The Eagle Ford Shale Laboratory: A Field Study of the Stimulated Reservoir Volume, Detailed Fracture Characteristics, and EOR Potential

Award No. DE-FE0031579

Texas A&M University

Lawrence Berkeley National Laboratory

Stanford University

Chesapeake Energy

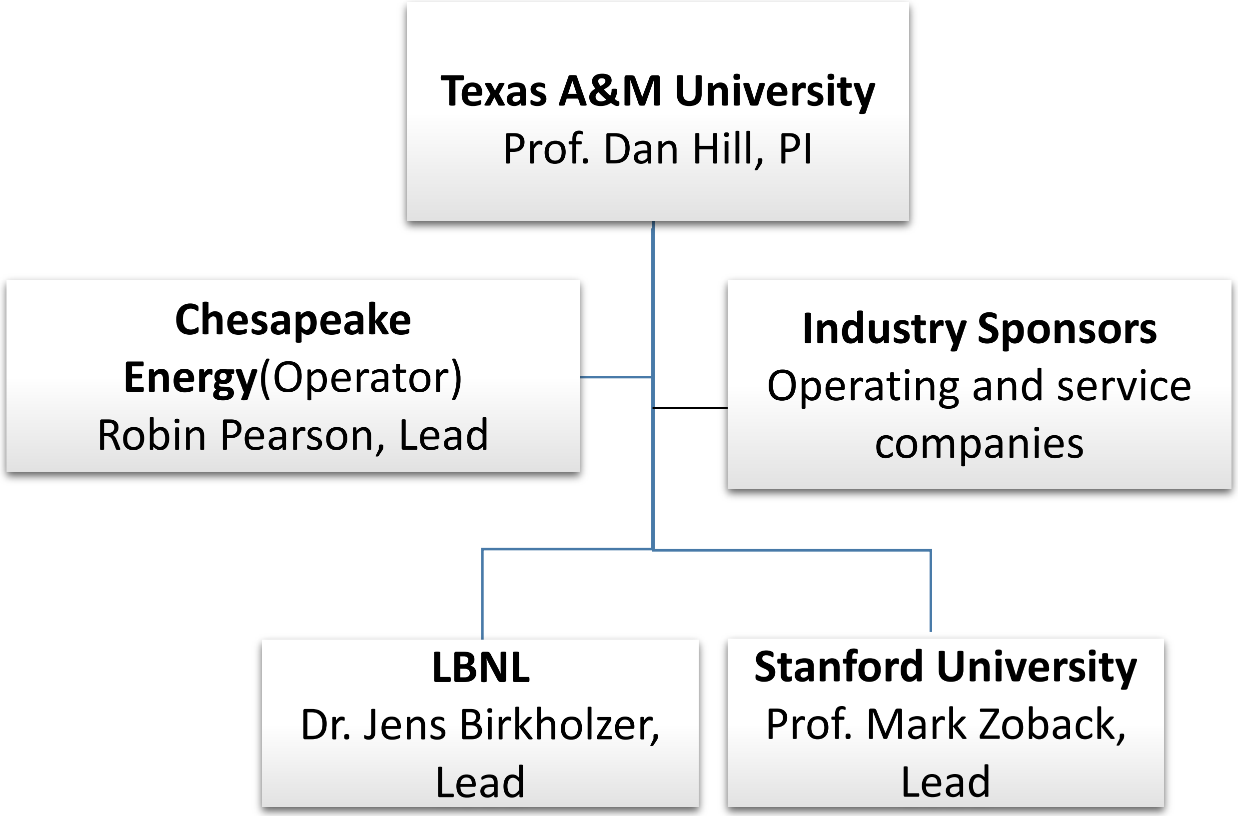
Eagle Ford Shale Laboratory (EFSL)

- Research Team:
  - **Texas A&M University**
  - Lawrence Berkeley National Lab
  - Stanford University
- Operator: Chesapeake Energy
- Field Site: Eagle Ford Shale near Caldwell, TX
- Project Period: 04/01/2018 – 08/31/2021

Eagle Ford Shale Laboratory (EFSL)

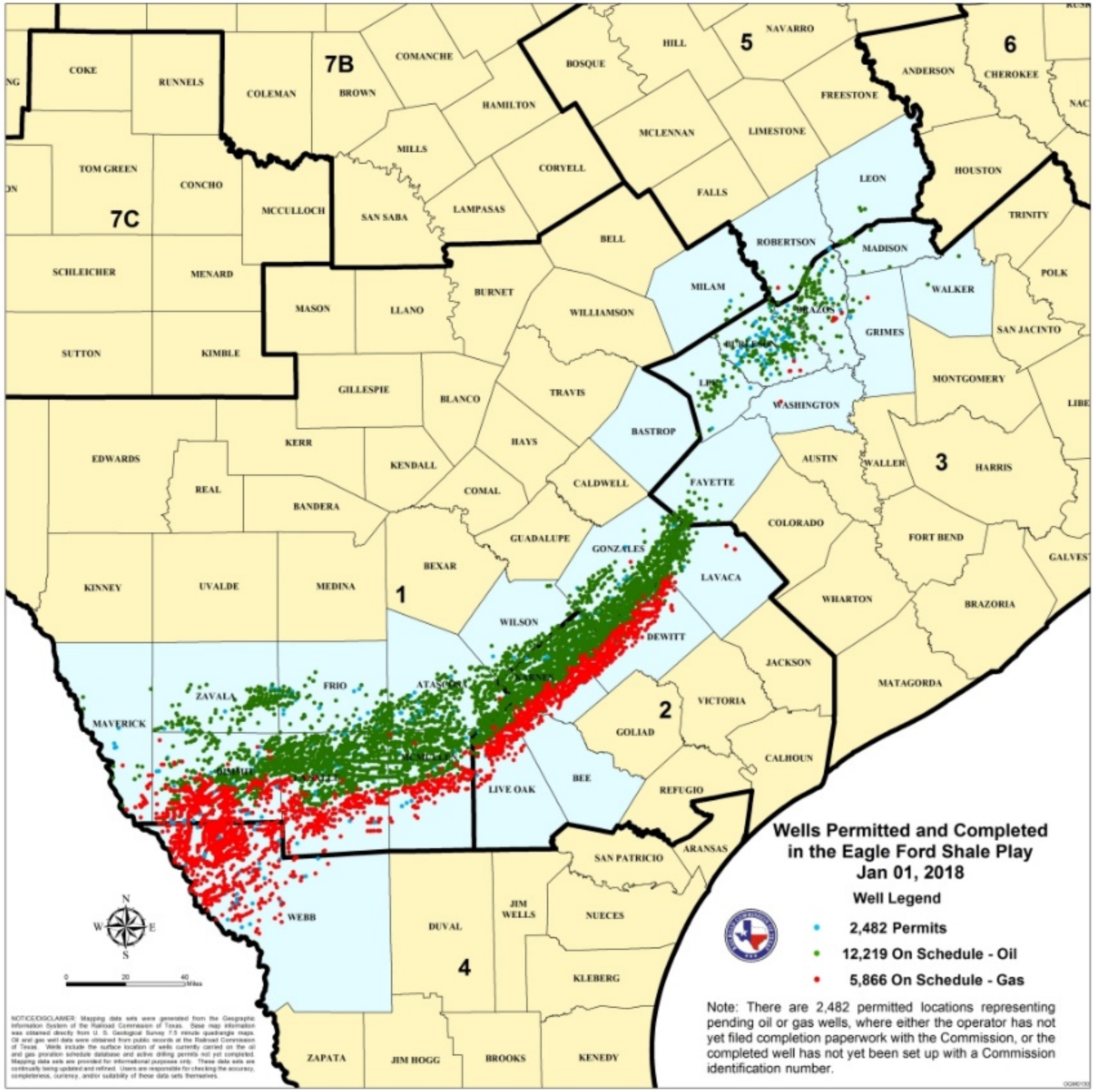
- Original Operator: WildHorse Resource Development
- December 2018, Chesapeake Energy announced purchase of WildHorse
- Sale closed February 1, 2019
- Operator change has caused some operational changes, delays

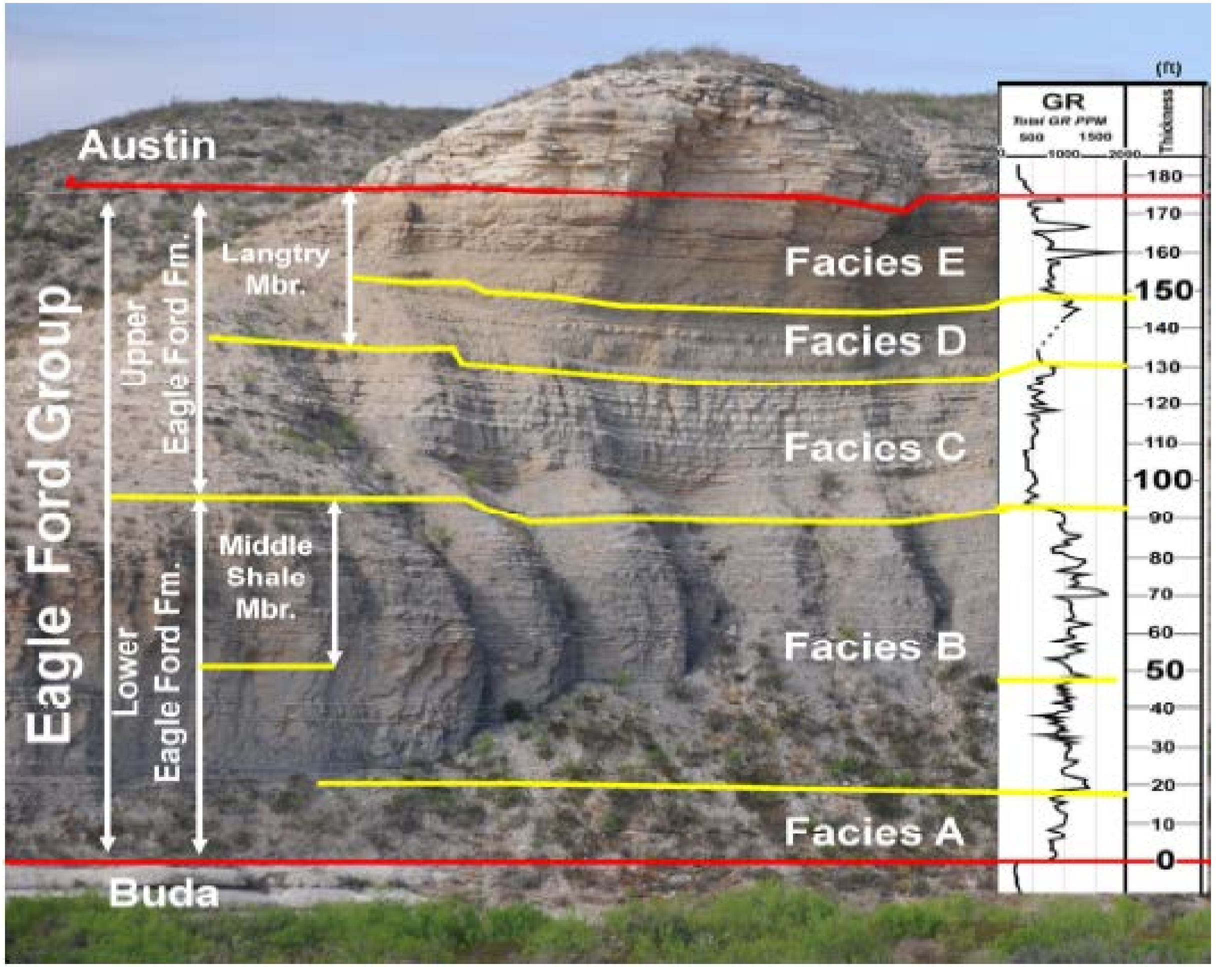
Project Team



- **Texas A&M University**
  - **Dan Hill** (lead PI for the project)
  - **Ding Zhu** (Fracture Monitoring)
  - **George Moridis** (Fracture Modeling)
  - **David Schechter** (EOR)
  - **Dante Guerra** (Program Manager)
- **Chesapeake Energy**
  - **Robin Pearson**
- **Lawrence Berkeley National Laboratory**
  - **Jens Birkholzer** (LBNL lead)
  - **Kurt Nihei** (Geophysicist)
  - **Jonathon Ajo-Franklin** (Active Seismic)
- **Stanford University**
  - **Mark Zoback** (Stanford lead)

