

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
Inpex Eagle Ford, LLC
Stanford University



HAROLD VANCE DEPARTMENT OF
PETROLEUM ENGINEERING
TEXAS A&M UNIVERSITY

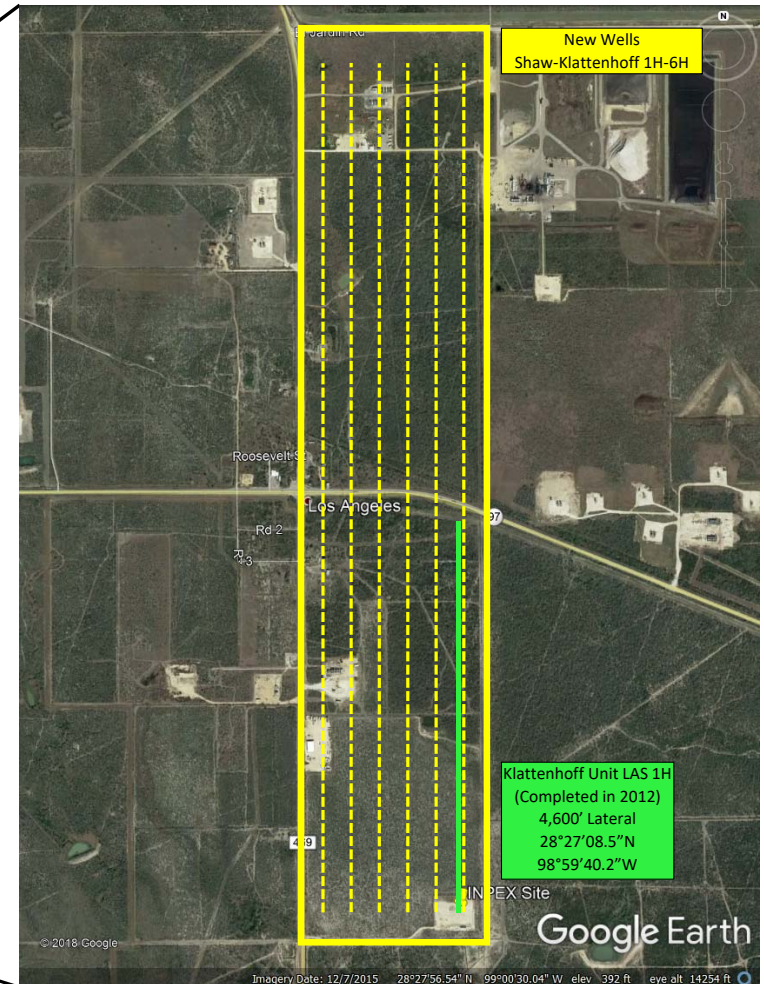
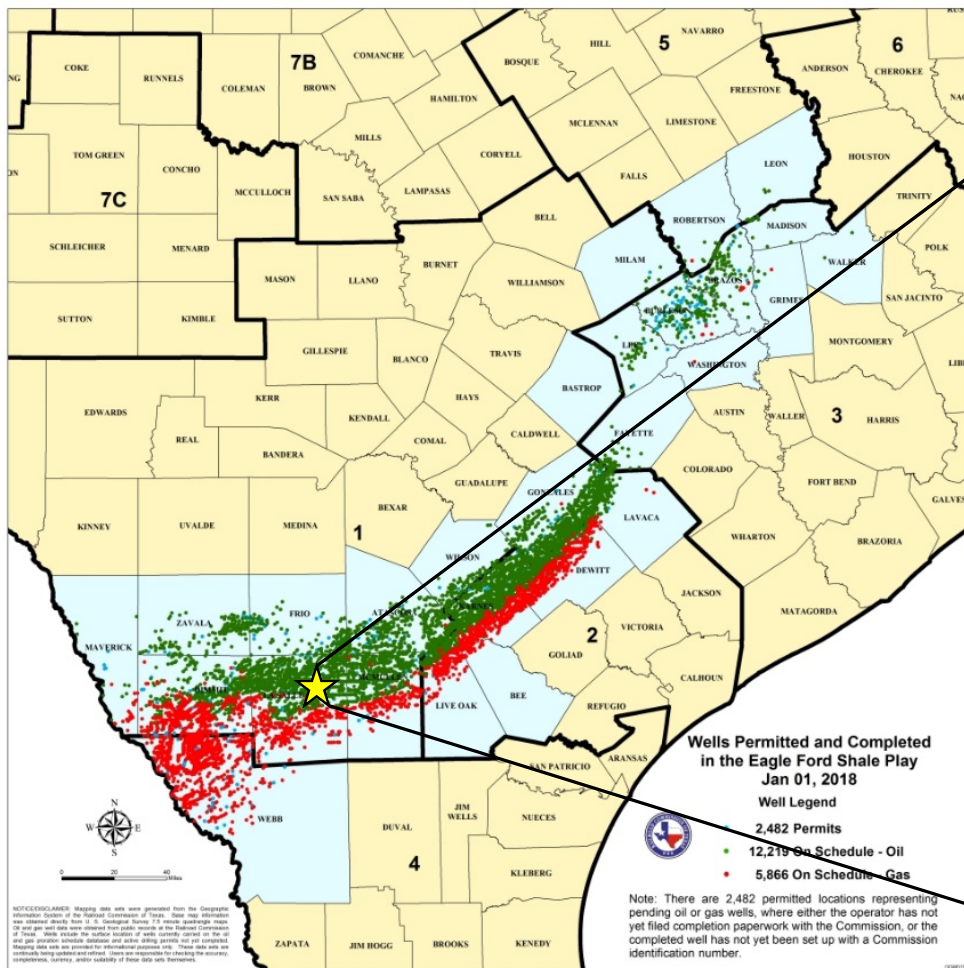
INPEX
INPEX CORPORATION



Eagle Ford Shale Laboratory (EFSL)

- Research Team:
 - Texas A&M University
 - Lawrence Berkeley National Lab
 - Stanford University
- Operator: Inpex Eagle Ford, LLC
- Field Site: Eagle Ford Shale near Los Angeles, TX (LaSalle County)
- JIP participants: CNOOC, ExxonMobil, Schlumberger

Site Location



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 pressures) in producing and observation wells
3. Improve drilling efficiency
4. Optimize the fracturing process
5. Evaluate EOR in the field
6. Calibrate fracture/reservoir models

