - No field-wide indication of CO_2, brine and/or hydrocarbon leakage from depth into USDW

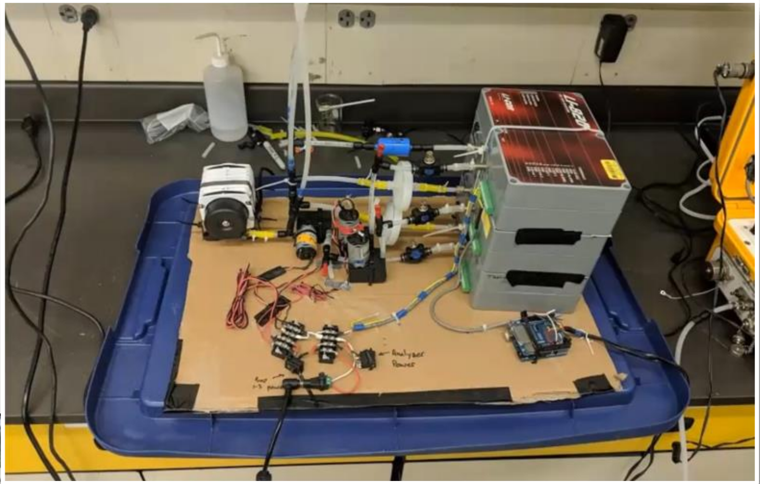


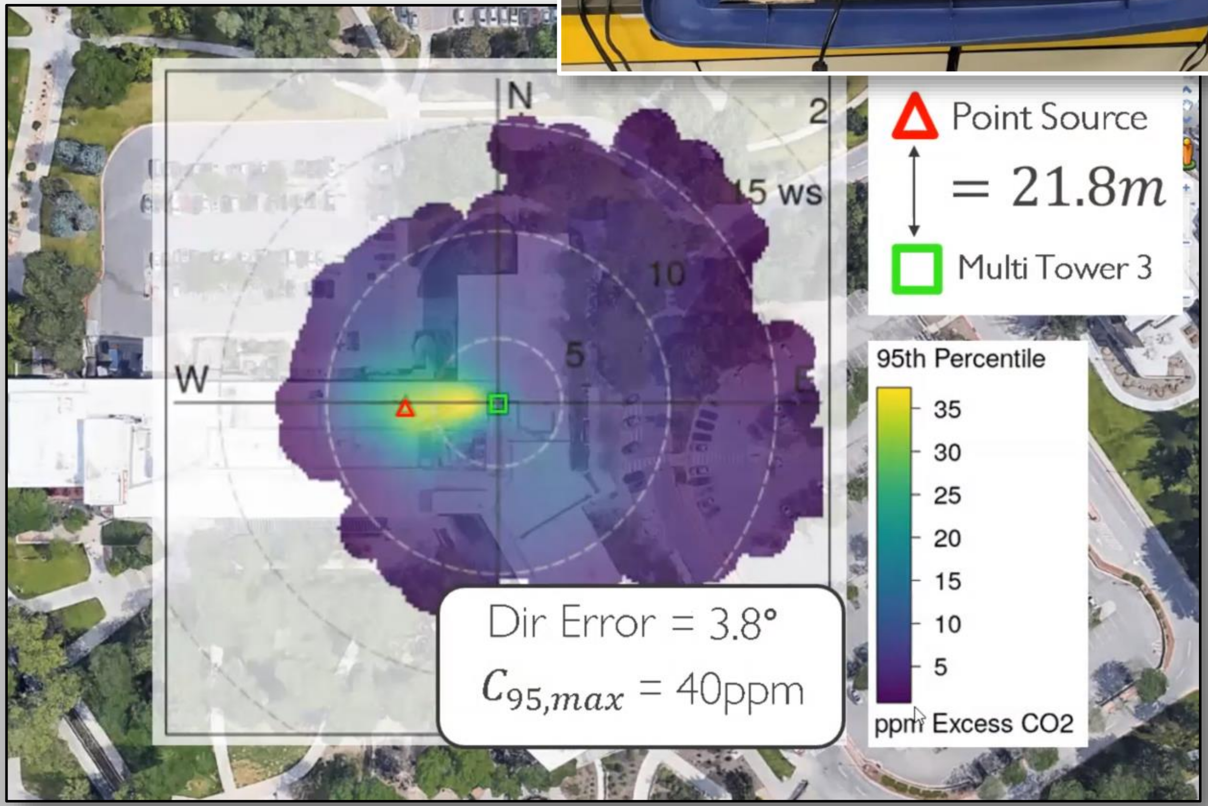




MAJOR ACHIEVEMENTS DURING 2019 - 2020

- **Subtask 7.1.1 Monitor Surface and Near-Surface**
  - Completed pilot-scale study of eddy tower and distributed sensors with implications for CO_2 point-source detection at CCUS sites, including the FWU
  - Low-cost sensor network and lower data collection rate may be just as effective as higher-costs systems for identifying and quantifying point source leakage.
  - Machine Learning provides a method for remote quantification of CO_2 emissions





MAJOR ACHIEVEMENTS DURING 2019 - 2020

- **Task 7.1.6 – Microseismic Monitoring**
  - Conducted survey design to optimize surface microseismic locations (20 stations)
  - Installed 20 surface microseismic stations in July 2019
  - Collected surface and bore-hole data to date. Data was analyzed and both datasets are being integrated

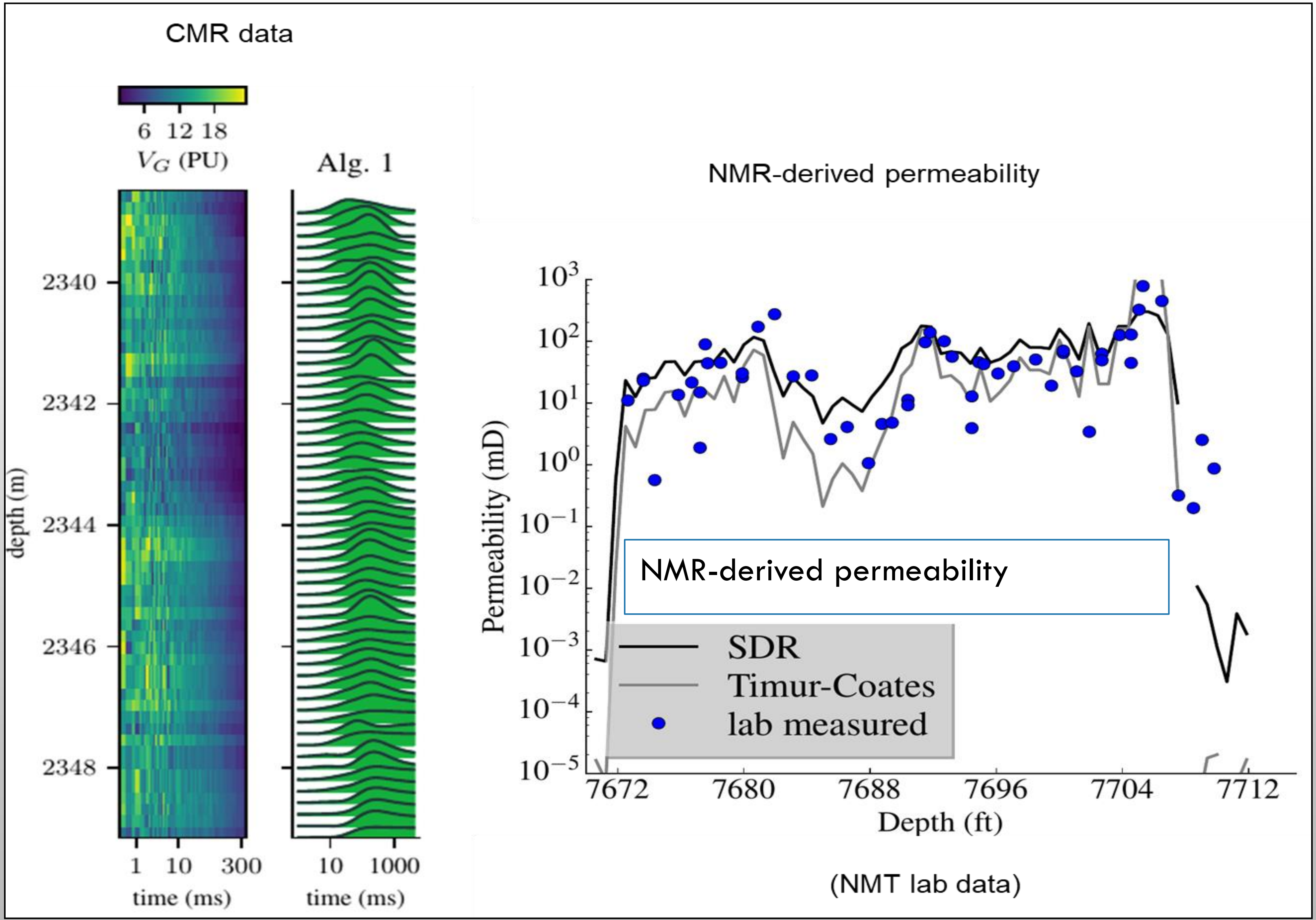
MAJOR ACHIEVEMENTS DURING 2019 - 2020

- **Subtask 7.1.4 Additional Geophysical Monitoring & Subtask 7.1.7 Continue Analysis of Time Lapse VSP Surveys**
  - Recorded walk-away and offset VSP shots into bore-hole geophone array in observation well 13 - 10 in September 2019. Shots were used to orient geophones