Eagle Ford Shale





Oil production: >1,400,000 bopd, gas:>7 Bcf/d

Objectives of the Project

1. Perform high-spatial and -temporal resolution active and passive monitoring to image the stimulated reservoir volume (SRV) during fracturing, re-fracturing and gas-EOR processes.
2. Monitor long-term production (inflow profiles and bottomhole pressure) in producing wells
3. Optimize the fracturing process
4. Map gas distribution in EOR in the field
5. Improve drilling efficiency
6. Calibrate fracture/reservoir models

EFSL Main Tasks

- Phase I : Monitoring and evaluation of re-fracturing of a legacy well
- Phase II: Monitoring, evaluation and optimization of multistage fracture stimulation (two new producers)
- Phase III: EOR pilot with gas injection

Advanced Technologies

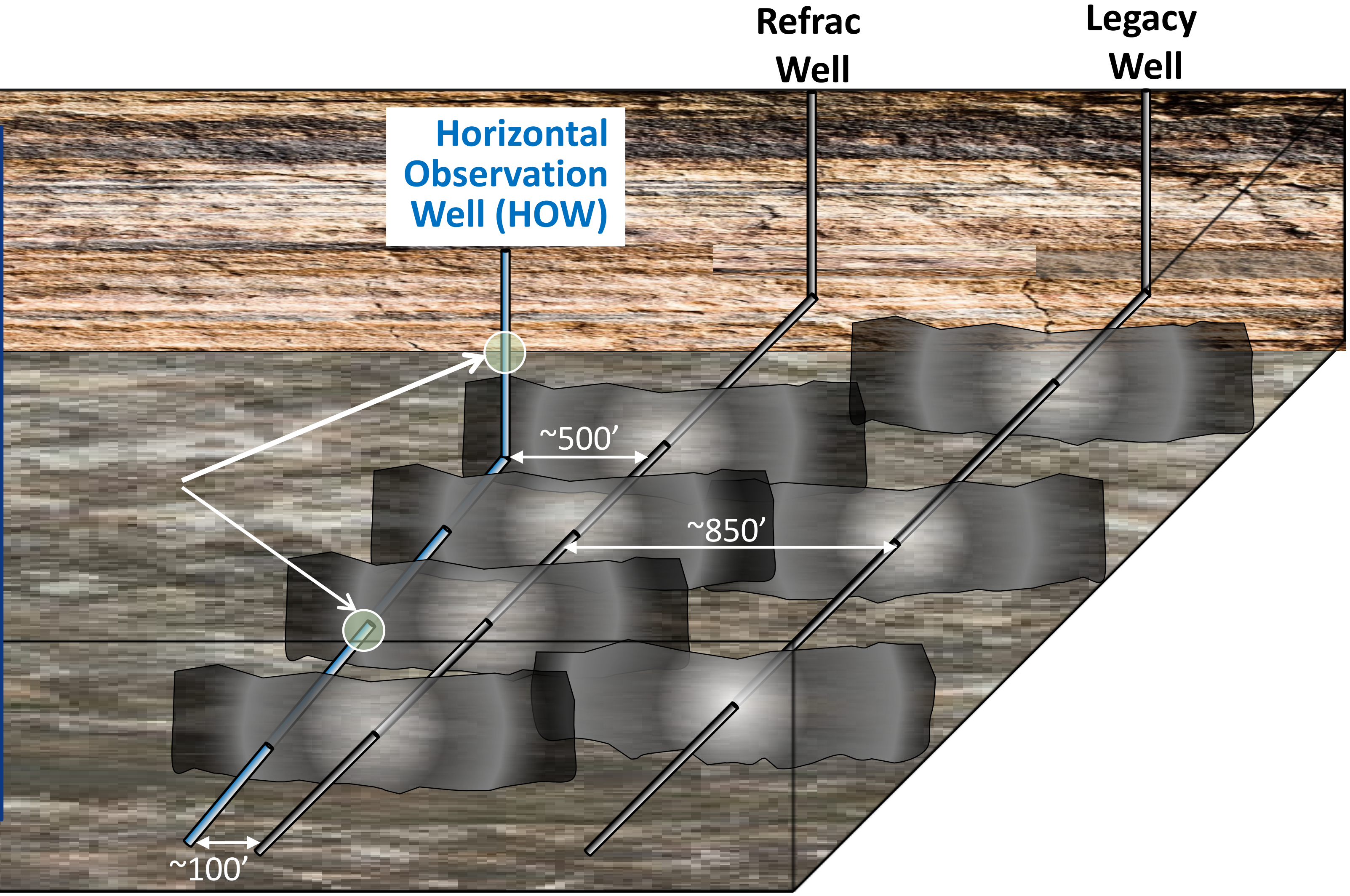
Extensive, robust, state-of-art monitoring, diagnosing and modeling abilities:

- Geosteering and Thru-bit monitoring during drilling
- Active seismic interrogation through surface orbital vibrators (SOV)
- Fiber optic sensing for distributed temperature, acoustic, strain (DTS, DAS, DSS)
- Extensive logging for formation evaluation and fracture diagnosis
- Tracer evaluation of re-fracture treatment
- Core analysis for formation flow properties and mechanical profile
- Theoretical and numerical modeling

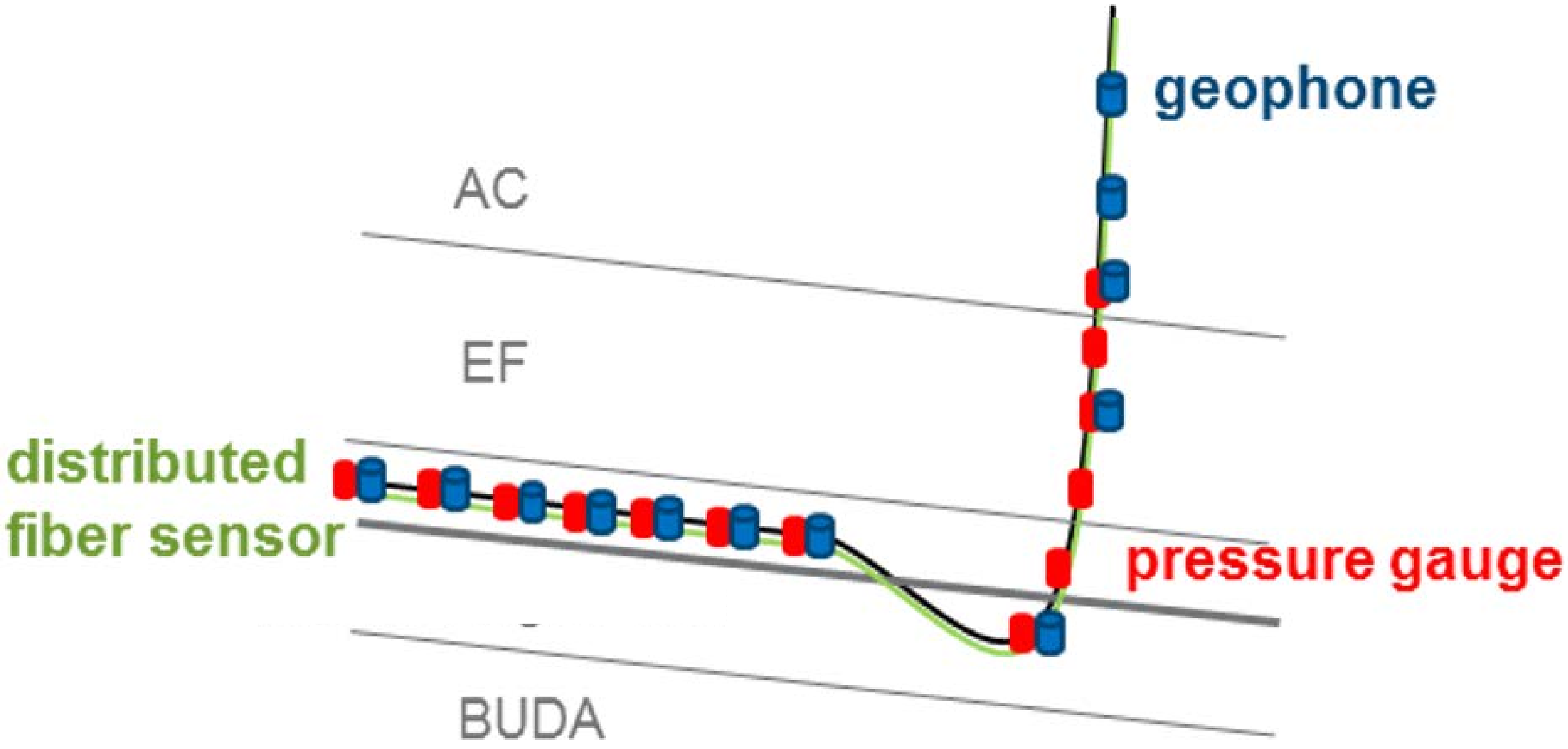
Phase I – Well Layout and Instrumentation

Instrumentation on HOW

- Behind casing P&T gauges
- Distributed fiber optic sensors (DTS, DAS, DSS)
- 3C geophone array for seismic/microseismic
- Surface orbital vibrators for active seismic monitoring
- Vibration sensor near drillbit while drilling