EFSL Main Tasks

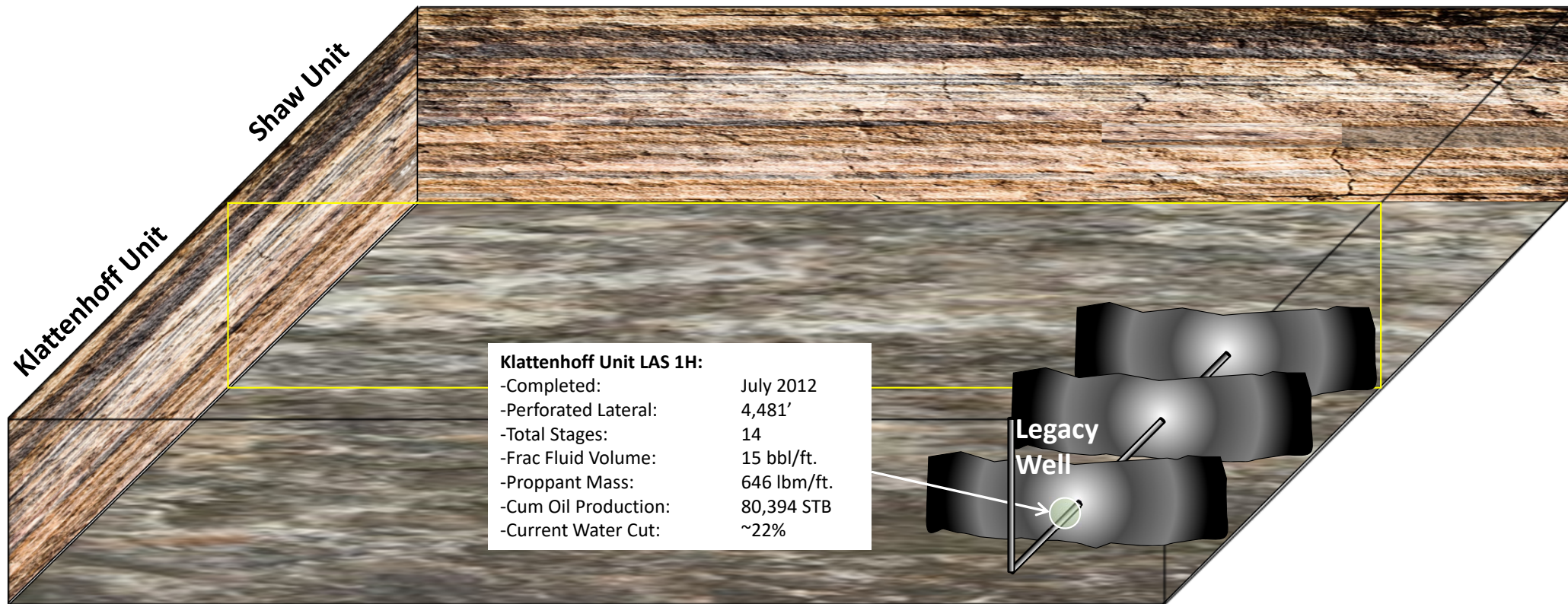
- **Phase I : Re-fracture monitoring and evaluation**
- **Phase II: Monitoring, evaluation and optimization of multistage fracture stimulation (three new producers)**
- **Phase III: EOR pilot with gas injection**

Advanced Technologies

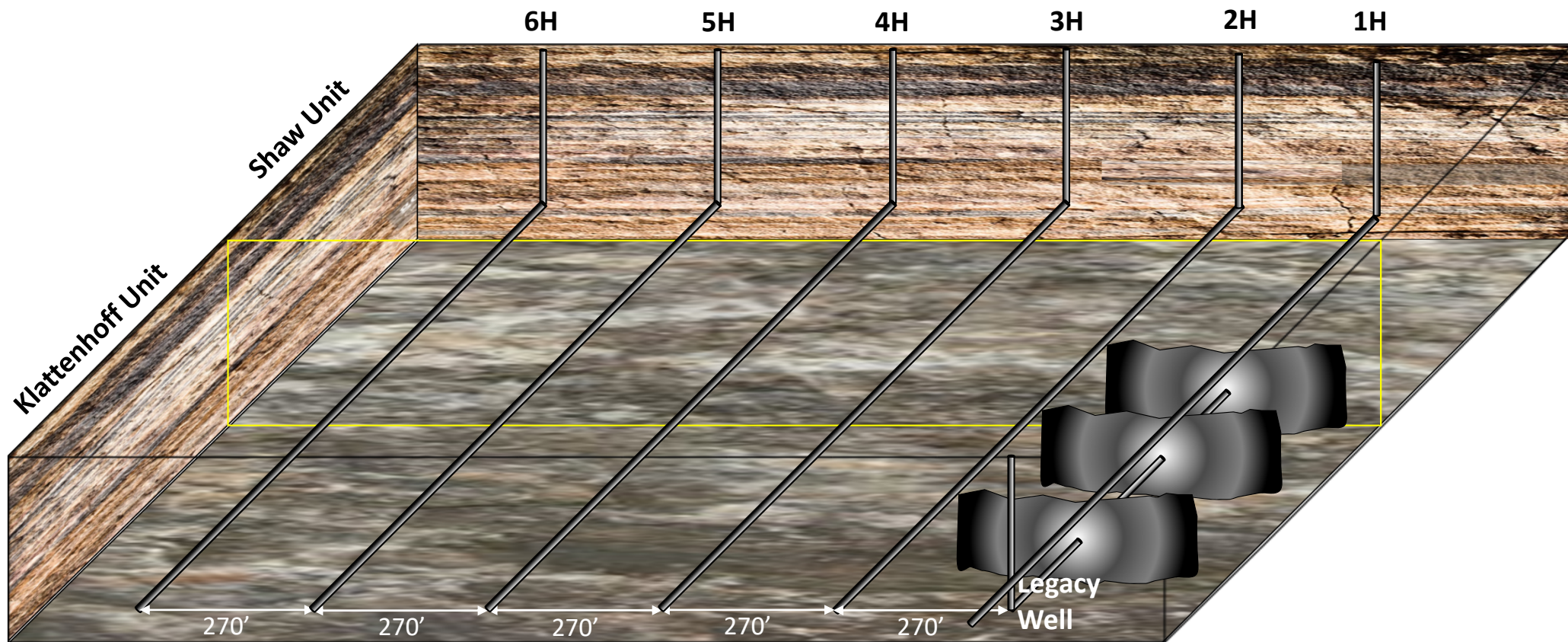
Extensive, robust, state-of-art monitoring, diagnosing and modeling abilities:

- **Geosteering and Thru-bit monitoring during drilling**
- **Active seismic interrogation**
- **Permanent fiber optic sensing (DTS, DAS, DSS)**
- **Extensive logging for formation evaluation and fracture diagnosis**
- **Tracer evaluation of re-frac**
- **Downhole video of perforation erosion**
- **Vertical well cores for supporting lab work**
- **Theoretical and numerical modeling**