SWP SIMULATION EFFORTS AND LESSONS LEARNED

SIMULATION: DATA SOURCES

- Geological Model
- Field Historical data
- Fluid Samples
- SCAL data/Capillary pressure data
- Borehole NMR (CMR)
- Tracer injection/recovery data
- Lab derived data



SIMULATION: TECHNOLOGIES AND APPROACH

SOFTWARE:

- Different software used to satisfy the full range of THMC processes
- STOMP-EOR (PNNL)
- Eclipse/Petrel (Schlumberger)
- Geochemist's Workbench (U. Ill.)
- TOUGHREACT (LBNL)
- Other in-house codes for specialty applications (proxy/ROMs, resource analysis, economics, etc.)

CALIBRATION:

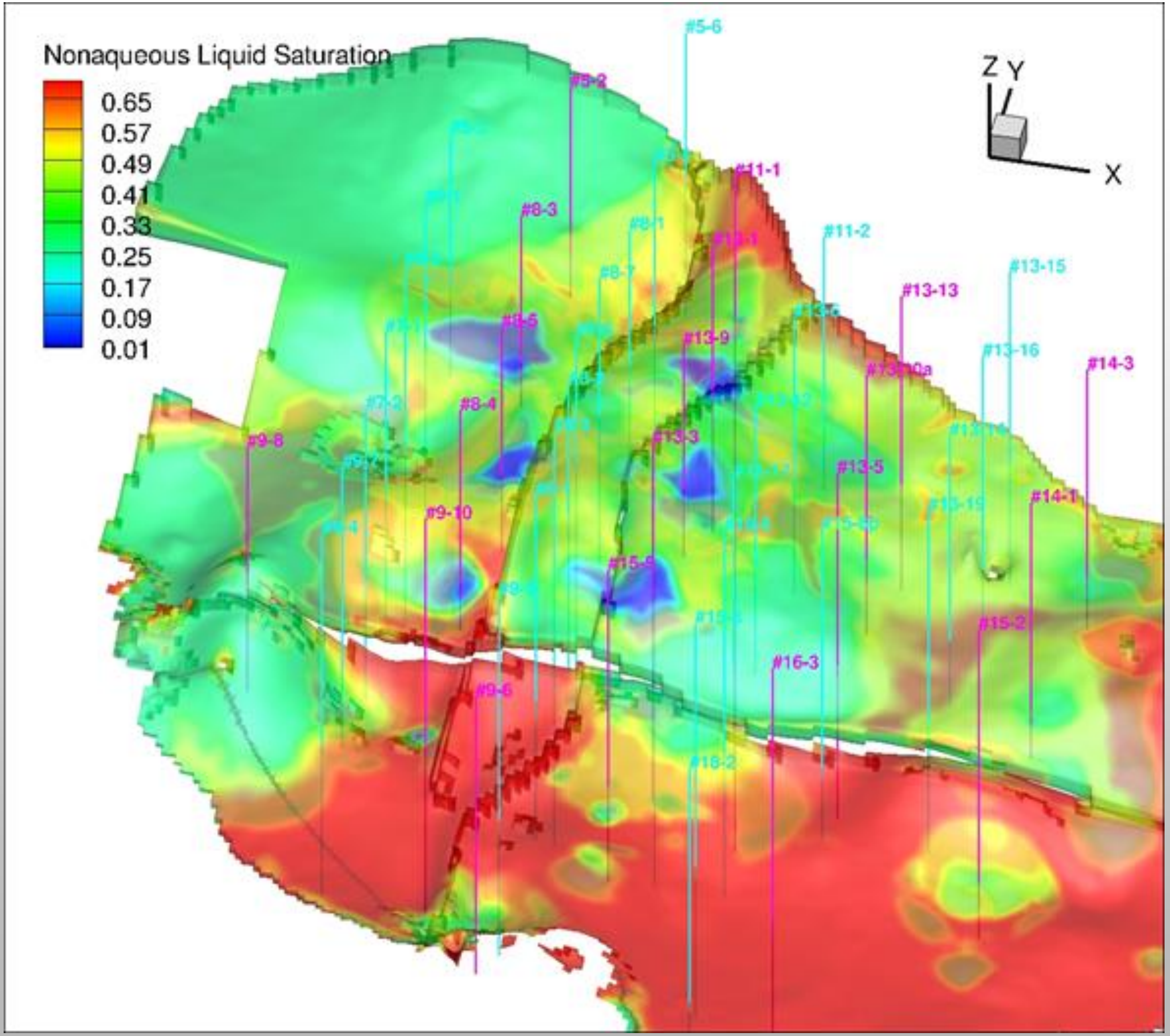
- Porosity & permeability inverted from logs
- Calibration with laboratory tests yields good results, e.g.
  - Slim tube experiment for MMP
  - Relative permeability tests

SOME HIGHLIGHTED GOALS:

- Computer assisted history matching
- Proxy Modeling (ROMs)
- Optimization framework