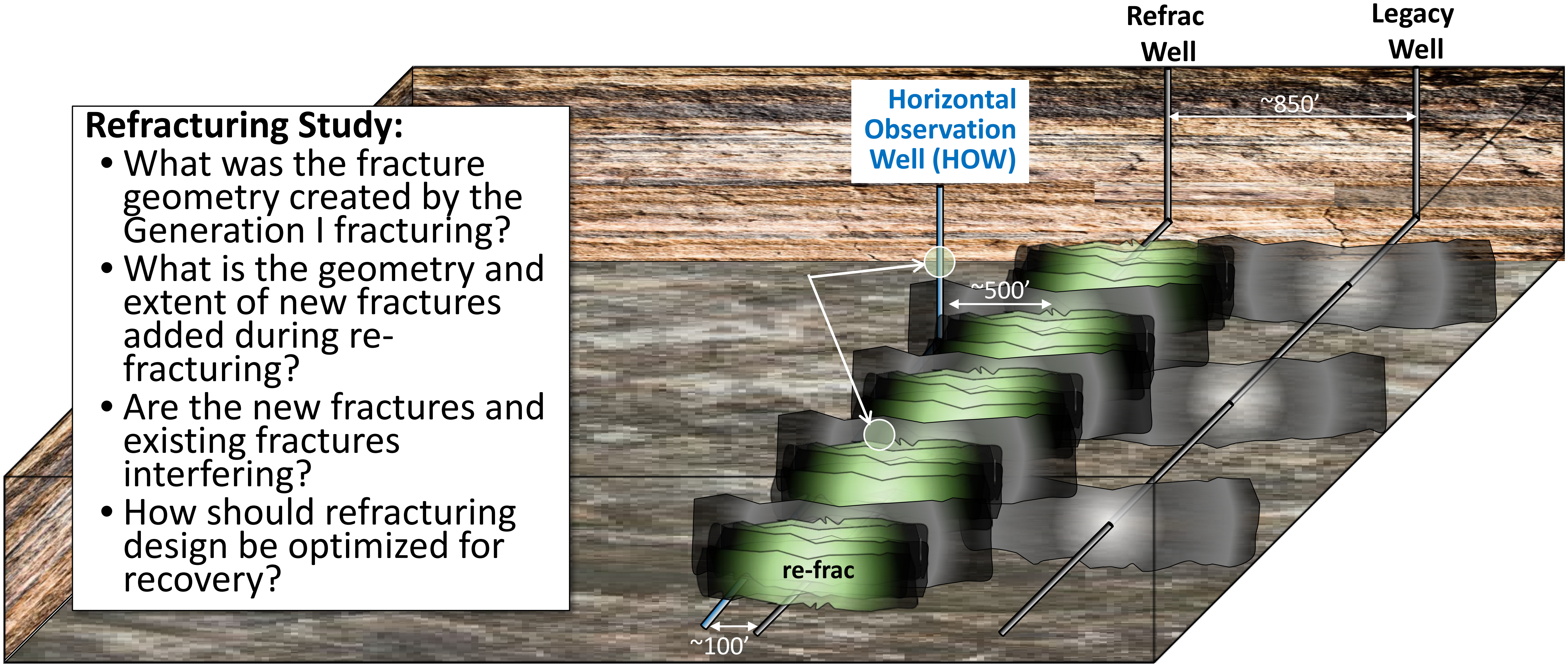
Phase 1 – HOW Trajectory



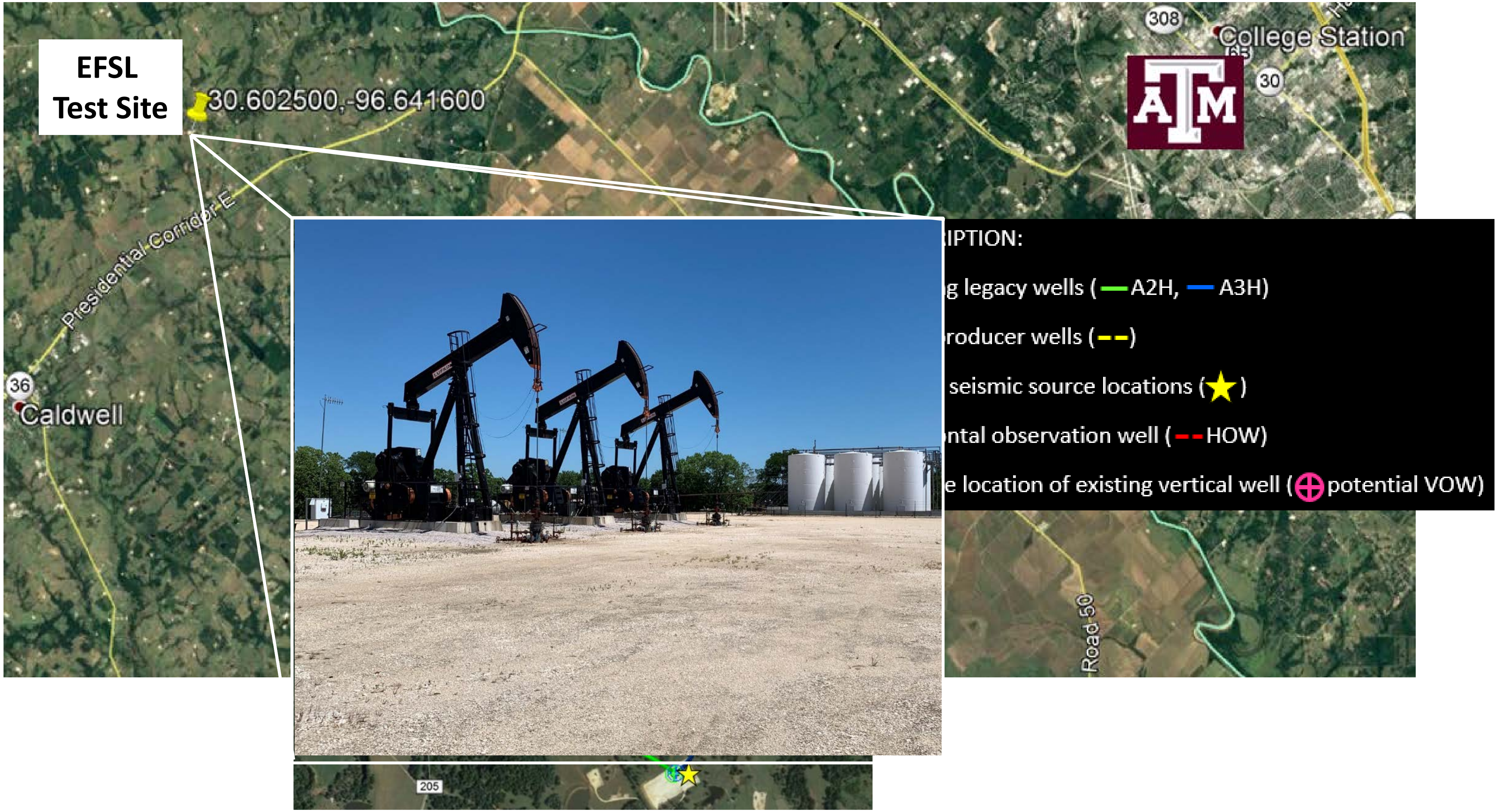
Phase I - Refracture Study

Refracturing Study:

- What was the fracture geometry created by the Generation I fracturing?
- What is the geometry and extent of new fractures added during re-fracturing?
- Are the new fractures and existing fractures interfering?
- How should refracturing design be optimized for recovery?



EFSL Test Site Location

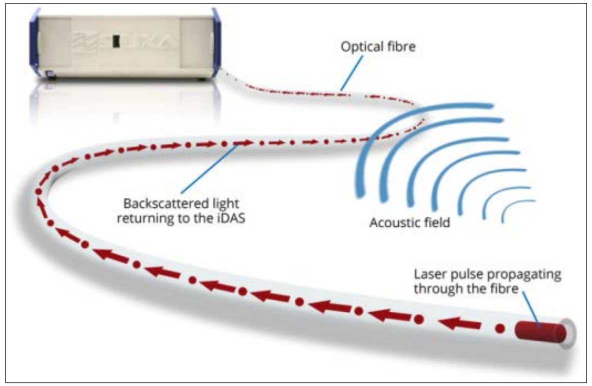


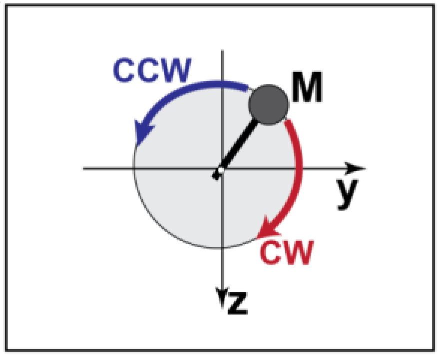
SOV/DAS for Monitoring

Challenge : High-repeatability/availability time-lapse for tracking fracture behavior in space & time?
Solution : SOV (Surface Orbital Vibrator) + DAS (Distributed Acoustic Sensing)
Details : SOV repurposes industrial shakers as a low cost semi-permanent seismic source
: DAS provides massive sensing arrays in monitoring boreholes
Impact : An approach for imaging fracture perturbations in Vp & Q (attenuation) during/after fracturing. Access short & long time property changes.

Conventional seismic monitoring
small T, large N

SOV-DAS permanent monitoring system
large T, moderate N

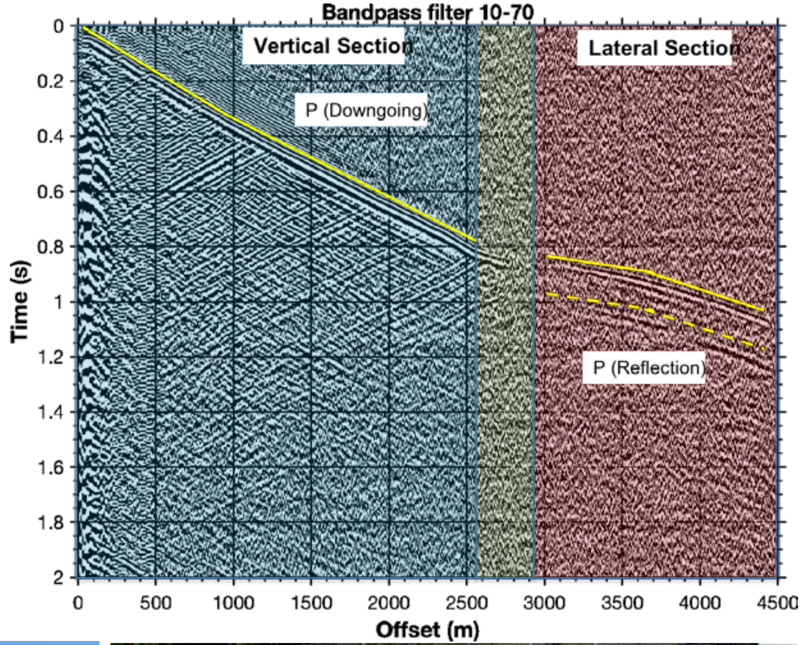




SOV Field Tests for EFSL

- April/May 2019 field tests of SOV/DAS combination in deviated well (CHK)
- First test in (a) lateral, (b) SOV on rotating stage.
- Goal to evaluate S/N, repeatability, imaging
- Effectively **derisks** EFSL deployment of SOVs

- ***Below*** : Construction & installation of SOV & control system.
- ***Right*** : Example VSP gather showing downgoing P arrival in vertical & lateral section of well.