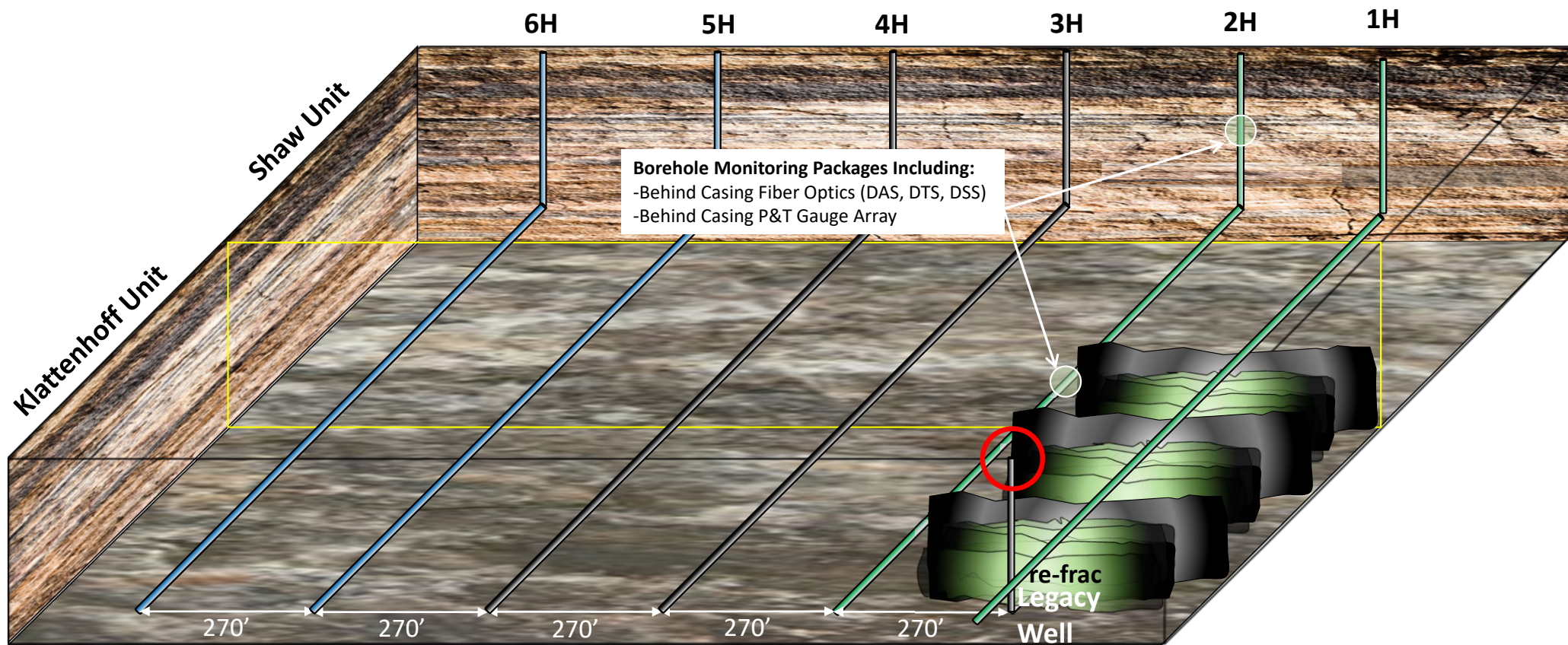
Existing Site and Legacy Well



Planned Wells (1H-6H)



Legacy Well Refrac



Phase 1 – During Re-fracture Treatment

- **Surface seismic – Active sources to downhole DAS and geophone array**
- **DTS/DAS/DSS along entire HOW**
- **Pressure & temperature gauge array in horizontal observation well**
- **3C geophone array deployed in HOW during fracturing**
- **Normal surface frac monitoring data**

Phase 1 – During Re-fracture Treatment

- **Frac fluid tracer – oil and/or water soluble tracers**
- **Post-frac logs in refrac well and 2H observation well**
- **Downhole video measurement of perforation erosion**

SOV/DAS for Seismic Monitoring

Target :

- High-repeatability time-lapse seismic for monitoring fracture opening and closure in space & time.
- Provide an active source approach for quantifying the SRV

Solution :

SOV (Surface Orbital Vibrator) + DAS (Distributed Acoustic Sensing)

Challenges:

1. Is the data quality acceptable for seismic monitoring?
2. Is the acquisition system repeatable for seismic monitoring?

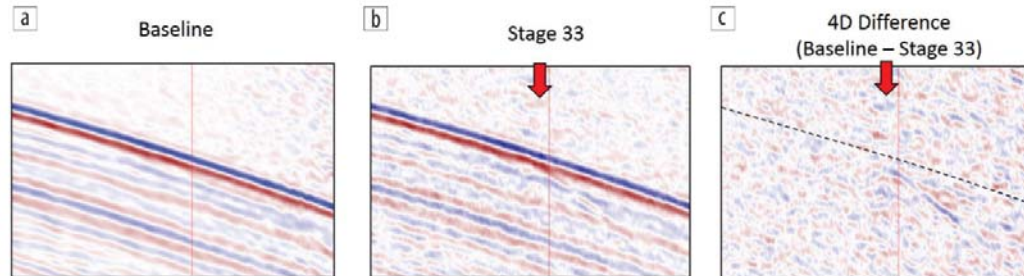


Figure 5. Zoom of north shot location shot gathers showing pre-frac (a) baseline, (b) shot acquired after stage 33, and (c) the difference between the two. Black dashed line shows the timing of the direct P-wave arrival. Red arrow shows the location where stage 33 was fracked along the well.

Byerley et al. (2018)

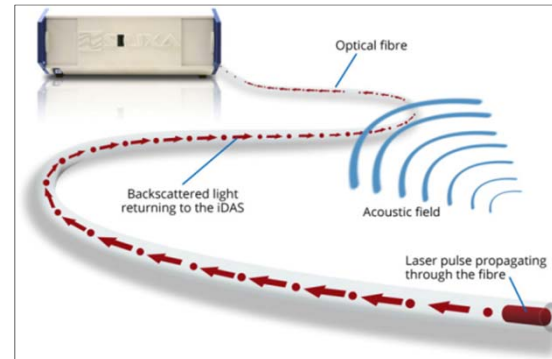
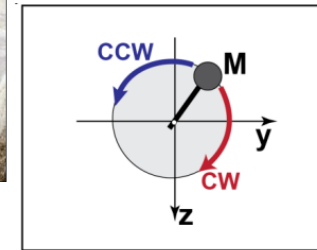
Conventional vs DAS Seismic Monitoring