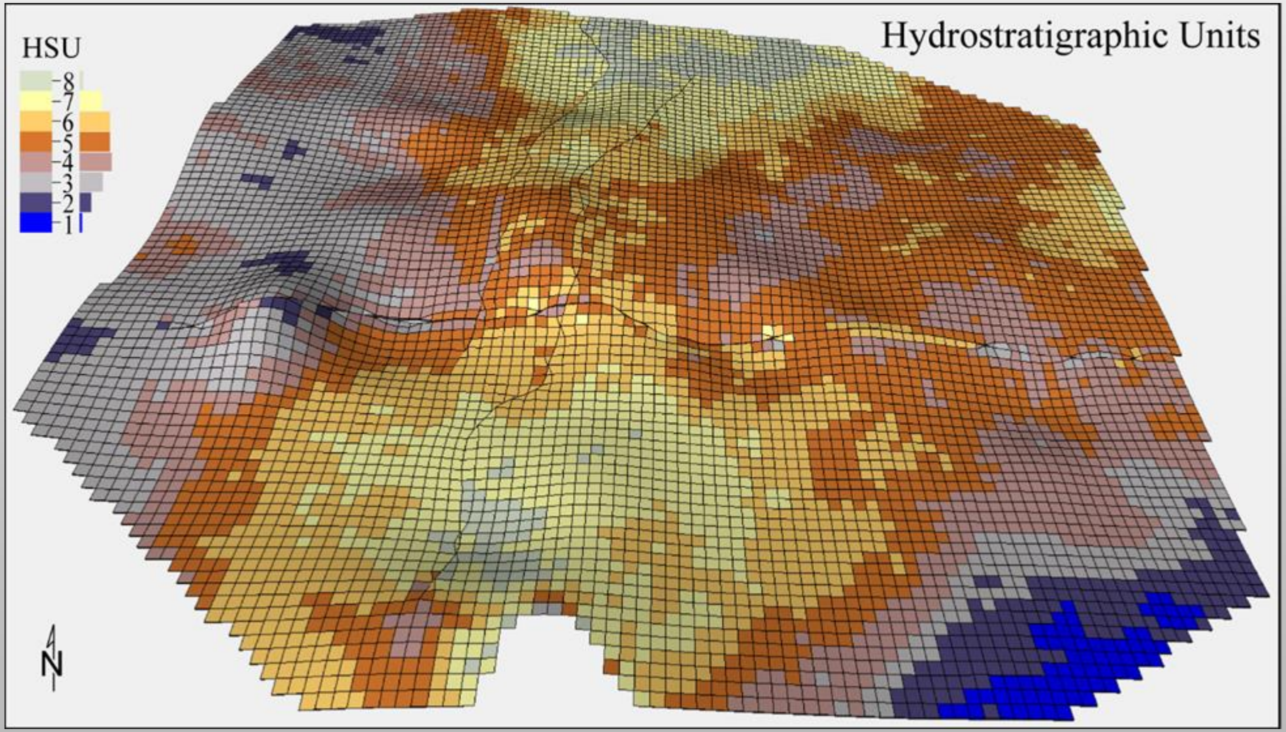
SIMULATION RESULTS: EXAMPLE

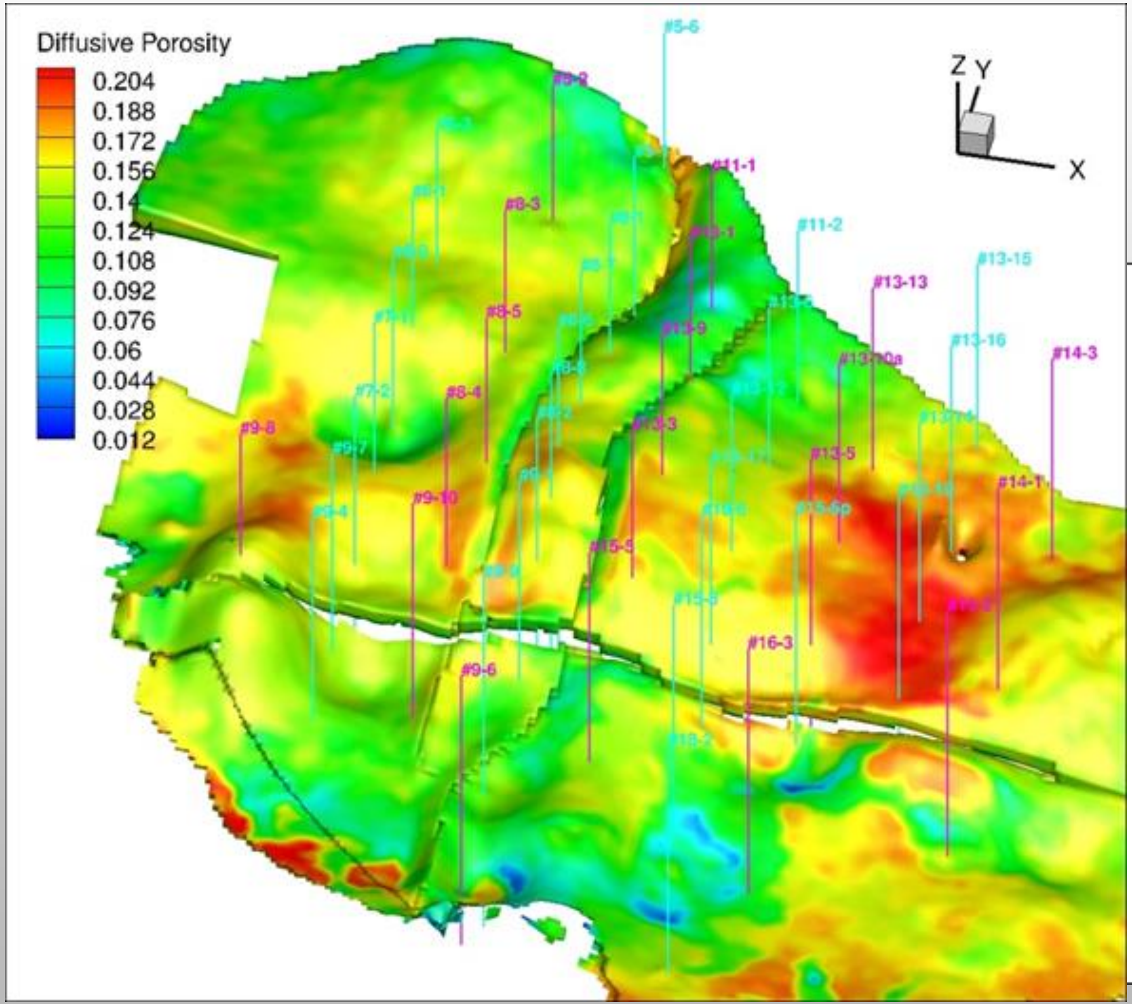
Simulation model showing Non-aqueous Liquid Saturation and impact of planar features on flow



SIMULATION: WHAT WORKED

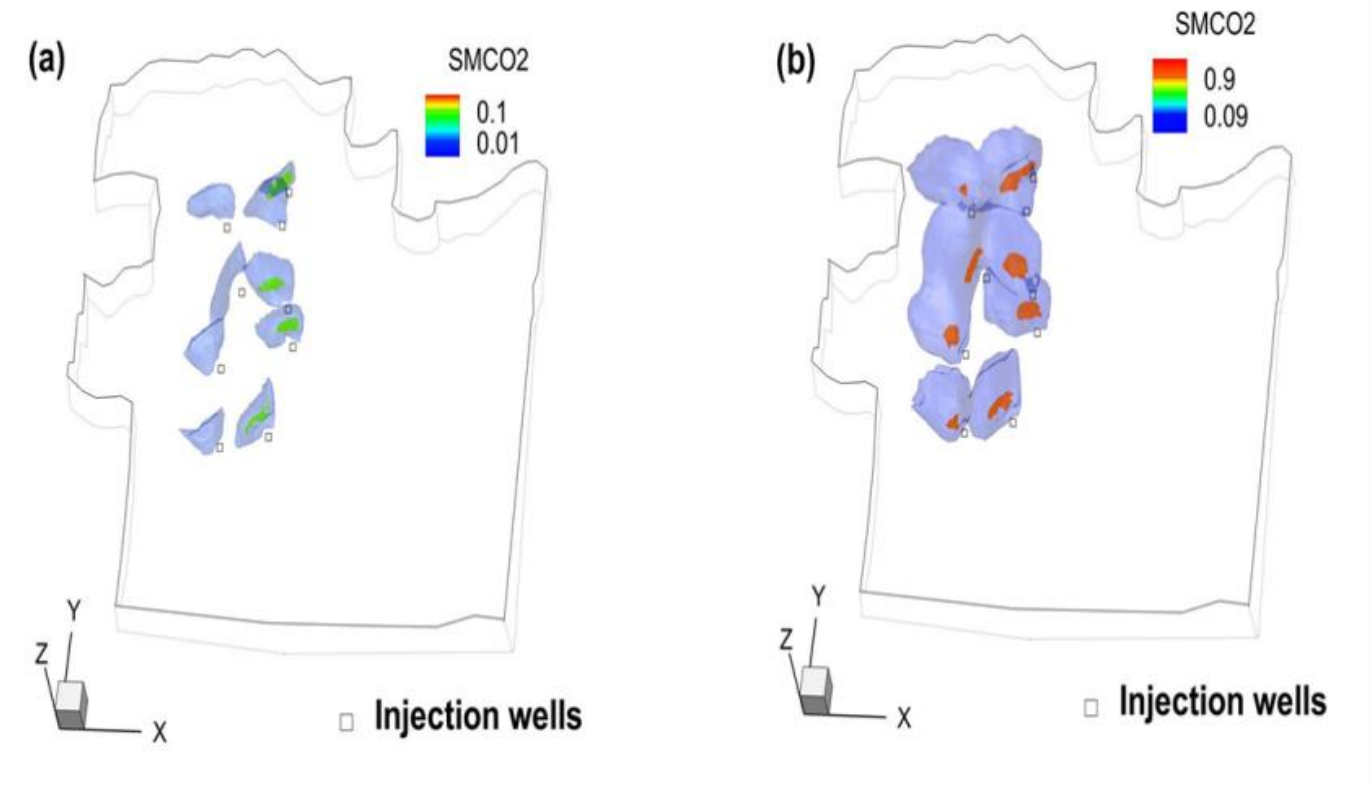
- Incorporation of Geologic models from characterization
- UU's model and NMT's history matched model are in good agreement with historical data
- Used as the basis for relative permeability analysis, fluid substitution analyses, etc.