Foundation Installation

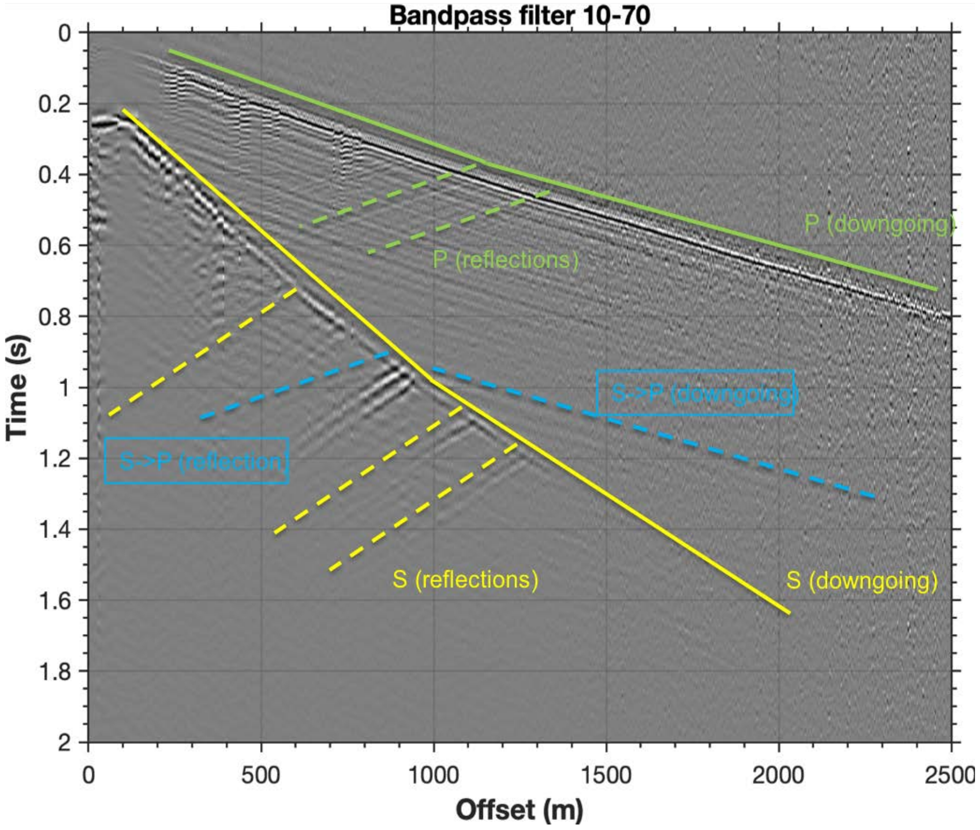

Control Electronics

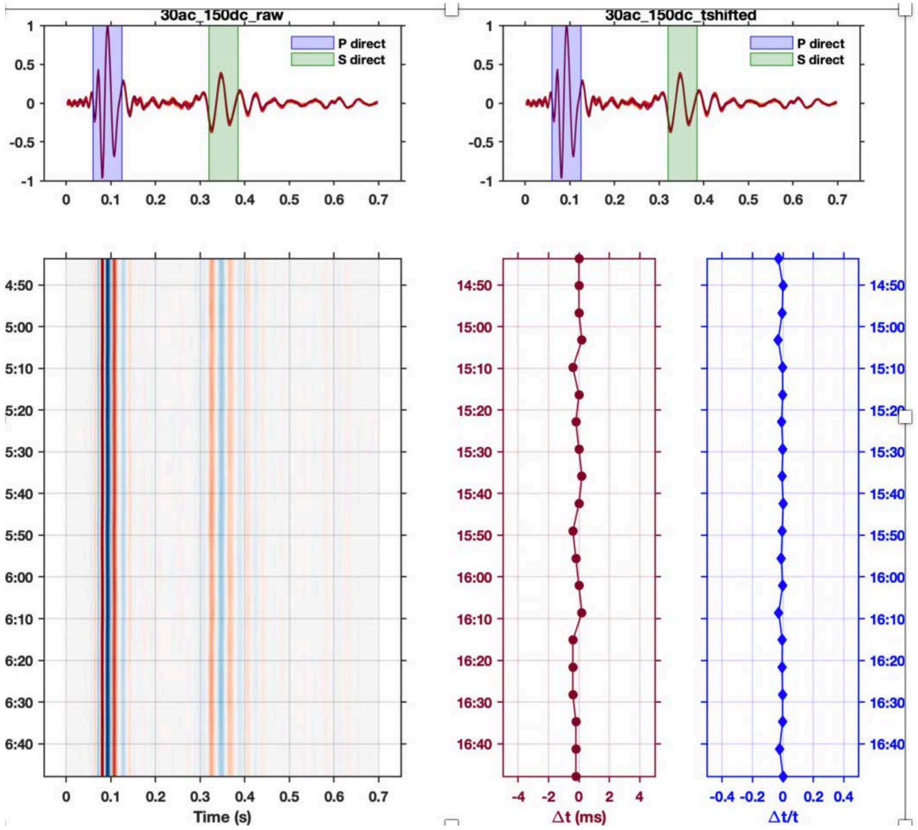

Completed SOV

SOV Source : P/S & Repeatability

- Rich elastic wavefield generated by source including P, S reflections, converted modes.
- Generated with small number of sweeps over short period.
- Sufficient S/N for high quality imaging

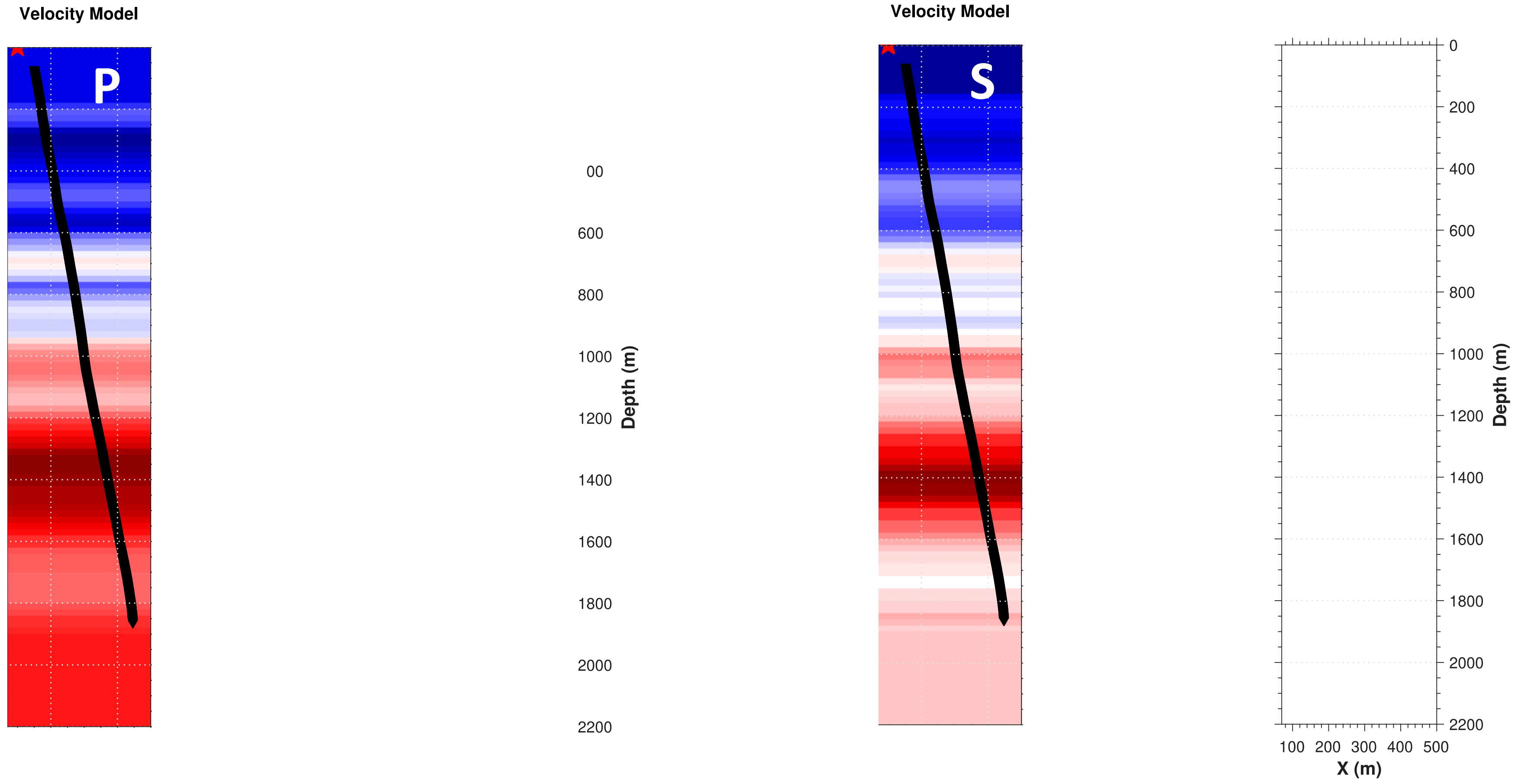
- Phase repeatability < 100 microseconds at depth before optimization.
- Better than 1 m/s velocity repeatability at 0.35 s.
- Excellent repeat quality for time lapse.





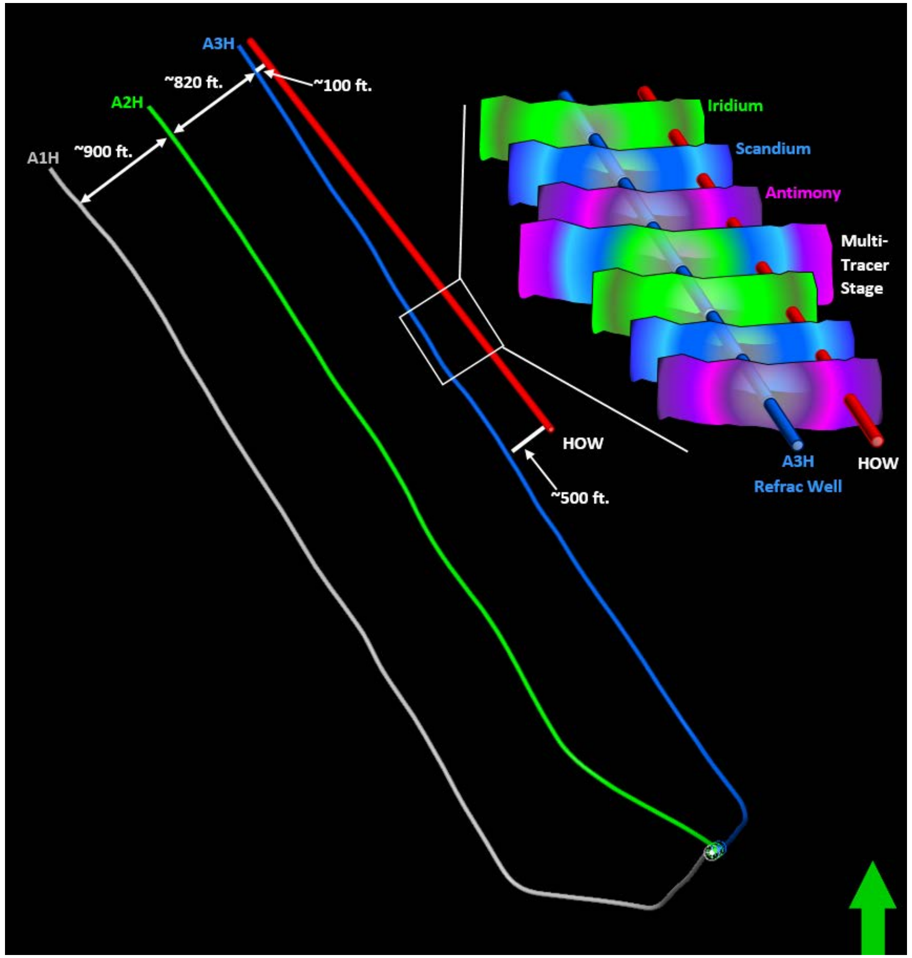
SOV VSP Reflection Imaging

- Experimenting with P & S reflection imaging (single source point).
- Testing VSP-CDP mapping and Kirchoff migration for both P-P and S-S components.
- Next step is log comparison and reflection repeatability tests.
- ***Conclusion*** : SOV/DAS de-risked as high-repeatability imaging solution for unconventionals.



Phase 1 – Tracer Program

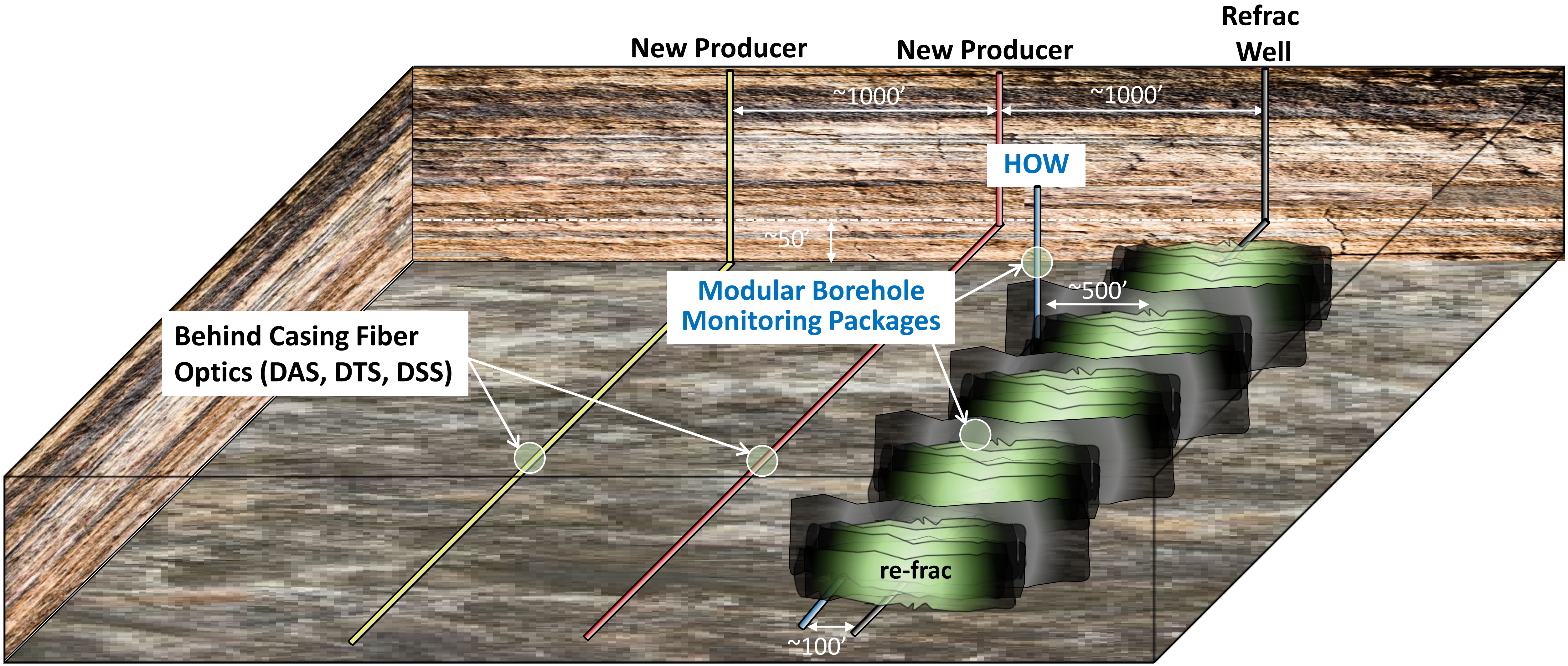
- Proppant will be tagged with single radioactive isotopes by stage (Ir, Sc, Sb).
- Specific stages will be tagged with all three isotopes in one stage
- Refrac well to be logged for near-wellbore proppant detection.
- HOW to be logged for far field proppant placement.
- Fluid will be tagged with gadolinium, detected in HOW with pulsed neutron log