Conventional
campaign-based systems



SOV-DAS permanent monitoring system

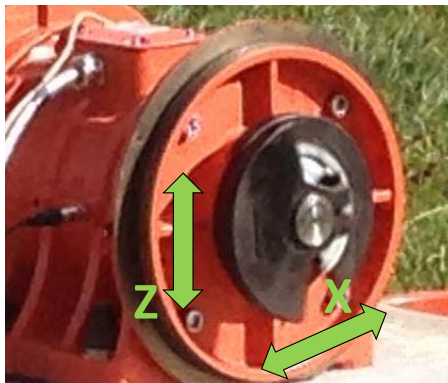
Provides a high-repeatability low cost platform for permanent seismic reservoir monitoring



Surface Orbital Vibrator – VFD Controlled AC Induction Motor

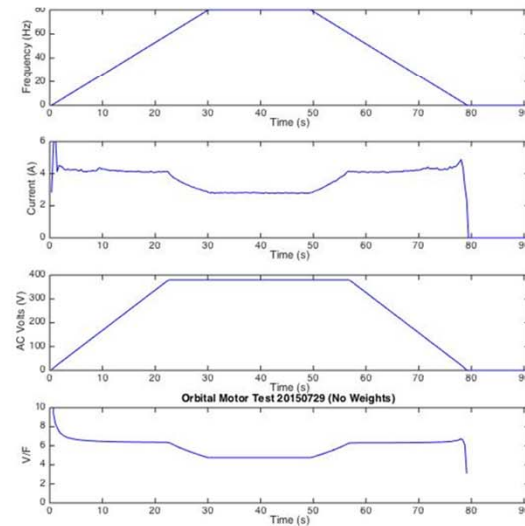
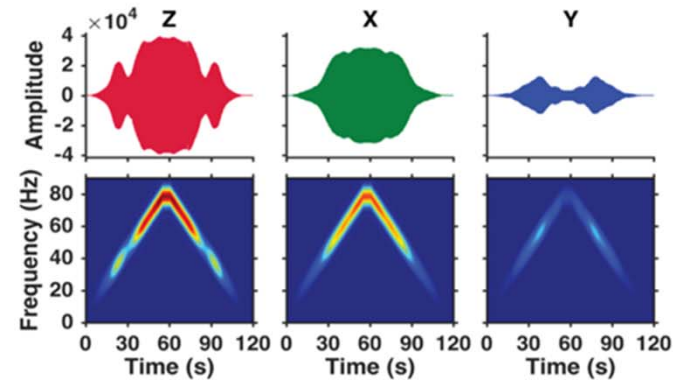


Max Frequency 80 Hz, Force (@80Hz) 10 T-f
Phase stability is not maintained

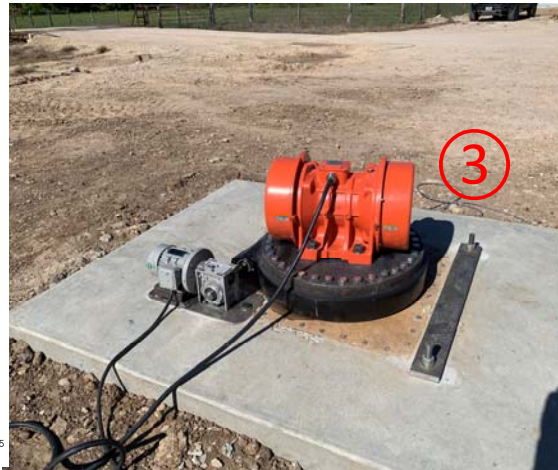
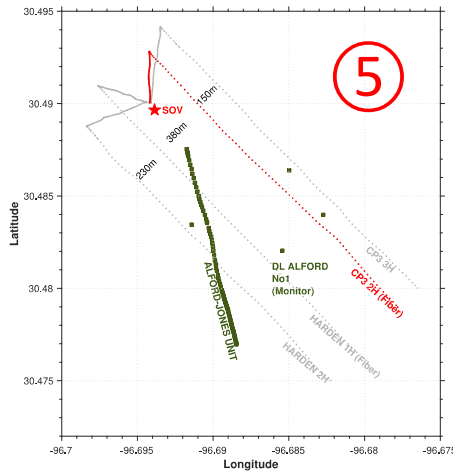


Force is adjustable

$$F = m\omega^2 r$$



SOV Field Tests for EFSL

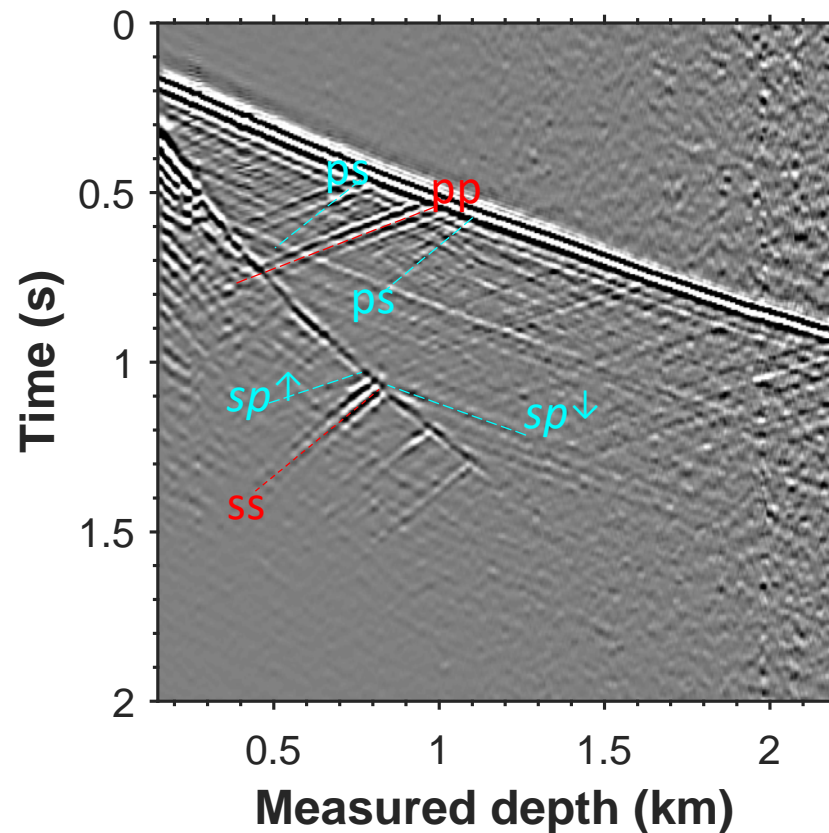


- ① WebDAQ geophone
- ② Foundation Installation
- ③ SOV
- ④ Control Electronics
- ⑤ Site map



SOV/DAS : Vertical Section

- Stacked gather (10 sweeps) of deconvolved SOV
- Just for vertical section of the well.
- Rich wavefield including direct/reflected P and S as well as both up and downgoing converted modes.