SIMULATION: WHAT WORKED

Exchange of field data, geologic models, and PVT data between disparate modeling / simulation software (e.g., for different capabilities, including Petrel, Eclipse, STOMP, TOUGHREACT)

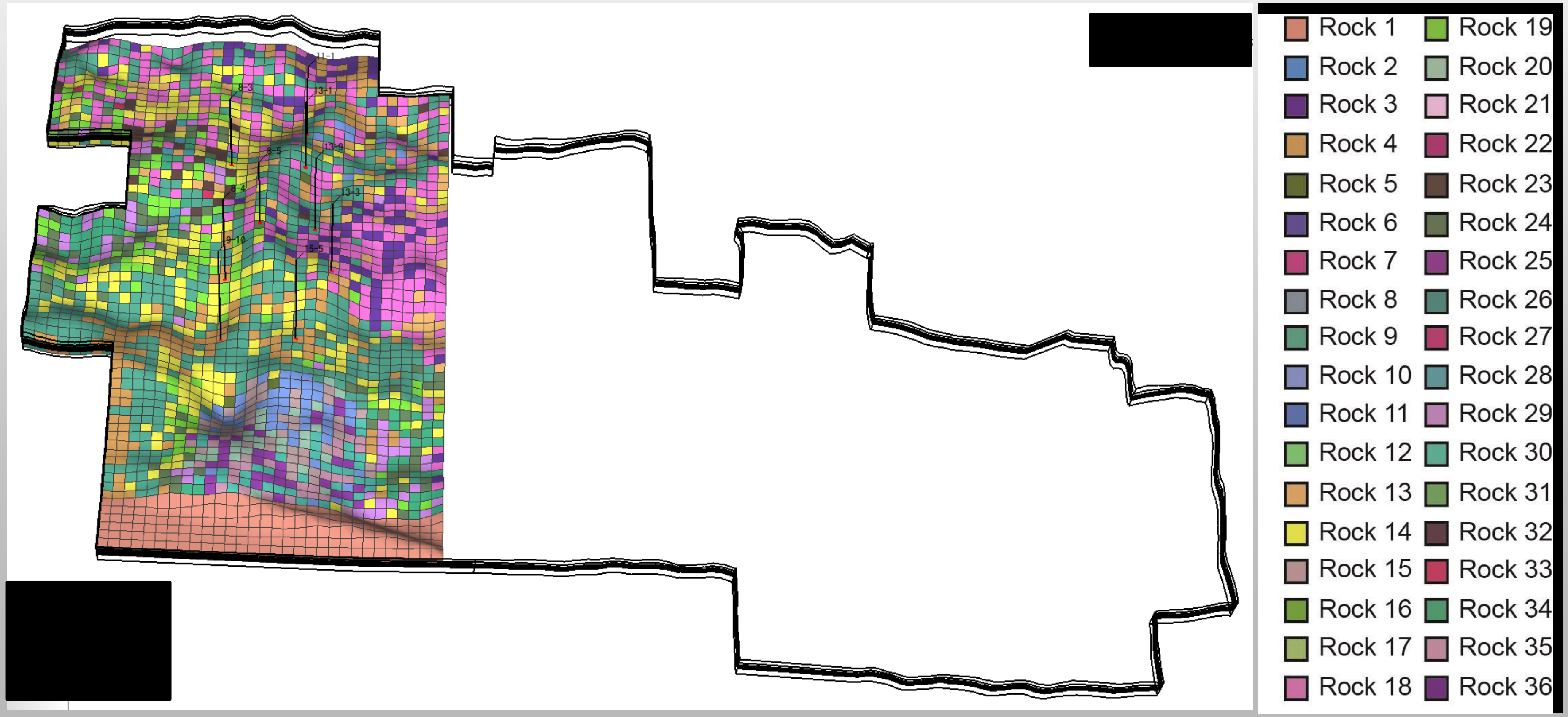


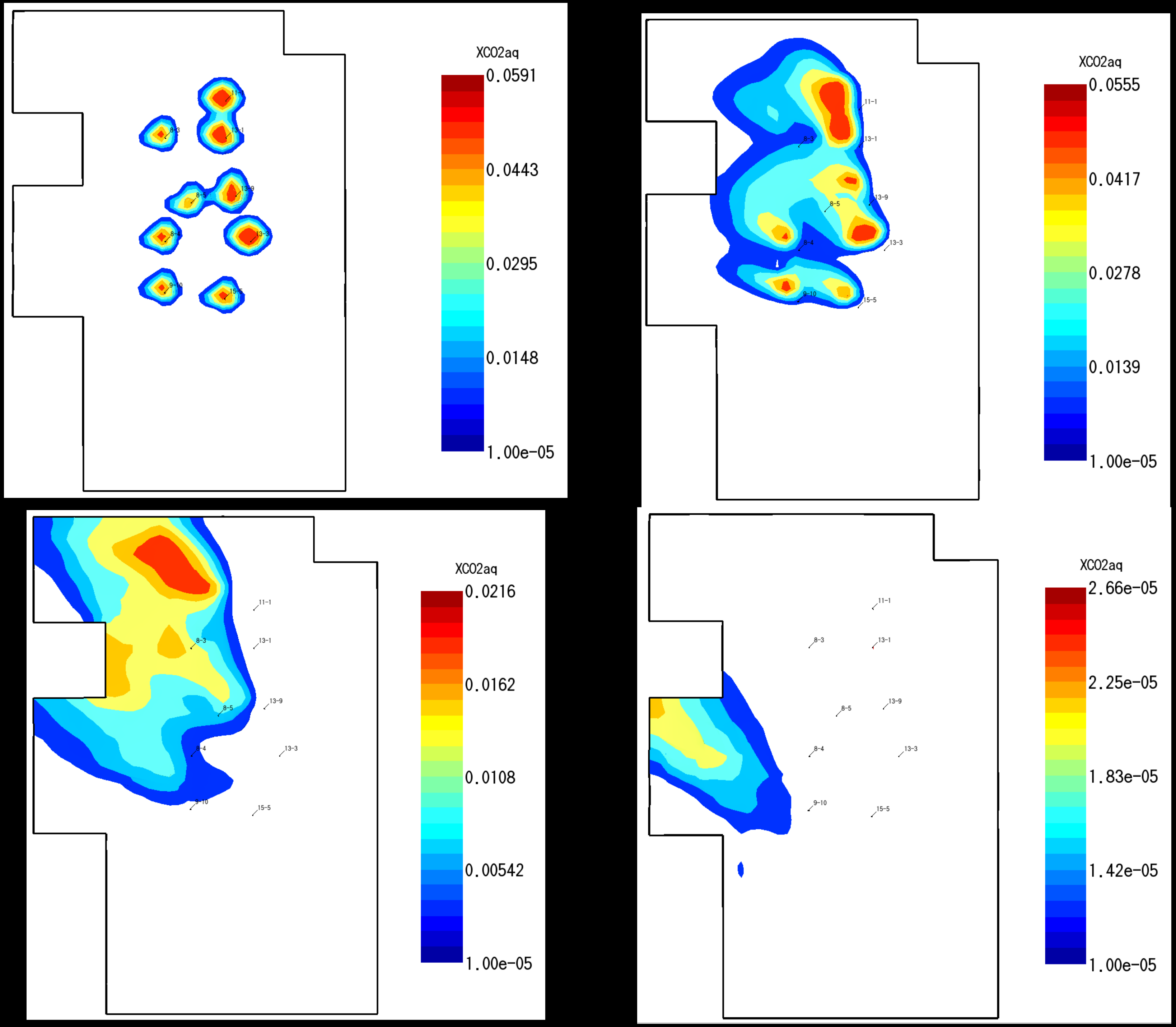
TOUGHREACT simulation plots of the western FWU showing the SMCO2 parameter, i.e. the mass of injected CO_2 sequestered as carbonate minerals in kg/m^3 of porous medium at times of (a) 1 year and (b) 57 years

- CO_2 was injected continuously for the first 10 years of the simulation

REFINEMENT OF TOUGHREACT MODELS

- Mass balance accuracy for Reactive Transport Model
- Extension of simulations to > least 1000 years
- Relative permeability and capillary pressure limitations