Phase 1 – Long-term Production Monitoring

- Post-fracture production logging
- Temporary optic fiber in re-fractured well for flow profiling and fracture distribution
- Pressure gauge array in both vertical and horizontal section of HOW for reservoir pressure monitoring
- Periodic active seismic interrogation
- History matching of production with reservoir simulation

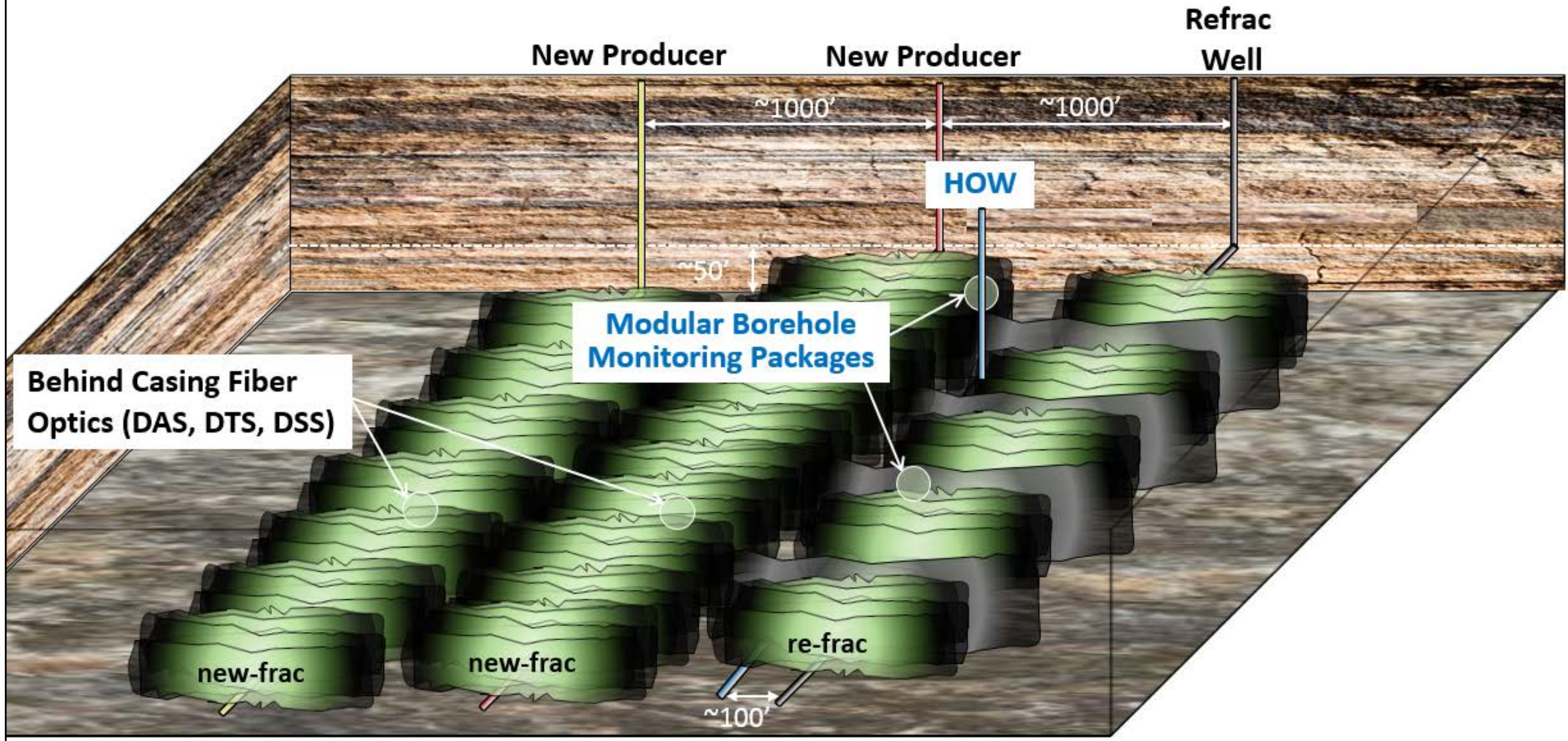
Field Plan: Phase II – Fracture Study



Field Plan: Phase II - Fracture Study

Fracture Study:

1. Optimization of drilling practices in the Eagle Ford shale.
2. Analysis and improvement of Eagle Ford targeting.
3. Mapping of created fracture geometry using active seismic monitoring and DAS/DTS/DSS technologies.
4. Evaluation of post-fracturing production by DAS/DTS/DSS downhole pressure gauges.
5. Calibration of advanced reservoir and fracture models using all monitored data.



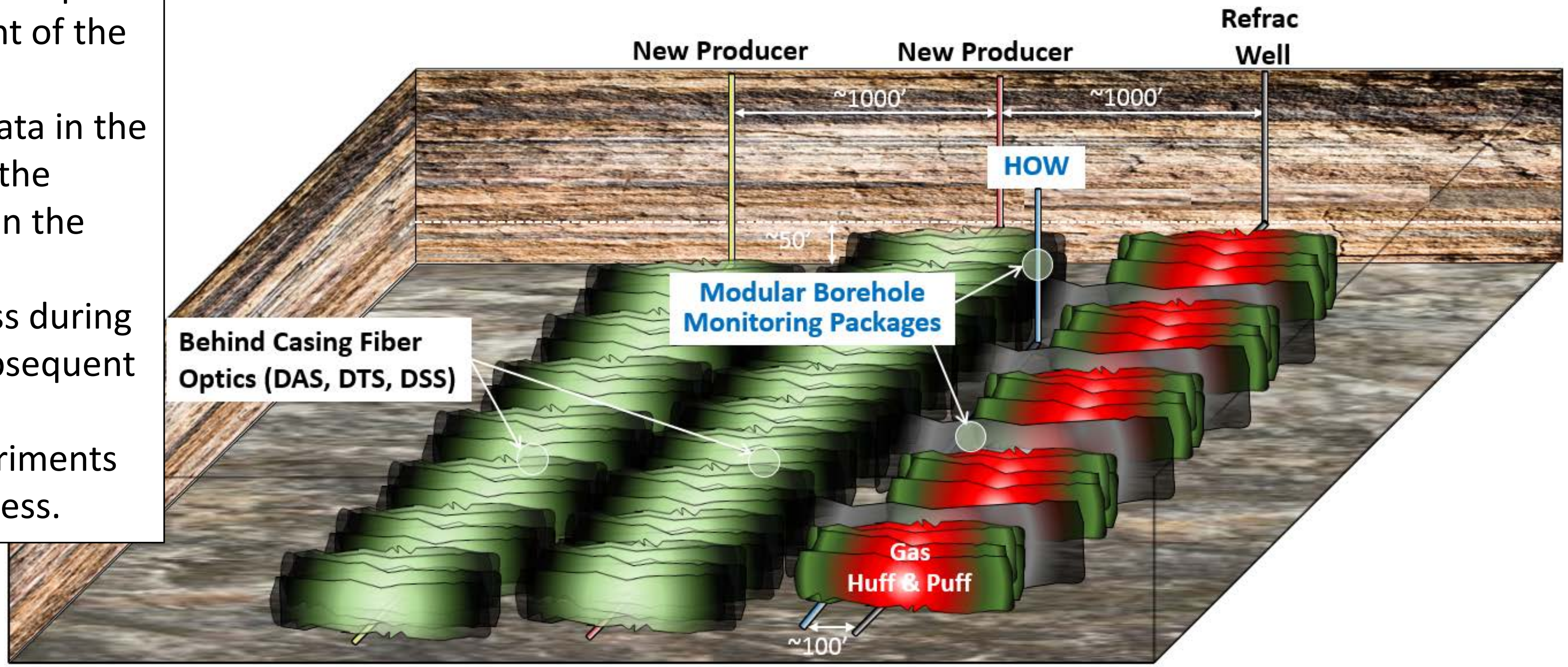
Phase II –Monitoring of New Producers

- Well logs
- Pressure gauge array in horizontal observation well
- DTS/DAS/DSS in new producing wells
- DTS/DAS/DSS in horizontal observation well
- Active seismic interrogation
- Surface pressure and phase flow rates in surrounding wells

Field Plan: Phase III – Gas EOR Study

Gas Injection EOR Study:

1. High-resolution spatial and temporal monitoring of the movement of the injected gas front.
2. Interpreted DAS/DTS/DSS data in the injection region to monitor the distribution of injected gas in the treated well.
3. Modeling of the EOR process during gas injection and during subsequent production.
4. Supporting laboratory experiments to understand the EOR process.



EFSL Status and Accomplishments

Overall Planning

- Legacy well has been identified and all feasibilities for the objective of the project have been confirmed.
- Monitoring string with fiber sensor, geophone, pressure and temperature gauges has been reviewed for installation and efficiency of monitoring
- Observation well(s) location and structure (trajectory, upper and lower completion design) have been studied based on monitoring requirement and agreed between the operator and researchers from all parties
- Historical field data for the site (microseismic, production history, formation evaluation) has been collected and is being studied

EFSL Status and Accomplishments

Modeling and Lab Testing (TAMU)

- Reservoir simulation model is established and coupled with the geological model for history matching and optimization – has been used to history match S. Texas Eagle Ford wells
- Interpretation models for Distributed Temperature Sensors (DTS) and Distributed Acoustic Sensors (DAS) were developed based on the preliminary completion design and ready to test with field data
- Fracture conductivity study in Eagle Ford Shale has been reviewed. Experimental apparatus is ready for field core testing
- Experimental procedure and data analysis method for EOR testing are established
- Experimental factorial design of refracturing begun

EFSL Status and Accomplishments

Active Seismic/Acoustic Monitoring (LBNL)

- Modeling of using surface orbital vibrators (SOV) to for active seismic monitoring is developed for scientific justification
- Feasibility of using SOV for monitoring has been tested in the field at a location near the legacy well and the application is confirmed
- New plan for SOV deployment is developed
- Fiber cable for distributed acoustic sensing (DAS) and distributed temperature sensing (DTS) has been designed and ready to be manufactured

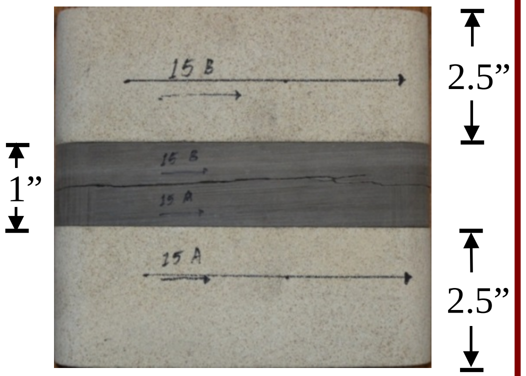
Questions and Comments?