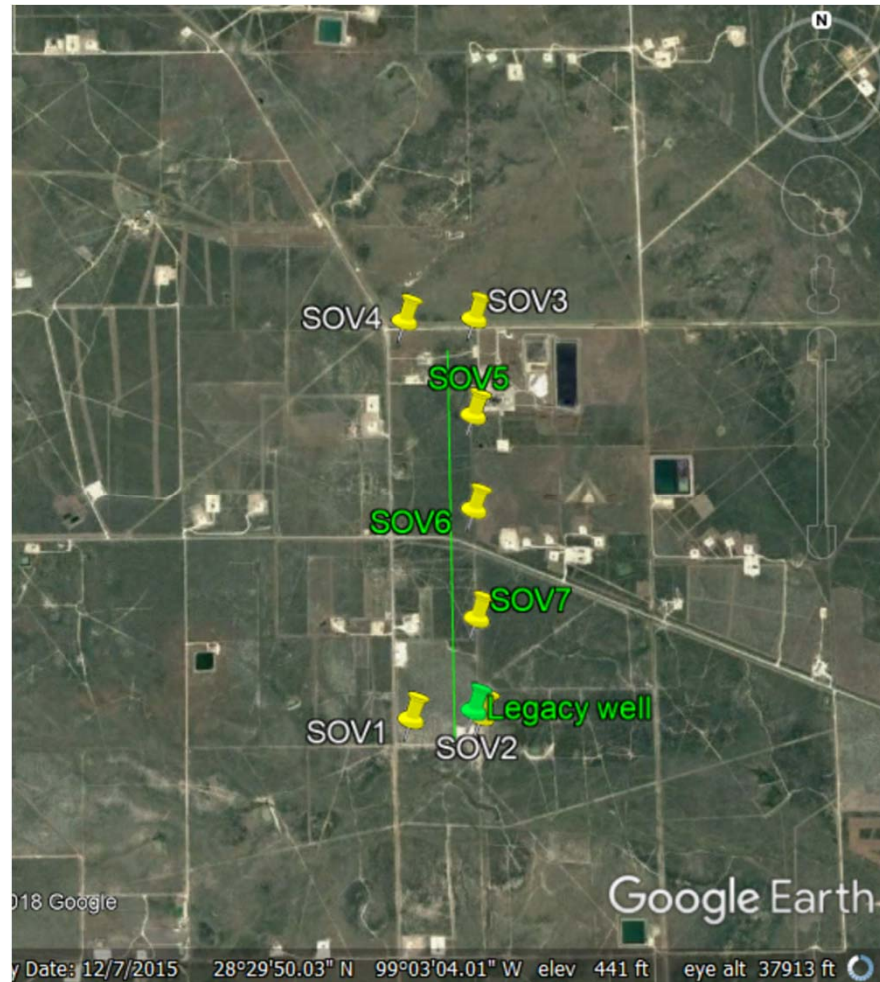
SOV monitoring status

- Our preliminary results indicate:
 - SOV/DAS provides a good alternative for true continuous monitoring at a low cost for unconventional reservoirs monitoring;
 - it enables high resolution seismic data acquisition in space & time, with high repeatability and good data quality.
- Our plan:
 - We will install engineered fiber cemented in the well along the vertical and horizontal sections
 - We plan to install an array of 8 SOVs
 - We will include static strain monitoring with Distributed Strain Sensing



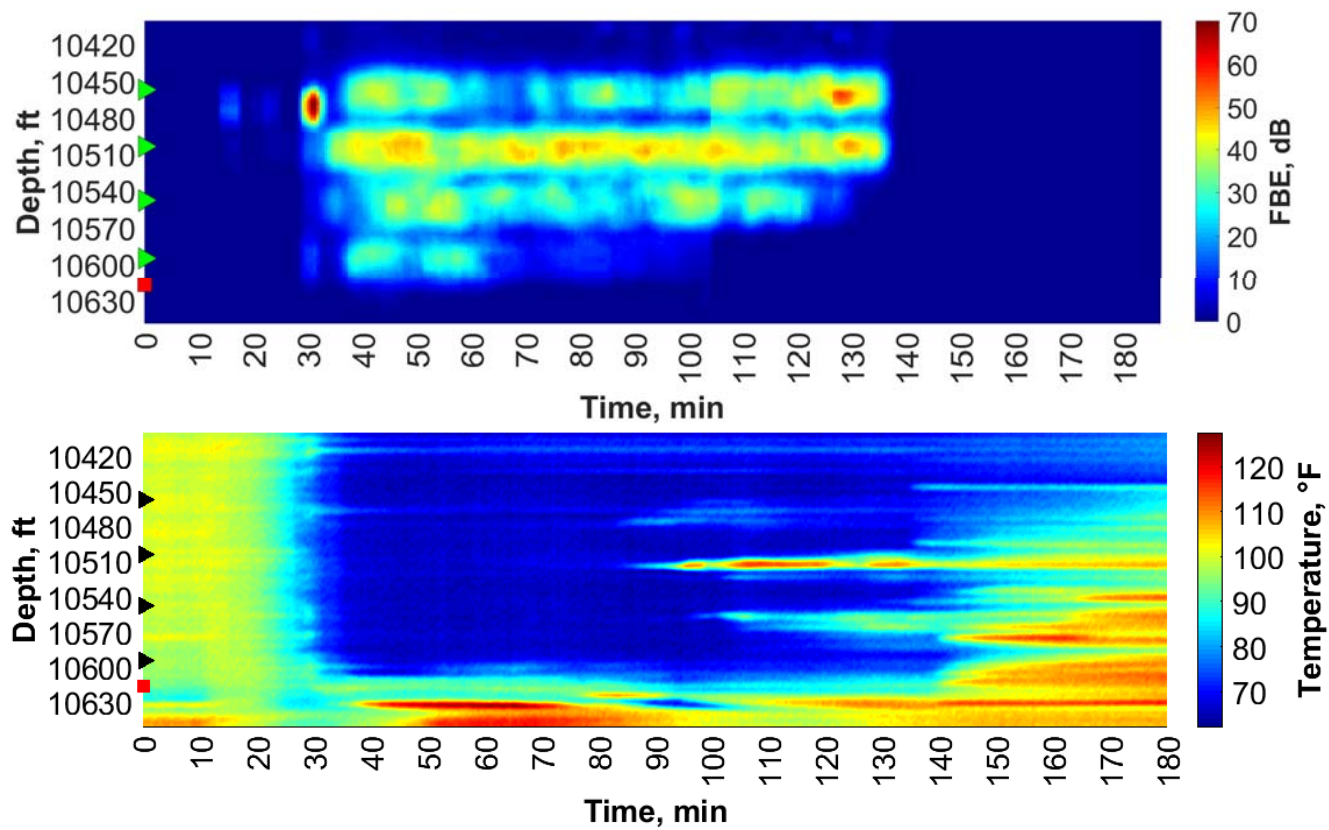
SOV Field Tests for EFSL

- Current SOV deployment plan
- Modeling work underway to optimize locations for reflection imaging