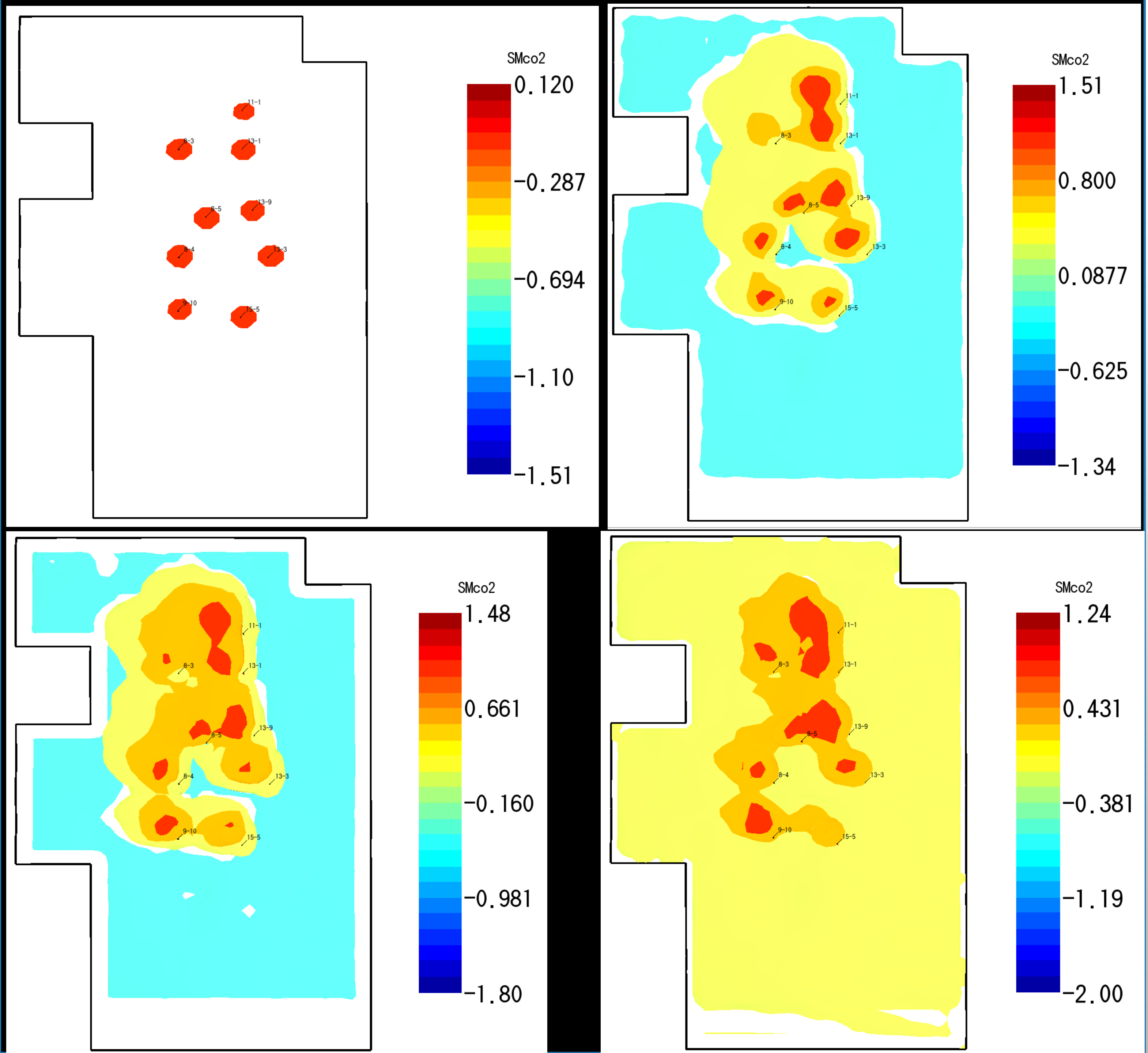




REFINEMENT OF TOUGHREACT MODELS

- Aqueous CO_2 can be transported beyond eastern margin of Farnsworth field within a few hundred years

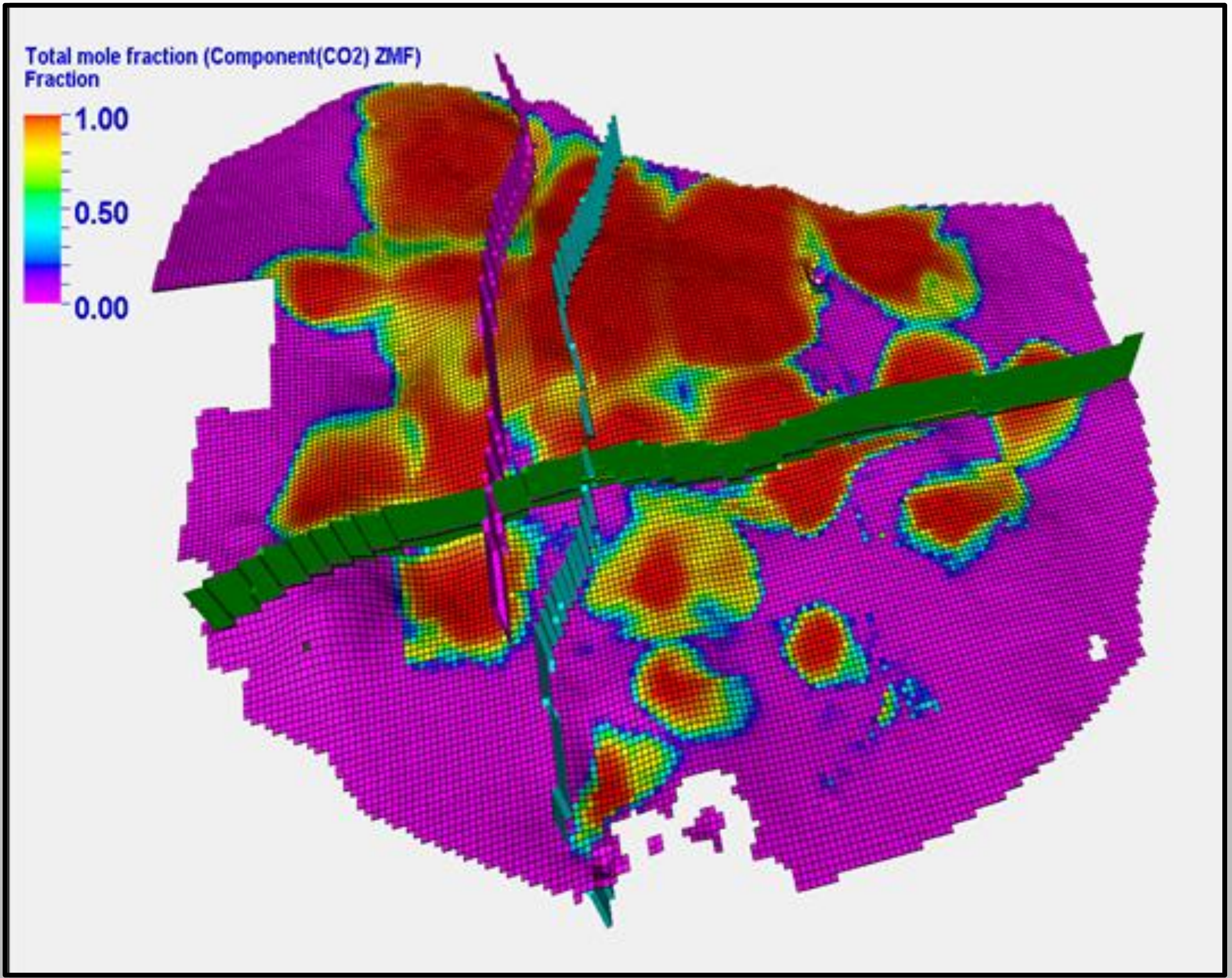
MINERALIZATION EFFECTS



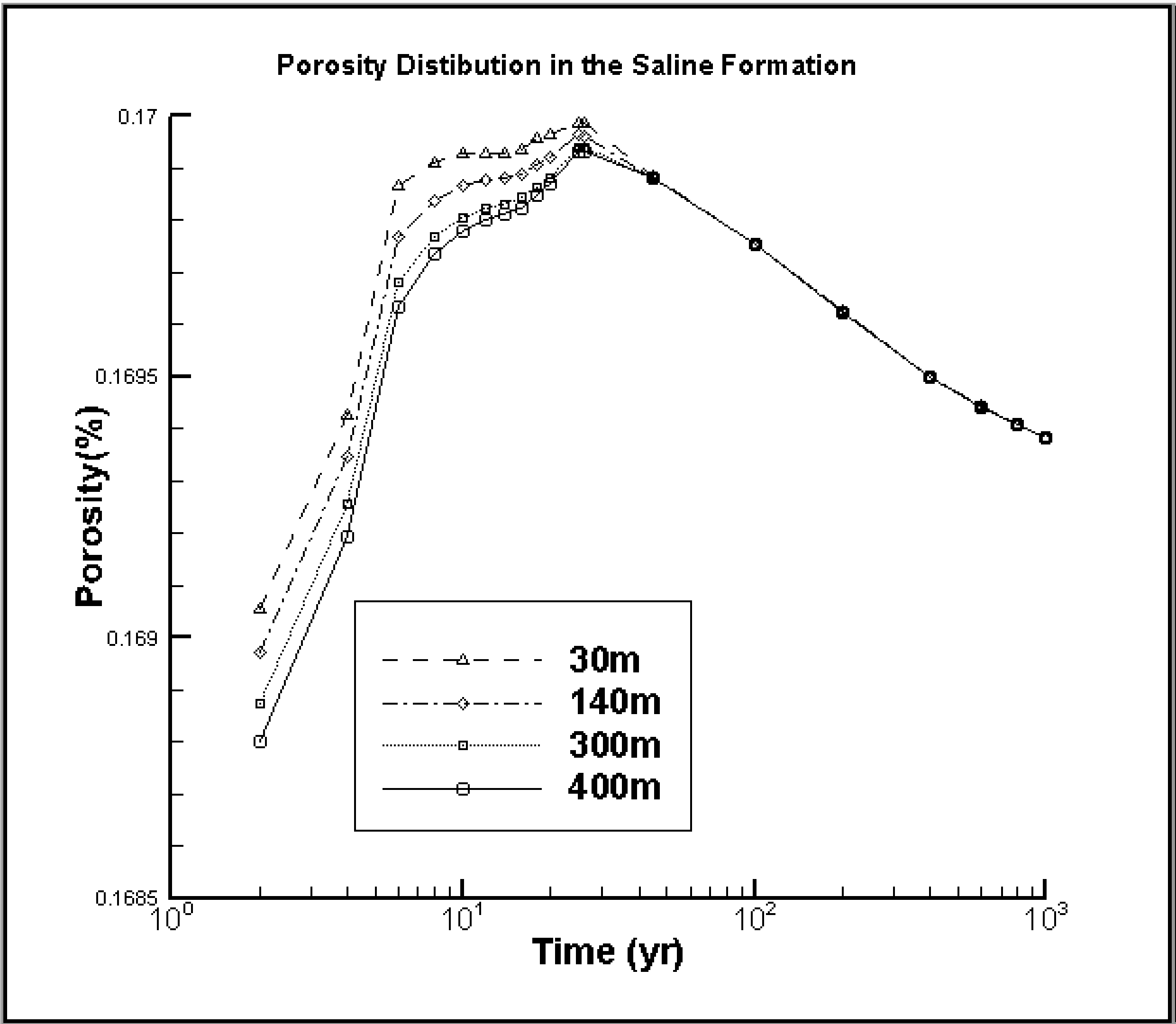
- During injection phase, net dissolution of carbonate minerals near wells
- After injection ceases, net carbonate mineral precipitation occurs
- However, later influx of CO_2-poor formation decreases overall carbonate mineral precipitation