Research Team: Texas A&M University

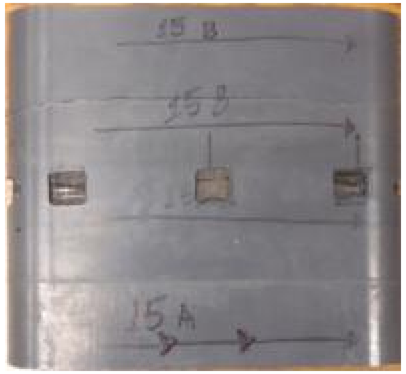
- Overall project management
- DTS/DAS interpretation
- Lab testing of fracture conductivity using cores
- Drilling performance monitoring and optimization
- Rock property measurements using drill cuttings
- Fracture/reservoir modeling and calibration
- Lab testing of gas injection EOR processes
- EOR pilot design

TAMU Research: Fracture Conductivity

1. Induce fracture

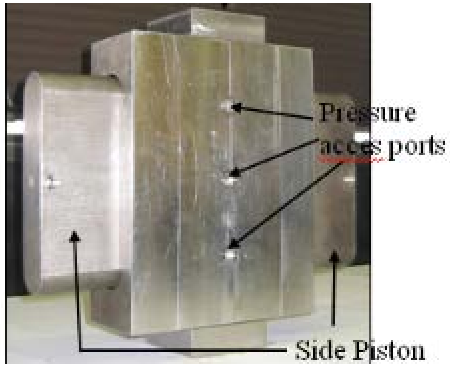


2. Coat samples



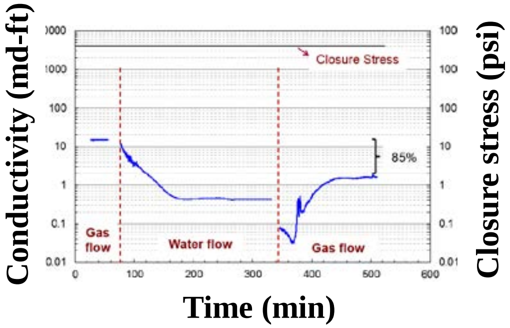
3. Place proppants

4. Mod. API cell

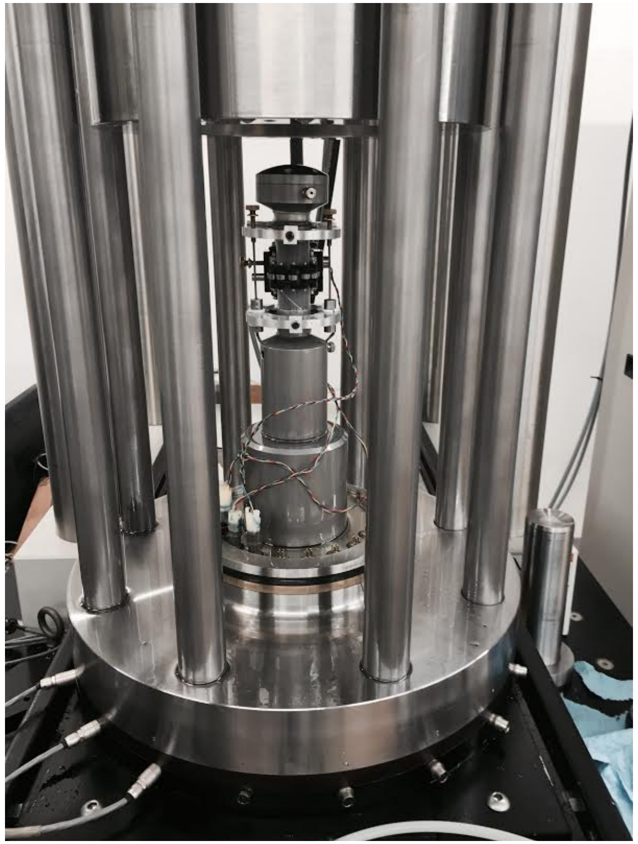


5. Measurement

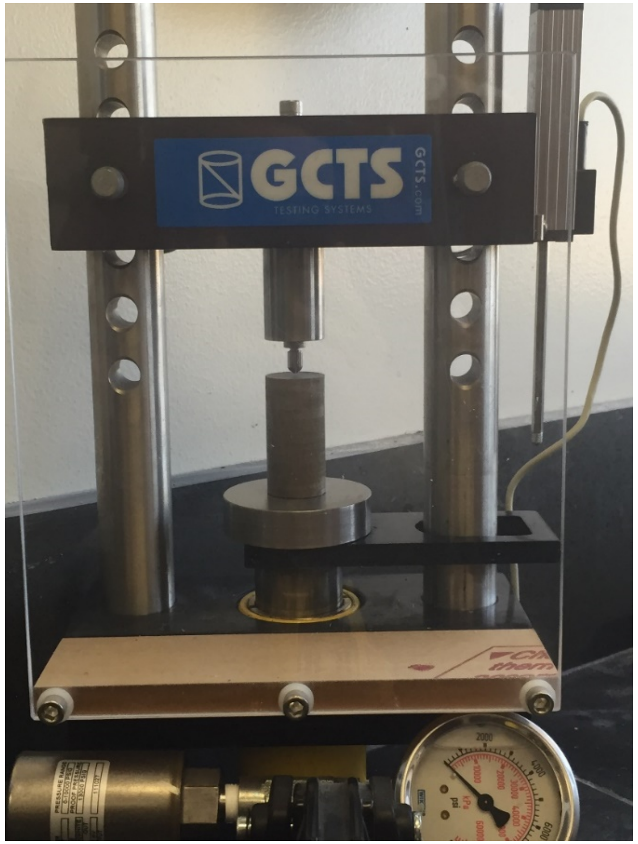
6. Analysis



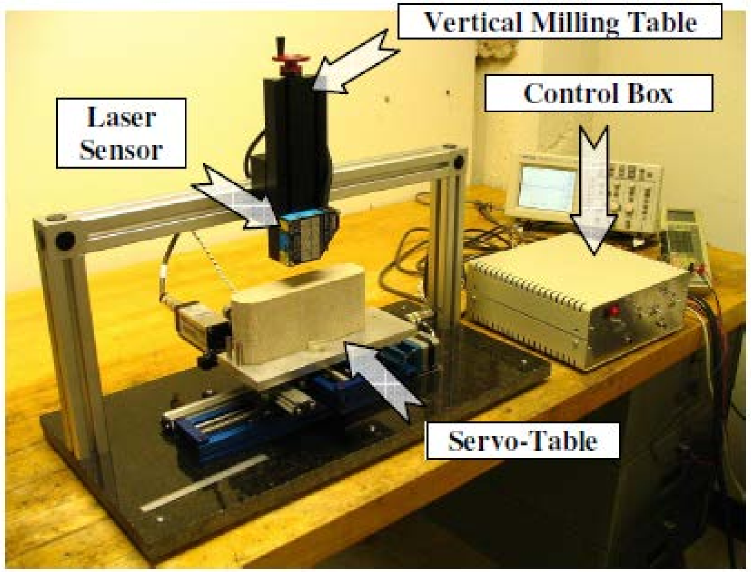
Other Mechanical Property Measurements

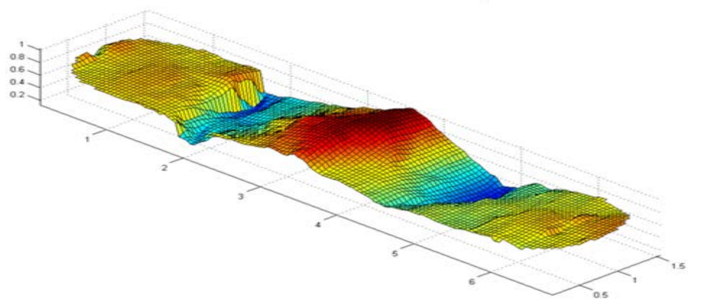


Young's Modulus and
Poisson Ratio



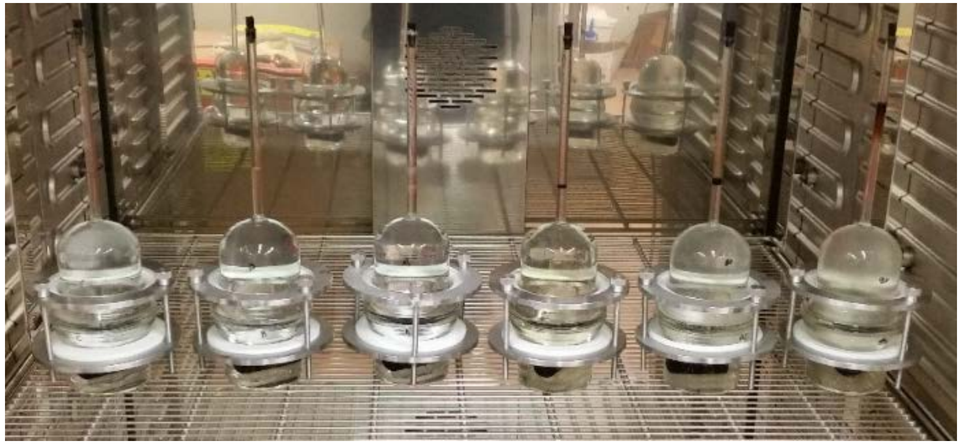
Brinell Hardness

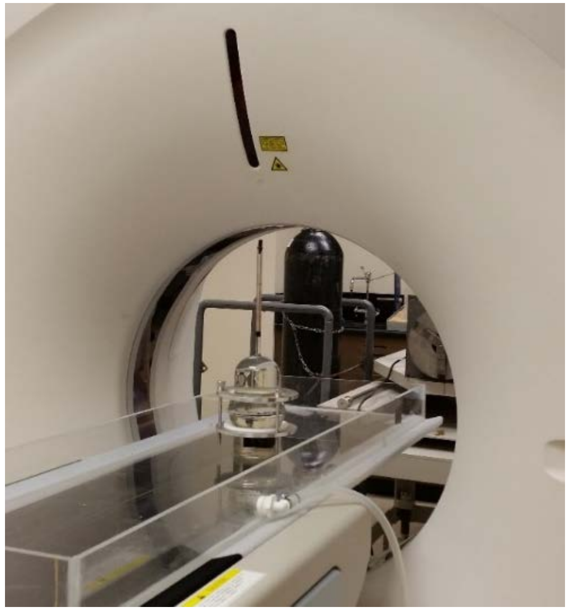


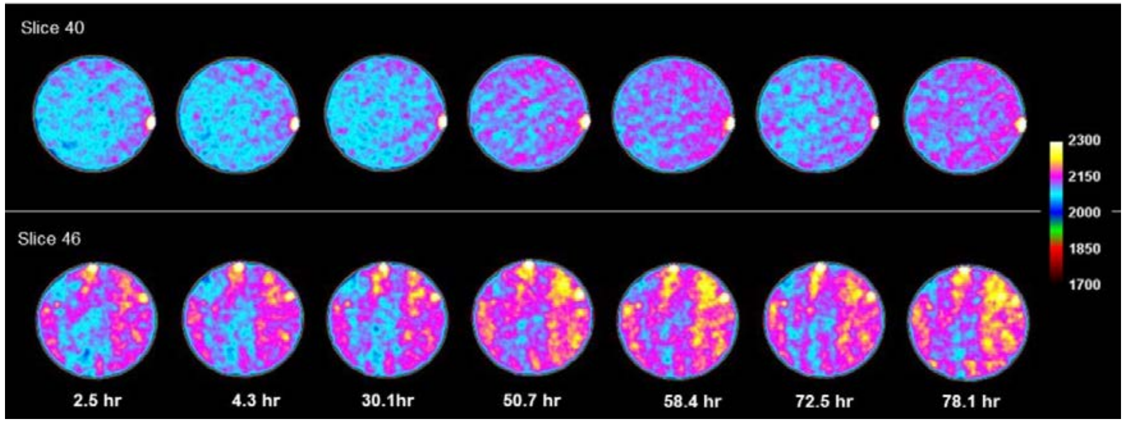


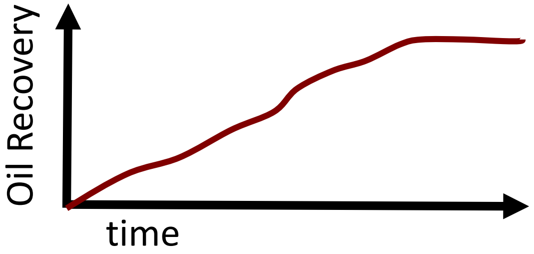
Surface topography