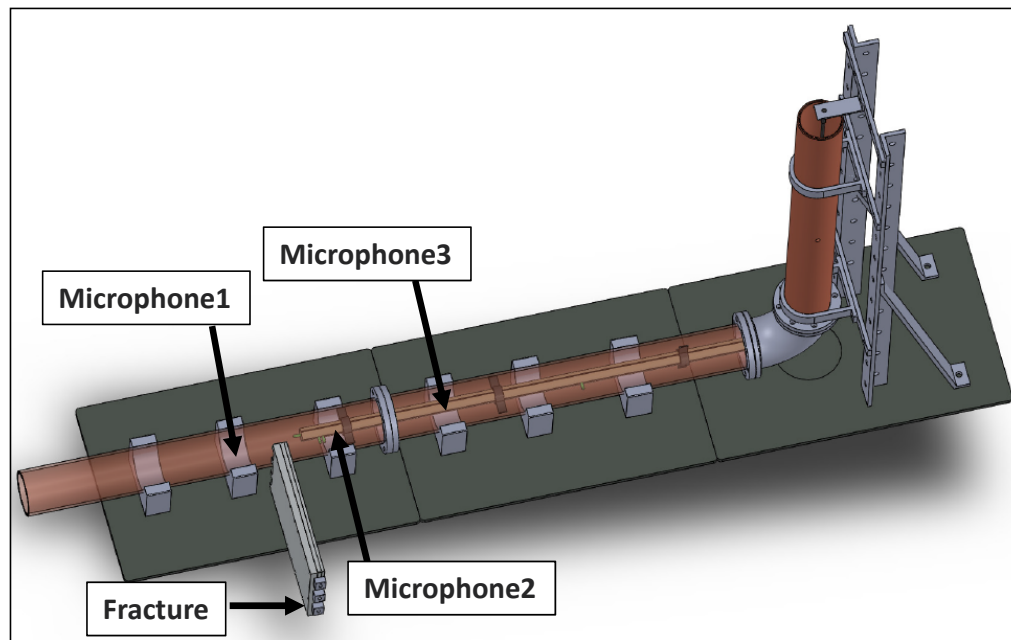


Interpretation of Distributed Acoustic Sensors (DAS) and Distributed Temperature Sensors to for Fracture Diagnosis

DAS and DTS Waterfall Plots



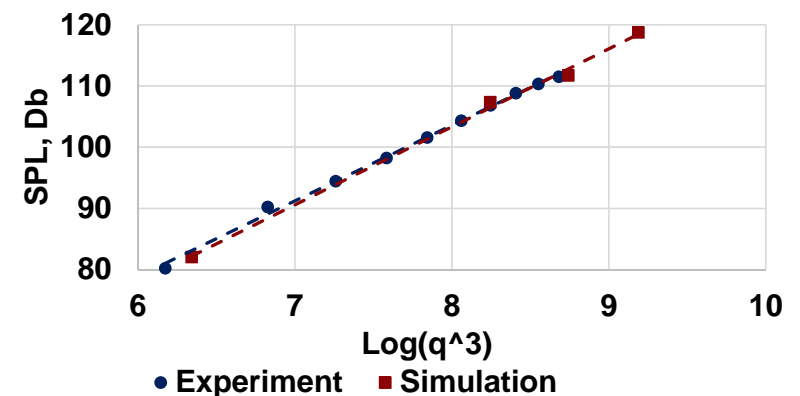
Laboratory Experiments and Computational Simulations



Correlation between acoustic signals and fluid flow rates:

$$\log(q^3) = A * L_{SP} + B$$

where q is flow rate, L_{SP} is sound pressure level, A and B are parameters of the correlation.