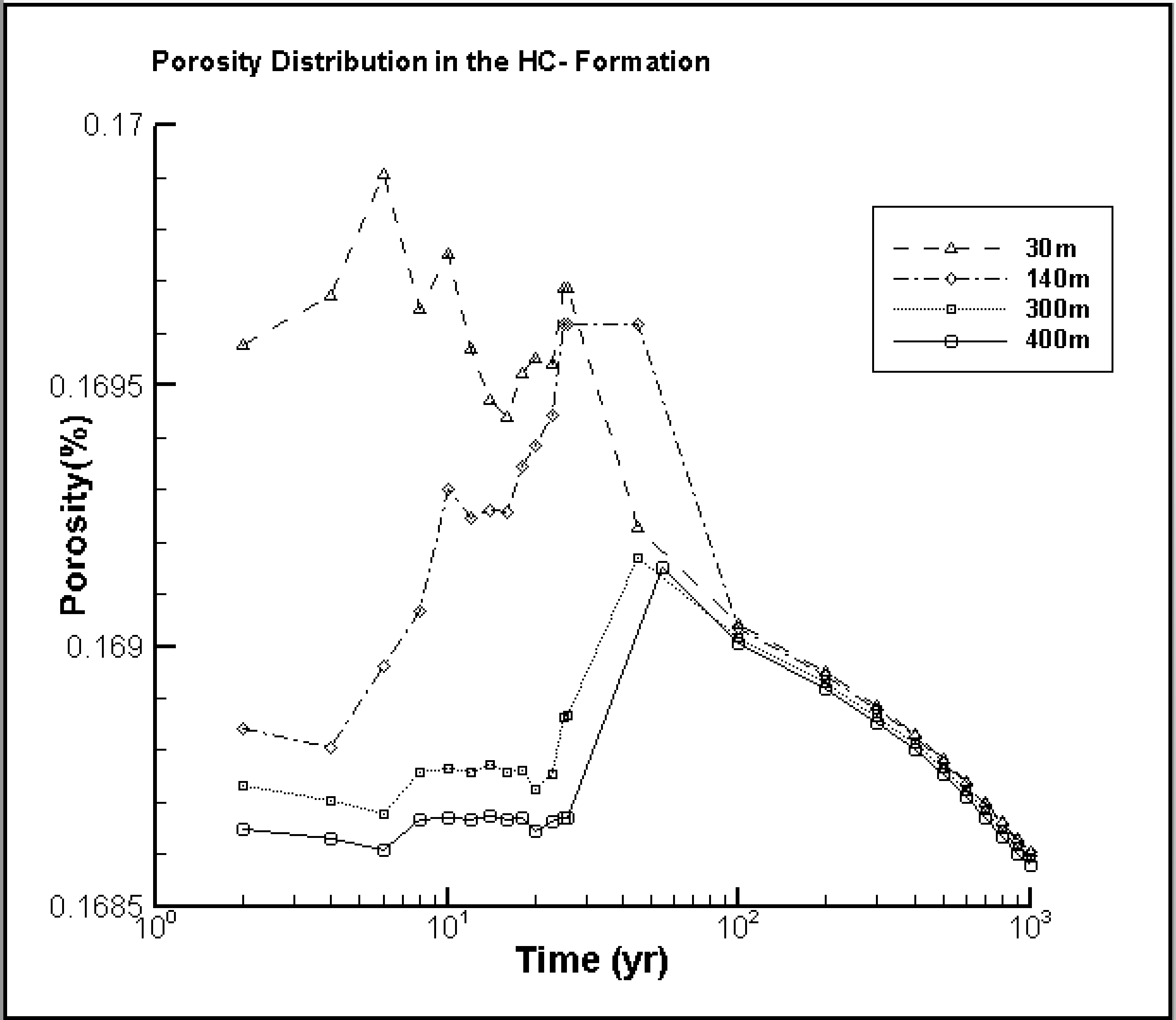
SIMULATION: MAJOR FINDINGS

- Successfully history matched several generations of geomodels provided by the Characterization group
- Successfully implemented proxy modeling technique to reduce computational time without compromising accuracy
- Successfully developed co-optimization of CO_2 storage and oil recovery framework which may be applied to other projects



SIMULATION RESULTS – POROSITY CHANGES DUE TO MECHANICAL EFFECTS





SIMULATION: RECENT FINDINGS

- For this field, injected CO_2 persists as an immiscible phase for only a few decades after injection ceases
- Calcite was predicted to be the most abundantly precipitated carbonate mineral over the entire study area (model domain)
- In the immediate vicinity of injection wells, dolomite was the most abundantly precipitated carbonate mineral
- Native reservoir minerals, albite, clinochlore, and illite, were predicted to dissolve, whereas quartz, kaolinite, and smectite were predicted to precipitate
- Dissolution and precipitation of minerals in the Morrow B Sandstone induce negligible changes in its porosity

SWP RISK ASSESSMENT EFFORTS
AND
LESSONS LEARNED

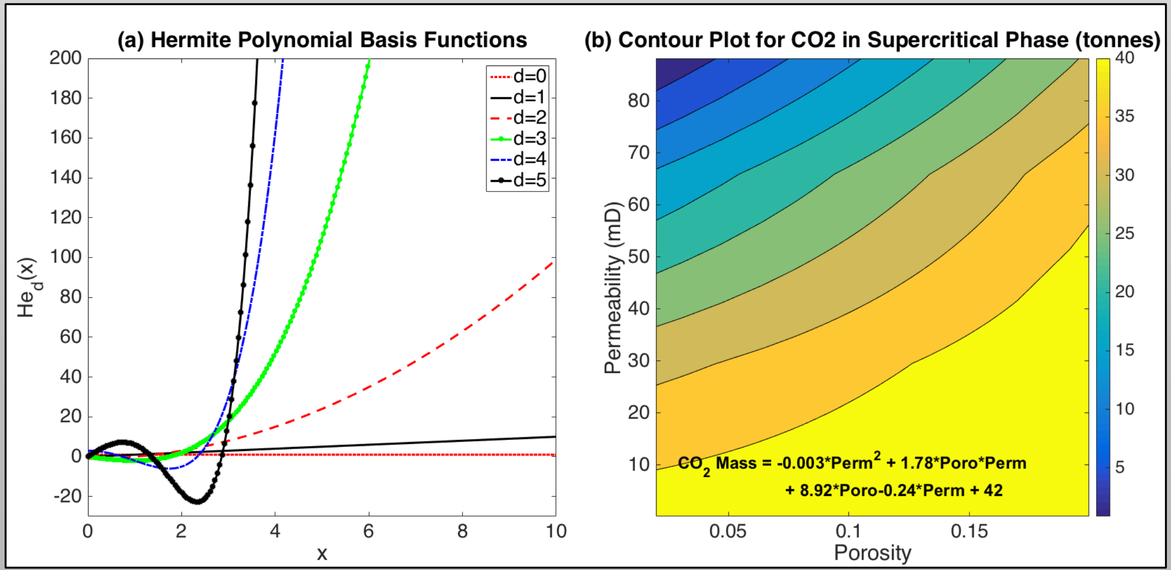
RISK ASSESSMENT: TECHNOLOGIES

- Qualitative Risk Analysis (MOSTLY COMPLETE)
  - Risk Registry via Failure Modes and Effects Analysis (FMEA)
  - Annual Risk Survey (2014-2017)
  - Process Influence Diagram (PID)
- Quantitative Risk Analysis (ONGOING)
  - Probabilistic Assessment
  - Geologic/reservoir models
  - Reduced Order Models (ROMs)
    - Response Surface Method
    - Polynomial Chaos Expansion (PCE)
  - NRAP tools: NRAP-IAM-CS, RROM-GEN

RISK ASSESSMENT: RECENT ACCOMPLISHMENTS

- Updated Risk Rankings
- Constructed process influence diagrams (PIDs) for quantitative risk assessment
- Developed apparently-robust ROMs for representing full-reservoir model simulation results, to save computational time and effort.
- Developed workflow from physics-based reservoir simulators to performing leakage calculations using NRAP-IAM-CS
- Developed integrated framework of combined batch experiments and reactive transport simulations to analyze mechanisms of trace metal mobilization.