TAMU Research: EOR



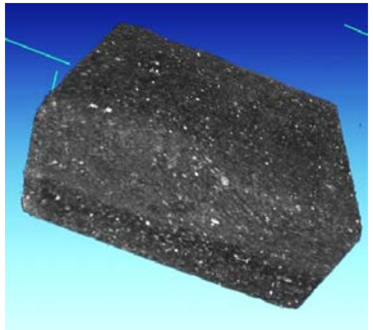




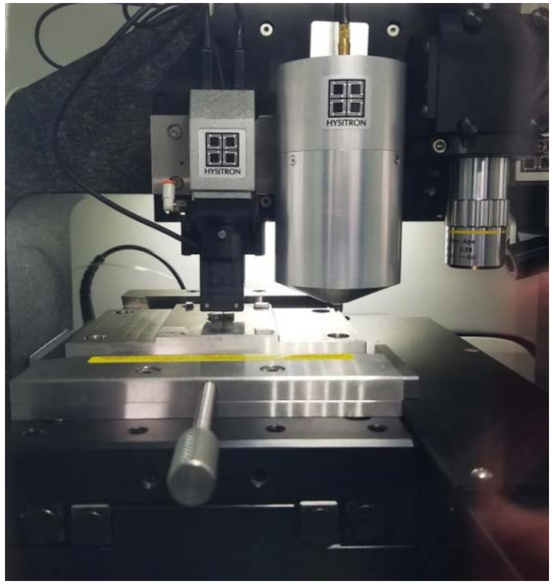


Changes in densities, fluid movements and imbibition

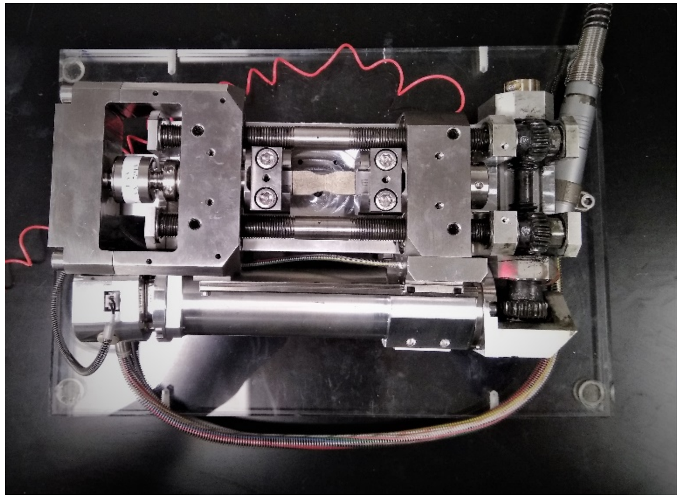
Nano-mechanical Property Evaluation

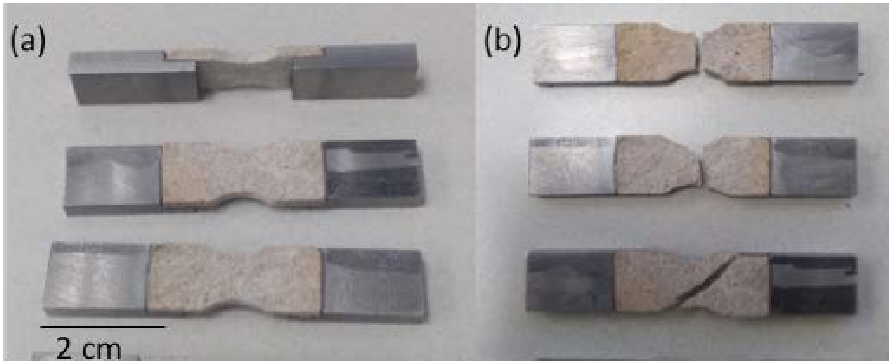


Nanotom micro-CT scanner and reconstructed 3D of rock fabric



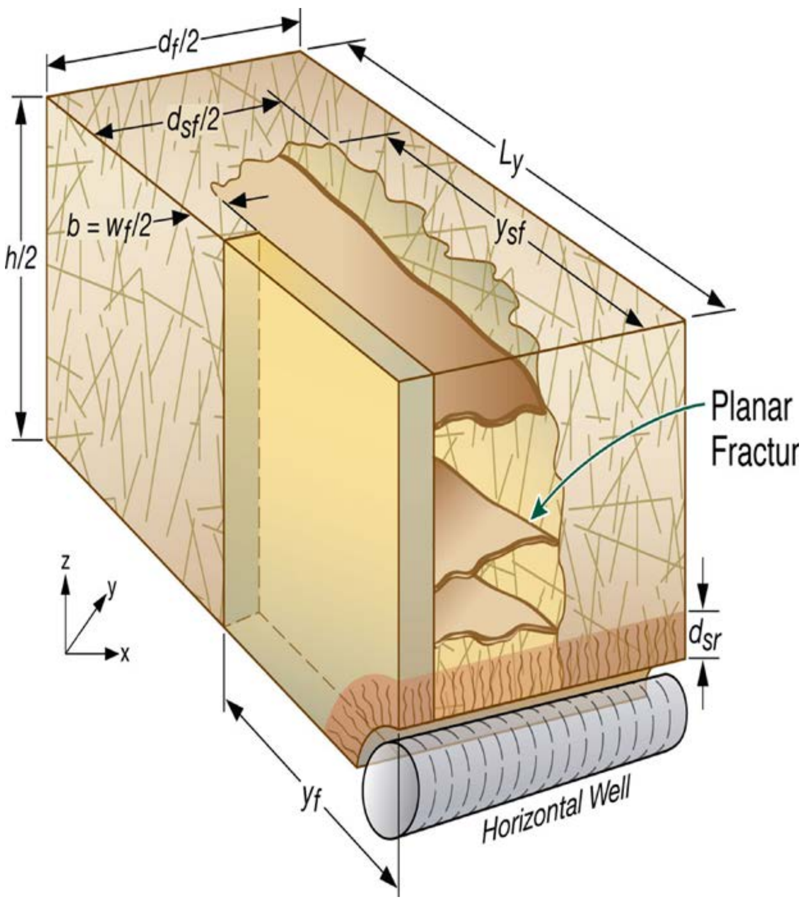
Hysitron TI-950 Nanoindenter for multiscale mechanical testing



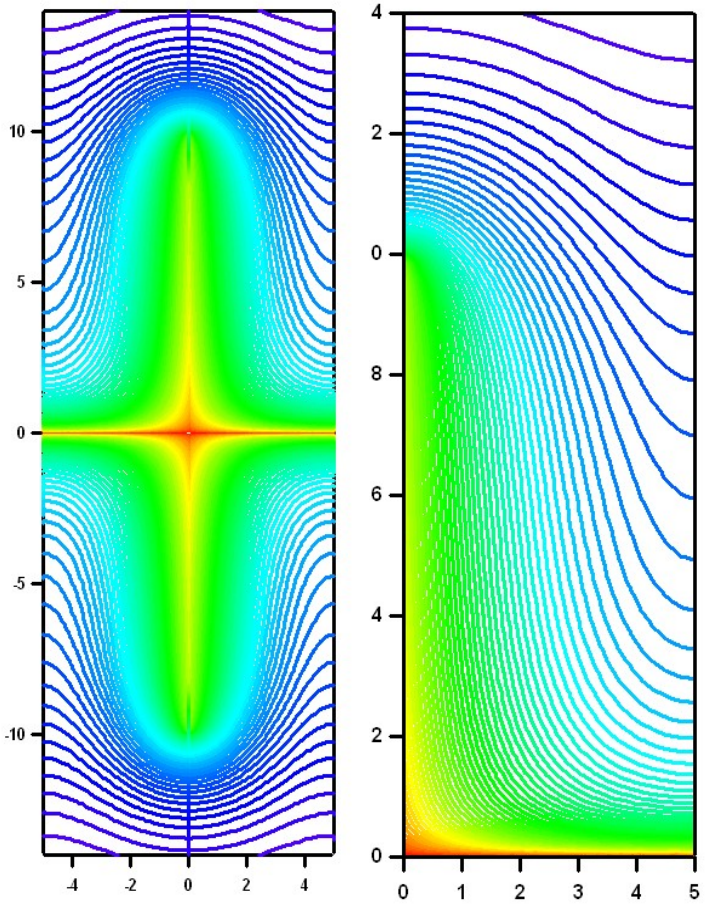


micro-tensile module and Eagle Ford rock before and after tensile test

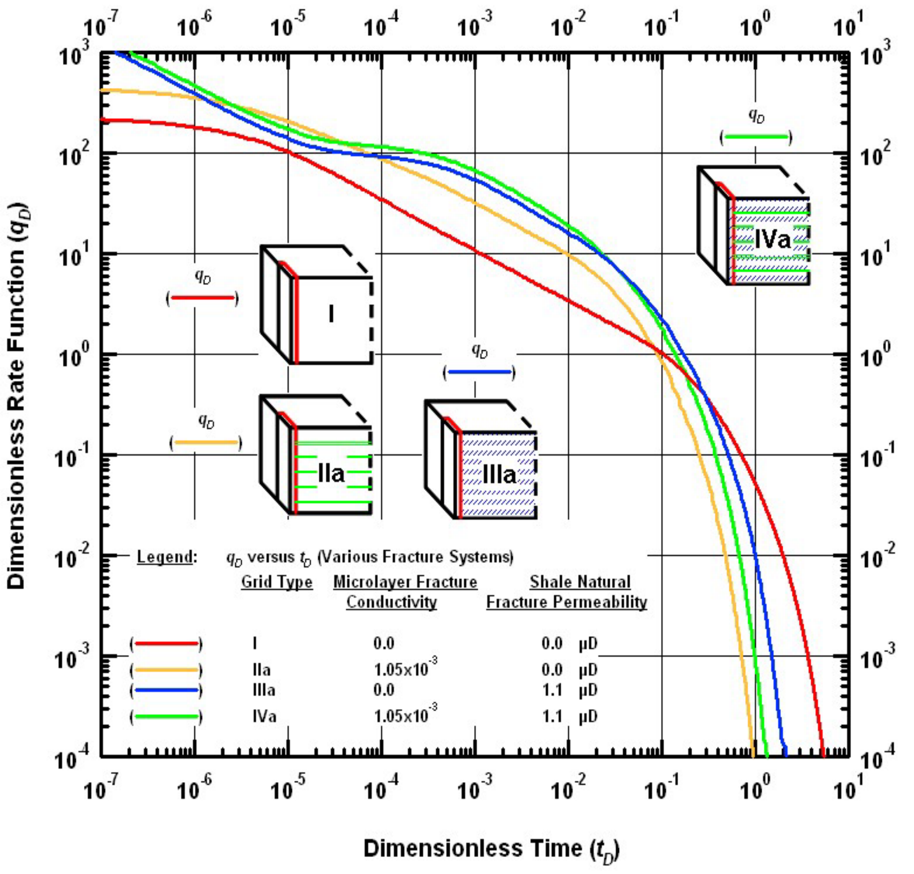
Coupled Flow + Thermal+ Geomechanical + Geochemical Simulation



Complex Fracture System



Simulated Pressure Field



Predicted Production

Research Team:
Lawrence Berkeley National Laboratory

Key Research Personnel:

- Jens Birkholzer (Multiphase flow)
- Kurt Nihei (Seismic modeling & imaging)
- Jonathan Ajo-Franklin (Seismic monitoring: DAS/DTS/DSS)
- Barry Freifeld (Borehole instrumentation: DAS/DTS/DSS)
- Kenichi Soga (Geomechanics & DSS)