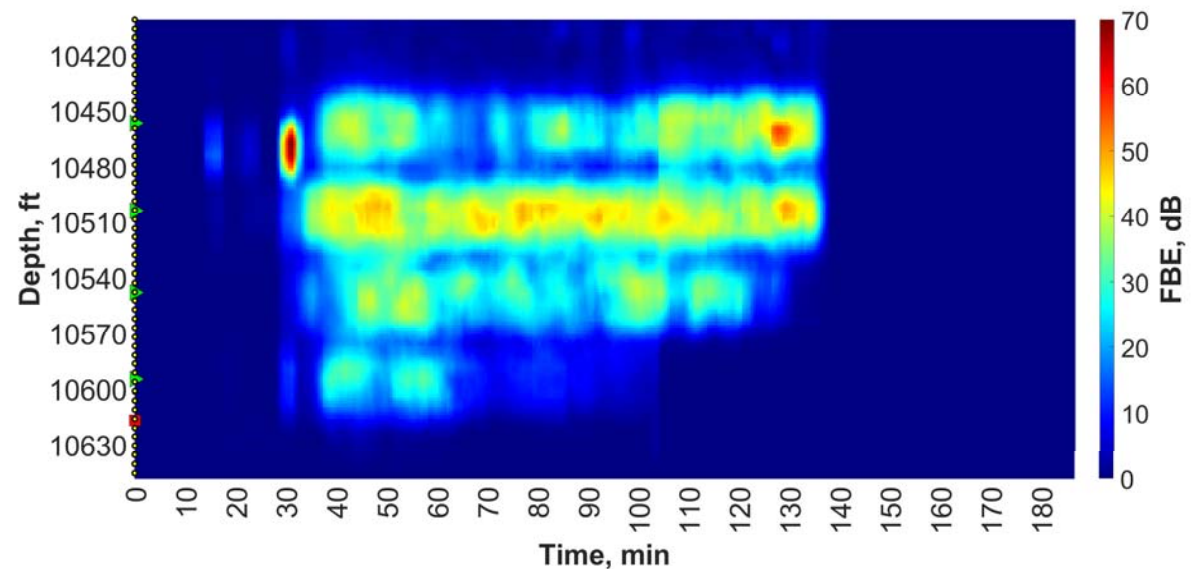
Energy Response of Acoustic Signal

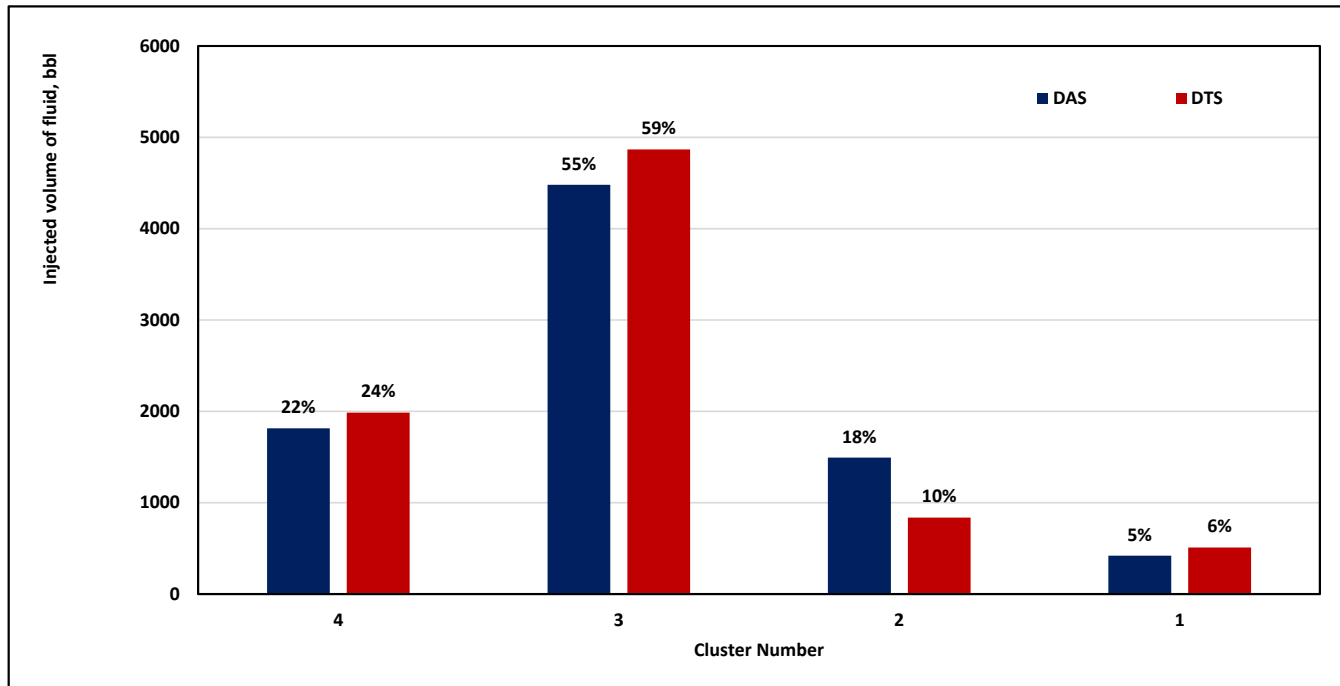
$$\log(q^3) = A * E + B$$

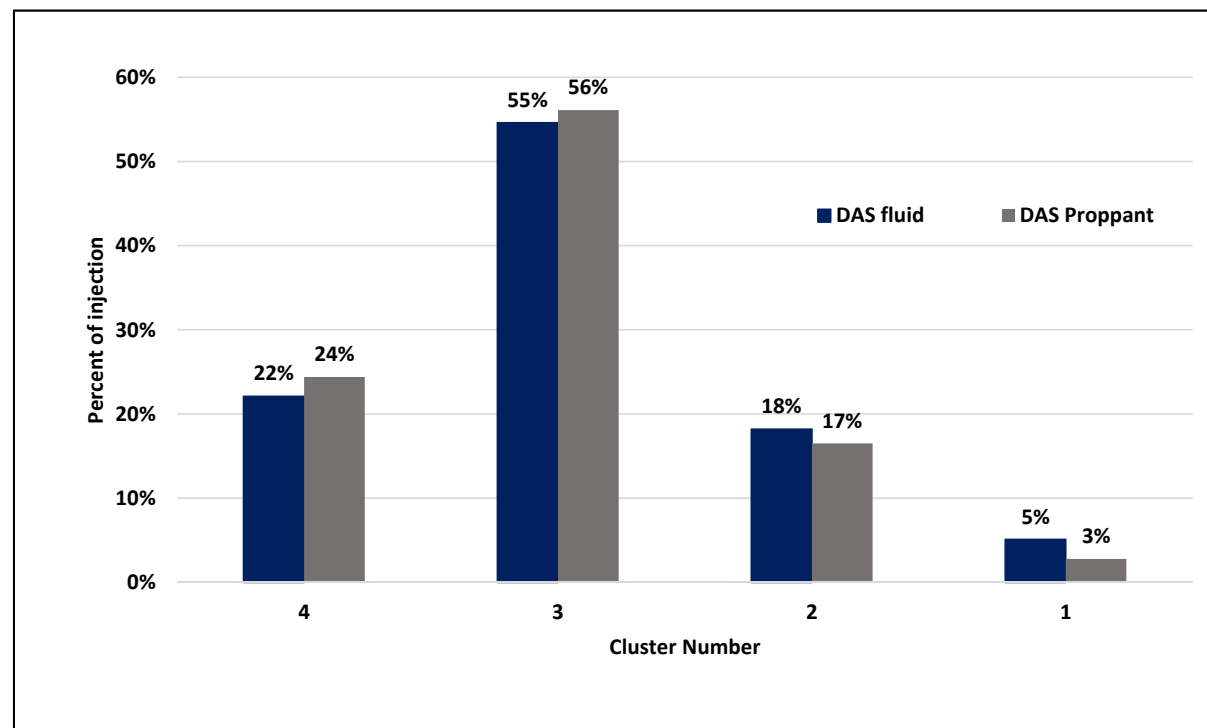
Frequency Band Energy (FBE):