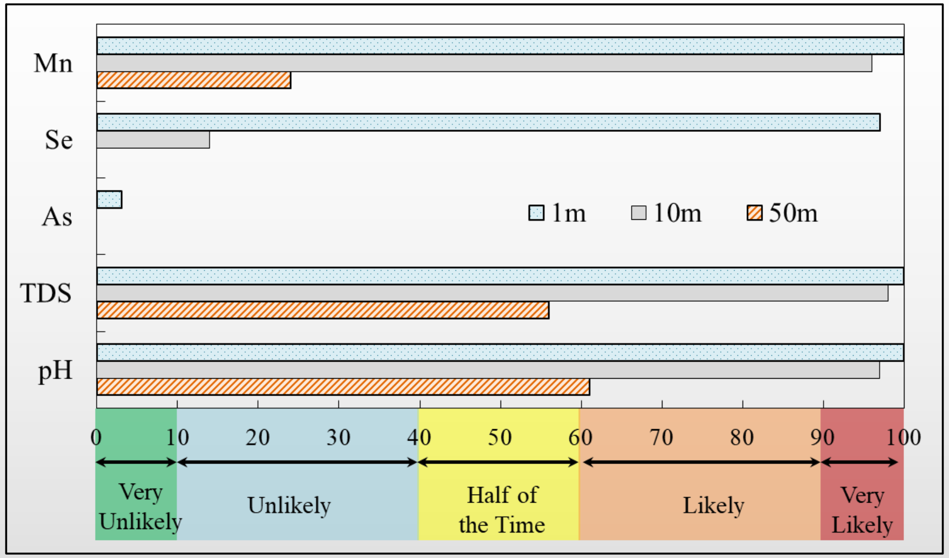
2017 FEP No.	2016 FEP No.	Rank 2014	Rank 2015	Rank 2016	Rank 2017	**2017 FEP** (* different wording in prior year/s)
F515	F22	6	1	1	1	Price of oil (or other related commodities)
F506	#N/A	#N/A	#N/A	#N/A	2	DOE financial support
F407	F65	35	28	16	3	On-road driving
F501	#N/A	#N/A	#N/A	#N/A	4	Change of field owner and/or operator
F502	F19	2	7	4	5	CO2 supply adequacy
F508	F23	37	2	7	6	EOR oil recovery
F513	F24	7	3	5	7	Operating and maintenance costs
F511	F63	29	18	2	8	Legislation affecting CO2 injection or CO2-EOR*
F306	F40	1	36	23	9	Simulation and modeling - parameters*
F609	#N/A	#N/A	#N/A	#N/A	10	Well component failure (tubing, seals, wellhead, etc.)
F109	F13	16	15	29	11	Reservoir heterogeneity
F401	F66	18	8	3	12	Accidents and unplanned events
F207	#N/A	#N/A	#N/A	#N/A	13	Workovers: Damage to instrumentation
F603	F53	48	16	24	14	Defective hardware*
F310	F36	9	6	25	15	Simulation of geomechanics
F206	F16	12	25	39	16	Seismic method effectiveness*
F608	F41	84	#N/A	10	17	Severe weather
F111	F06	52	#N/A	51	18	Undetected features
F516	F26	21	9	31	19	Project execution strategy (DOE project, not EOR or production)*
F304	F33	10	10	41	20	Over pressuring



RISK ASSESSMENT: MAJOR FINDINGS

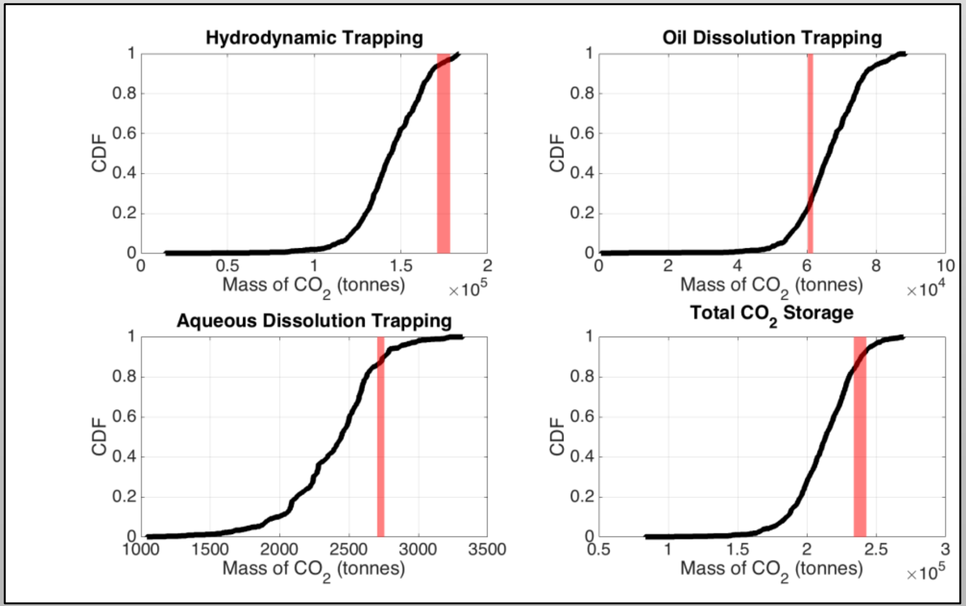
Wellbore Leakage:

- Wellbore cement at the FWU will likely maintain its structure and integrity within 100 years, and is unlikely to provide leakage pathways.



USDW Impact:

- Toxic trace metals may be considered an insignificant long-term concern for the Ogallala formation: simulations indicate that clay adsorption mitigates impact of CO_2 and brine leakage from the reservoir
- Increased salinity of USDW via leaked saline water may likely be a larger concern than associated trace metals release.