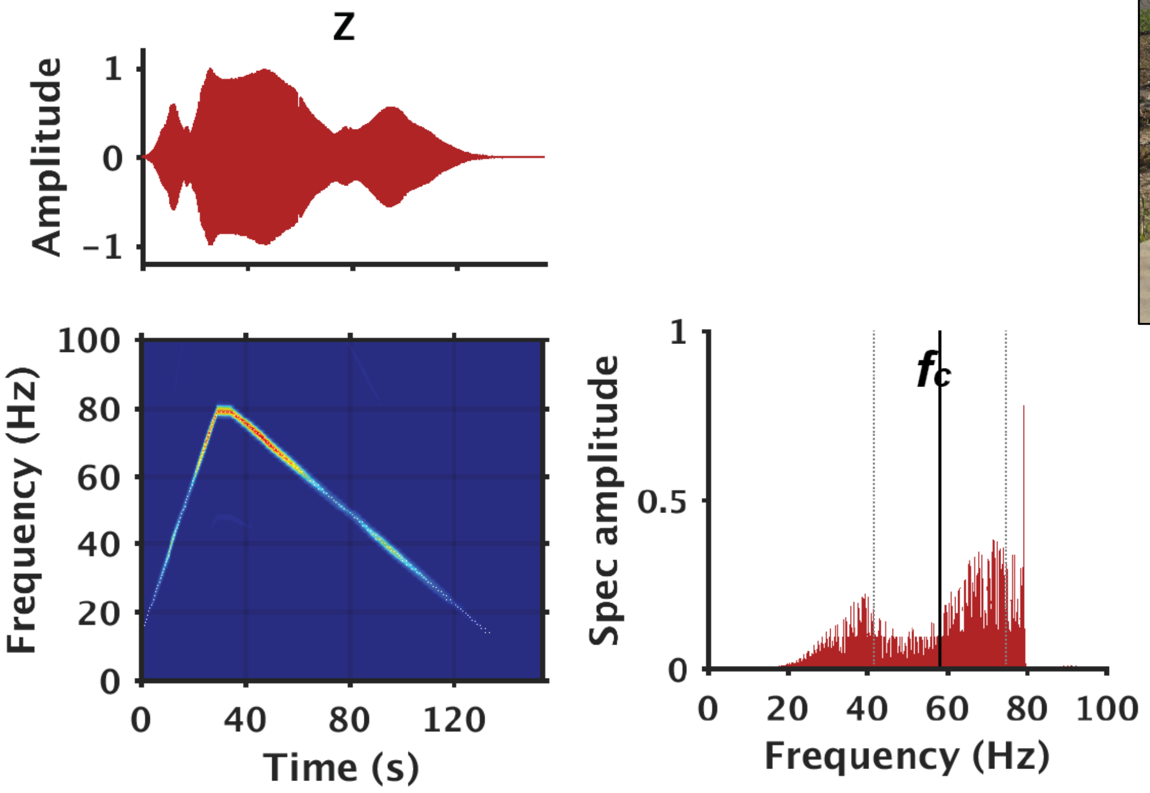
Subject Matter Experts:

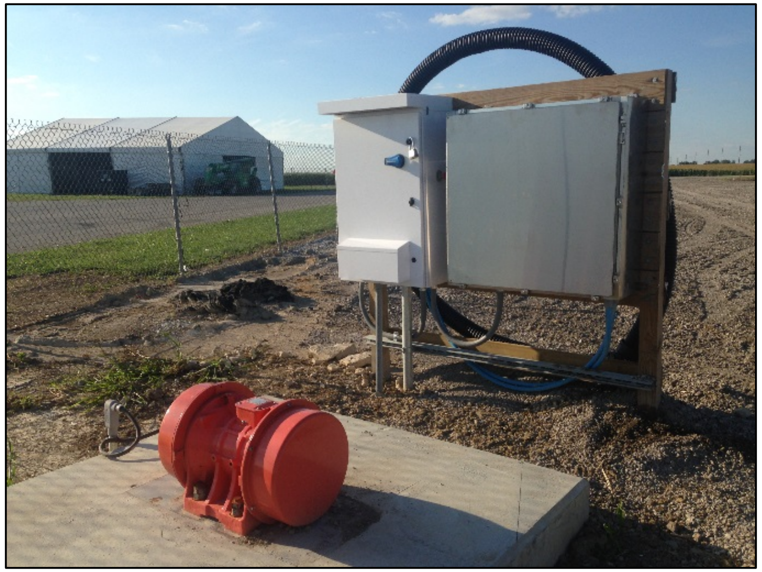
- Jonny Rutqvist (geomechanics), Yingqi Zhang (flow optimization), Matt Reagan (multiphase flow modeling), Tim Kneafsey (lab hydromechanics), Seiji Nakagawa (rock physics & rock mechanics), Abdullah Cihan (microscale modeling), Yves Guglielmi (geomechanics), Tom Daley (borehole geophysics & DAS), Ernie Majer (MEQ & borehole seismics), Quanlin Zhou (EOR)

BERKELEY LAB
Bringing Science Solutions to the World

LBNL: Surface Orbital Vibrator for permanent monitoring

Sweep-based:
controlled release of seismic energy





Research Team:
Stanford University

Key Research Personnel:

- Mark Zoback (Reservoir geomechanics)
- Fatemeh Rassouli (Laboratory testing)
- Robert Cieplicki (Machine learning)
- Lei Jin (Poroelastic modeling)

Optimization of Geosteering

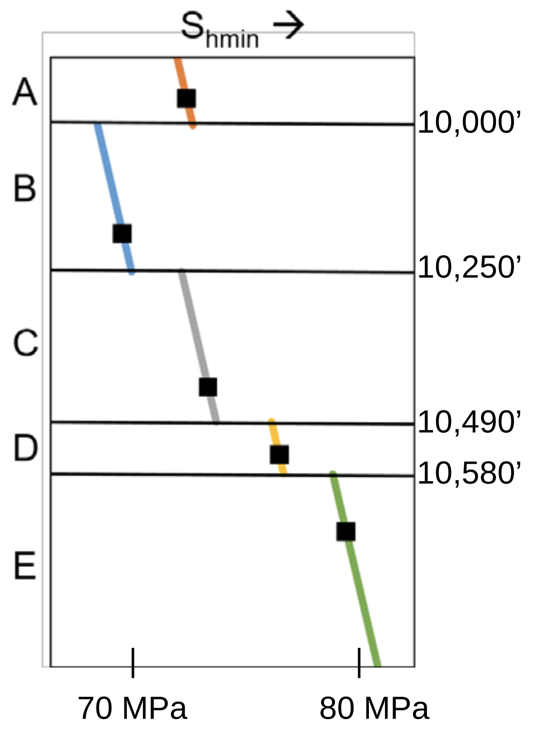
- Laboratory measurement of elastic and viscoplastic properties using core samples
- Analysis of drilling/logging data
- Optimal targeting of Eagle Ford sub-intervals for landing laterals

Geomechanical Modeling

STANFORD UNIVERSITY

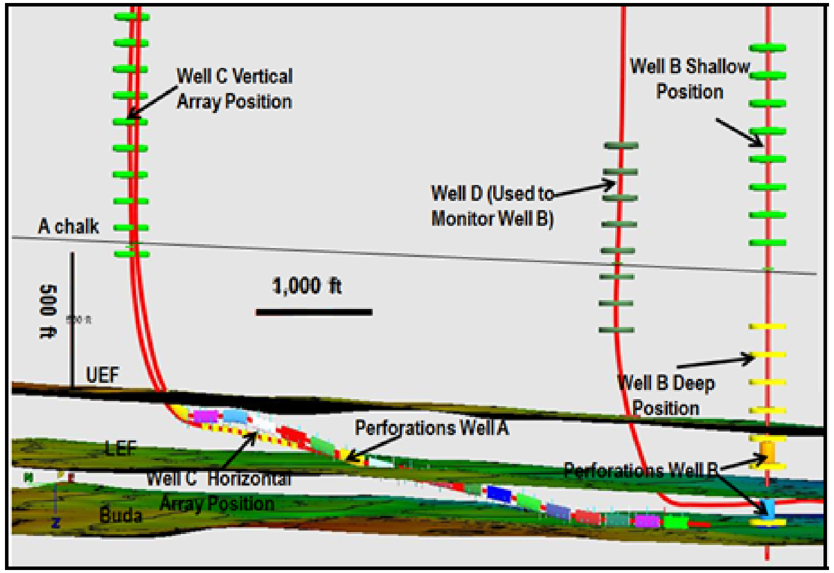
Stanford Rock Creep Tests

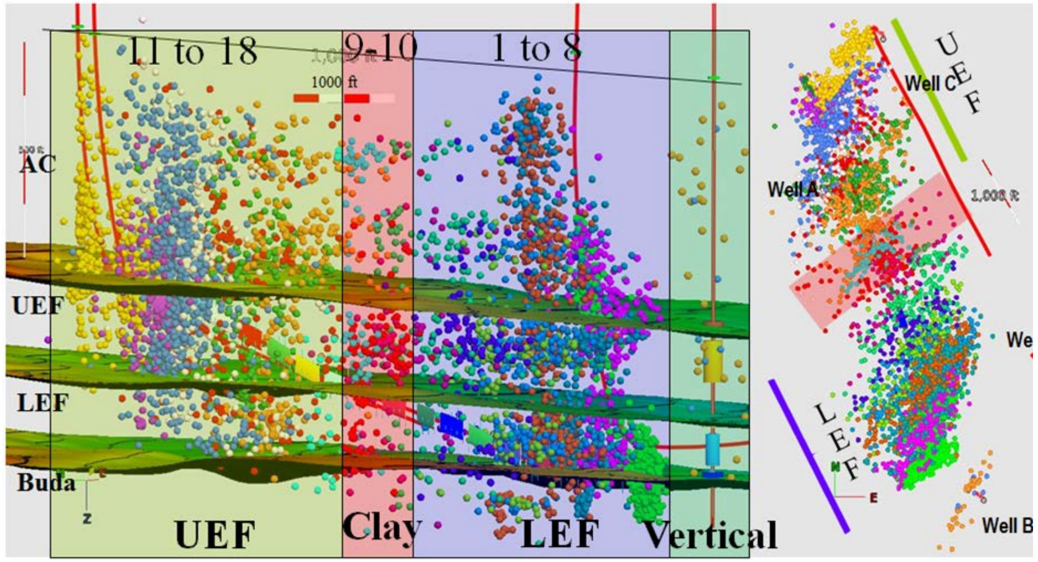
Predicting Stress Magnitudes from Laboratory Creep Experiments

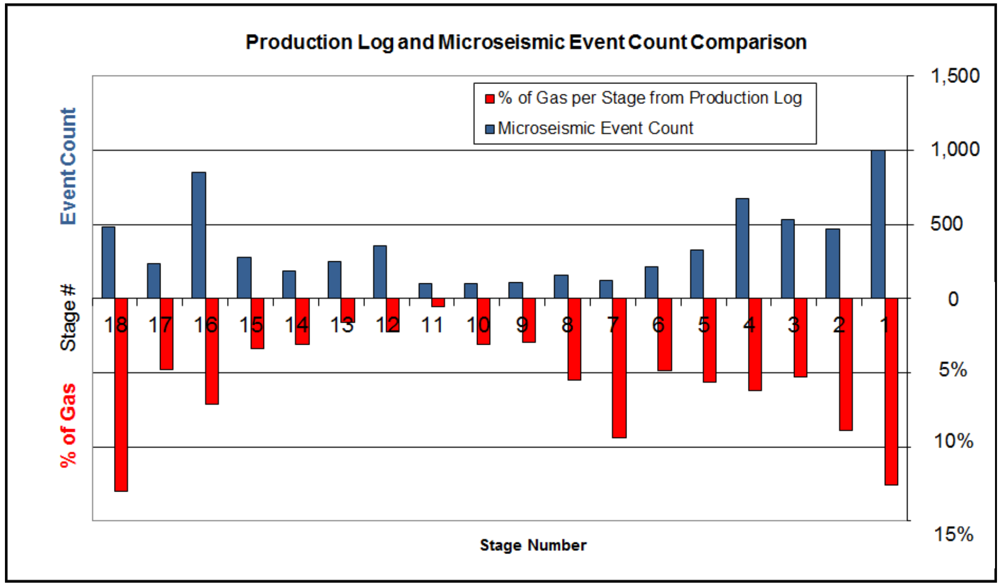


Shaochuan Xu, on-going research

Landing Point Optimization - Eagle Ford







Patel et al., URTeC, 2013