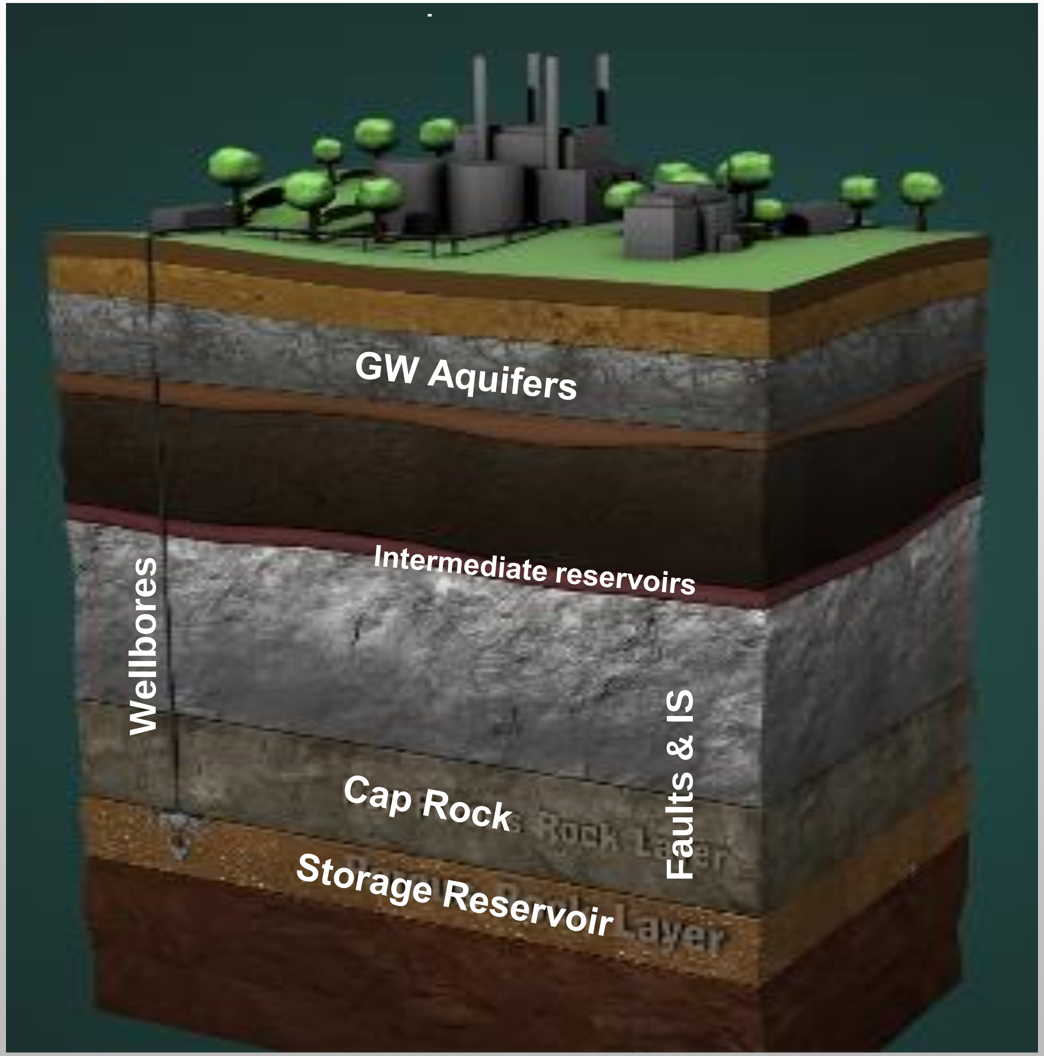


CO_2 Storage and Economics:

- Hydrodynamic trapping sequesters the most injected CO_2 at the FWU, followed by oil dissolution trapping, and aqueous dissolution trapping.
- ROMs analyses suggest that 31% of the 1000 realizations designed for FWU may be profitable.

RISK ASSESSMENT: NEEDS FURTHER EVALUATION

- Leakage Assessment
  - Compare leakage risk for FWU in current EOR operations to FWU if it had been developed as a greenfield, CO_2-storage-only site
  - Enhance wellbore leakage models to include oil with the CO_2 and brine leakage.
- Uncertainty Reduction
  - Heterogeneity of groundwater (Ogallala) formation/caprock/reservoir could be included in simulations for further site characterization.
  - Further calibration of geochemical reactions/cement degradation of site-specific samples may be utilized to reduce uncertainty of forecasted key parameters.
  - Uncertainty may be reduced with more and/or higher-resolution characterization data.



RISK MAJOR ACHIEVEMENTS DURING 2019 - 2020

- Simulations using core-scale clastic samples to study the role of effective stress on permeability measurements as a result of pore pressure increases due to changes in fluid flow rate. A multi-laminate framework was also developed and applied for the geomechanical risk analysis in the cap rock with a simple 3D layer cake case.
- CO2 and brine leakage calculations for open well scenario, to check on the largest possible CO2 and brine leakage in the hypothetically open well condition.
- Developed a simulation plan that is consisted of three scenarios, the Base Case scenario, the Depleted Pressure scenario, and the Greenfield ROZ scenario. Simulation results are being used for subsequent analysis using NRAP tools.
- Accomplished both column experiments and associated numerical simulations to analyze the reaction mechanisms in the overlying shallow groundwater due to elevated CO2 level, as well as to obtain site-specific reaction parameters for uncertainty reduction in the future simulations
- Developed a coupled reactive-transport-geomechanics model of the FWU caprock based on site-specific geological data. Key results suggest that the Thirteen Fingers Limestone is a rather effective caprock. Geomechanical response of the caprock due to CO2 intrusion and mineral alteration suggests low risk of induced fractures.

Risk Major Achievements during 2019 - 2020

- Developing a workflow for quantifying uncertainty associated with grid upscaling. After the workflow and techniques have been validated via a simplified and generic model, they will be applied to the FWU model.
- Developing a set of core-scale 3D models with CMG-GEM to replicate flow-through experiment conducted in SWP BP3. Geochemical parameters will be calibrated against the lab results and will then be used in larger scale FWU simulations.
- The Risk WG has compiled a Risk Communication Report that addresses the information content of risk communications among project stakeholders, as needed to support decisions by those stakeholders. This report specifies the key content of risk information that in the best case will pass among both internal and external project stakeholders, to best support achieving all project objectives including effective risk management.
- The Risk WG is developing a set of treatments designed to lower likelihood and/or severity of the ranked risks. The treatments are being characterized by the other workgroups as to their cost, risk-reduction effect, and degree completed.

ONGOING AND FINAL WORK ITEMS

Critical ongoing work

- Support work
  - Characterization
  - Simulation
  - Monitoring (MVA)
- Passive seismic
- Depleted oilfield storage analysis (post EOR storage)
- Risk assessment (quantitative things)
  - Storage security
  - Leakage pathways
  - Wellbore integrity

Risk relies on much input from prior tasks and is a focus at this time

FOCUS AREA: RISK ASSESSMENT

Major work left in:

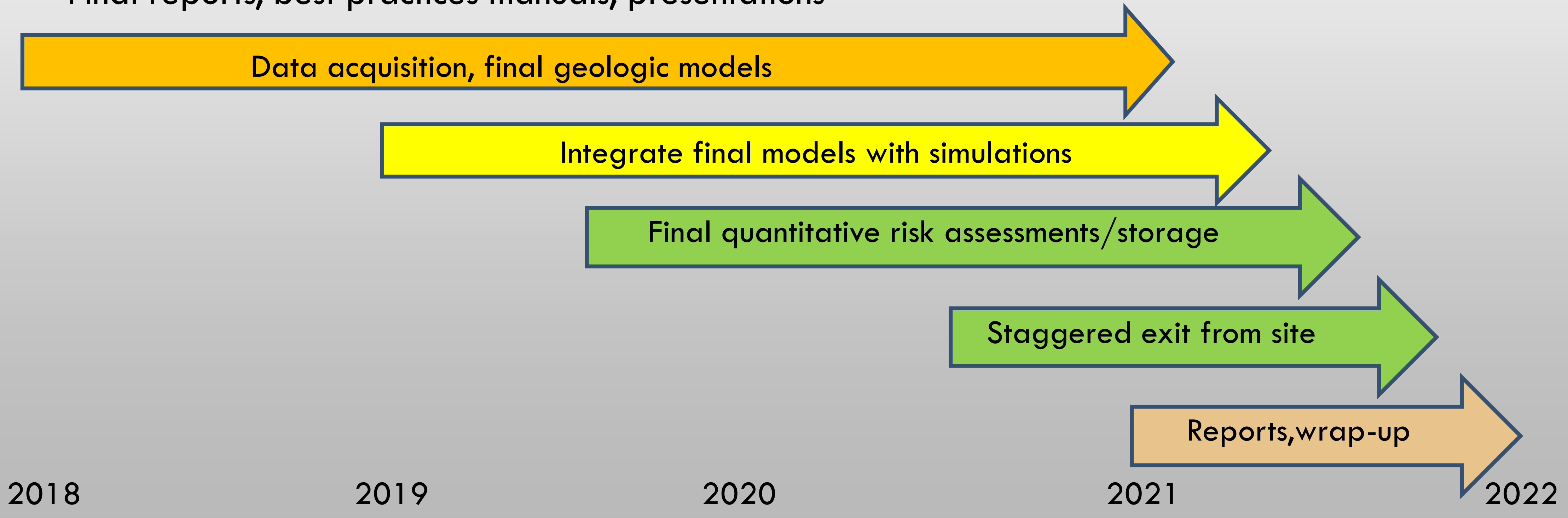
- Storage security
- Leakage pathways – chemomechanical studies of rock/fluid interactions under reservoir PT conditions
- Wellbore integrity – inventory older wells for cement quality, do sidewall coring, study effects of CO_2 on cement and near-wellbore rock
- Take results from reduced order models back into full-scale simulation

FOCUS AREA: DEPLETED OILFIELD (POST-EOR) STORAGE ANALYSIS

- Capacity analysis – quantifying capacity for commercial storage when factoring in post-EOR storage.
- Portability to other Anadarko or SW basins (Morrow reservoirs in particular – screen other fields based on FWU criteria and results).
- Evaluate impacts of credits such as 45Q on future projects
- Provide example and operational procedures for future EOR operations utilizing storage credits

TIMELINE TO COMPLETE PROJECT – 4 YEARS

- 24-36 months data collection: Passive seismic installation, acquisition, processing, and assimilation; Hydrophone Cross-well baseline and repeat; tracer results to be acquired and assimilated
- Integration of new data into geologic, simulation, and risk models
- Quantitative risk estimates using final models
- SWP exits FWU site
- Final reports, best practices manuals, presentations



Southwest Regional Partnership on Carbon Sequestration

Project DE-FC26-05NT42591

http://SWP.rocks