$$E = \sum_{j=1}^N x^2(j)$$

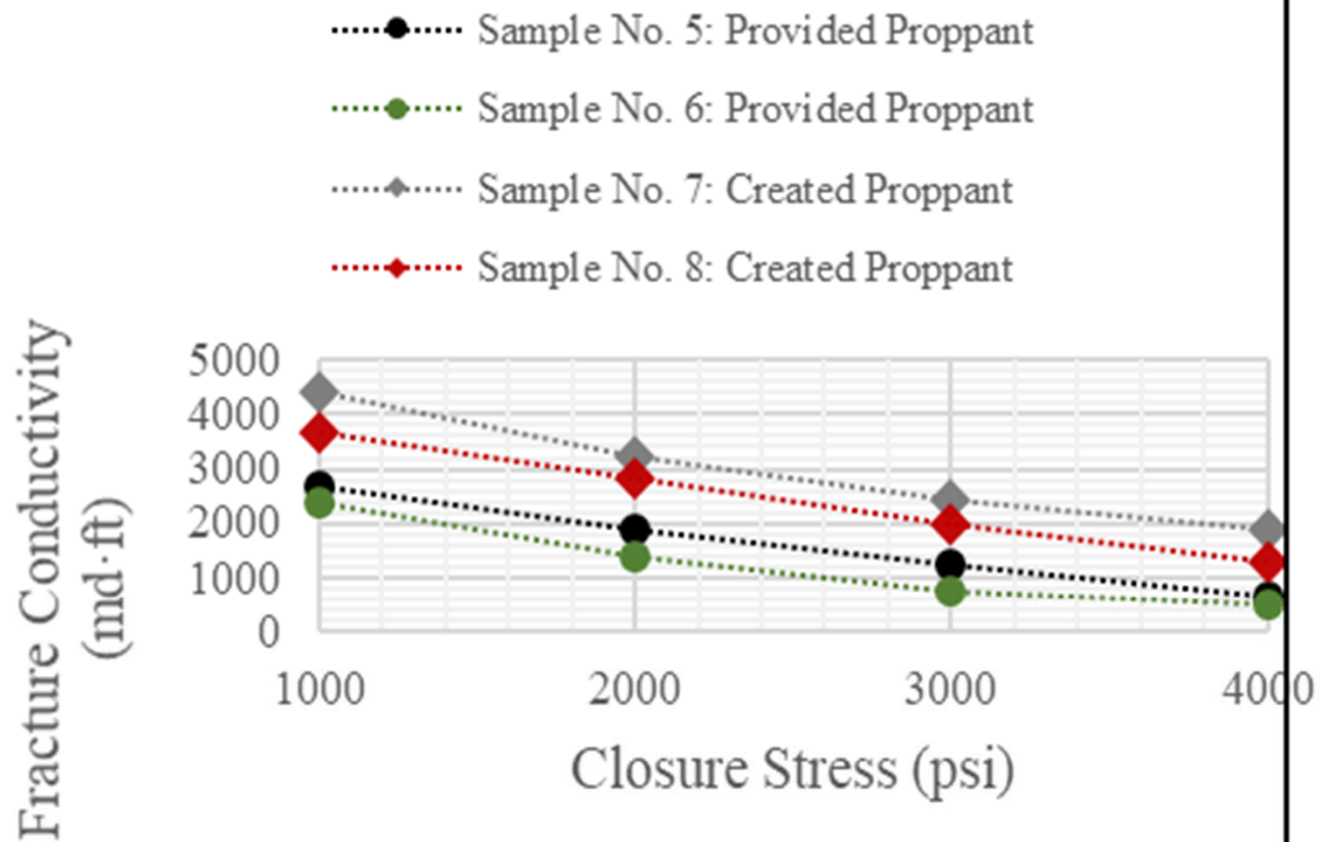
$x(j)$ is sample j out of N samples in a fixed period of time (for example every 1 second).





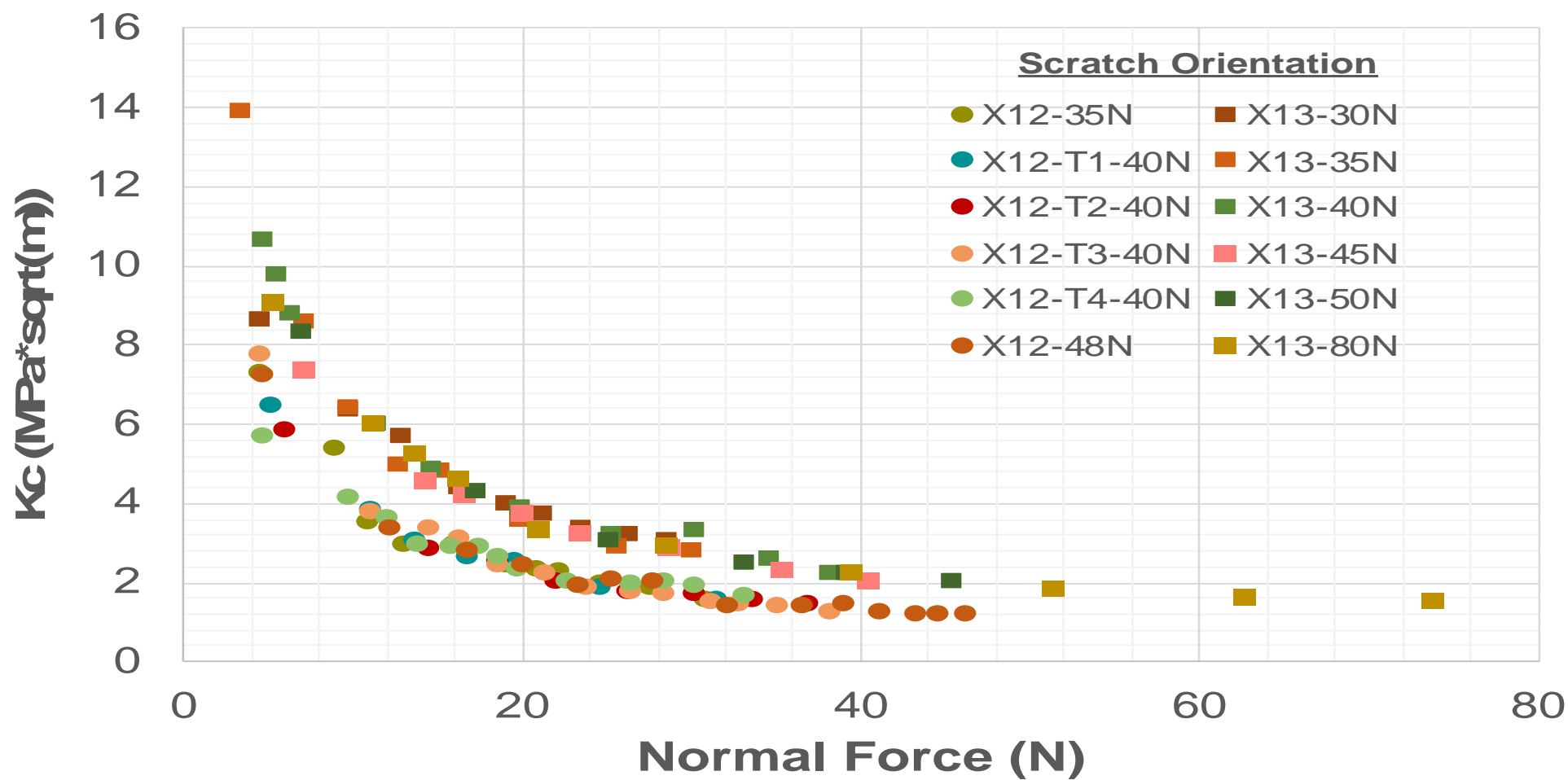


- ## Laboratory Measurements of
- Propped Fracture Conductivity
 - Relative Permeability



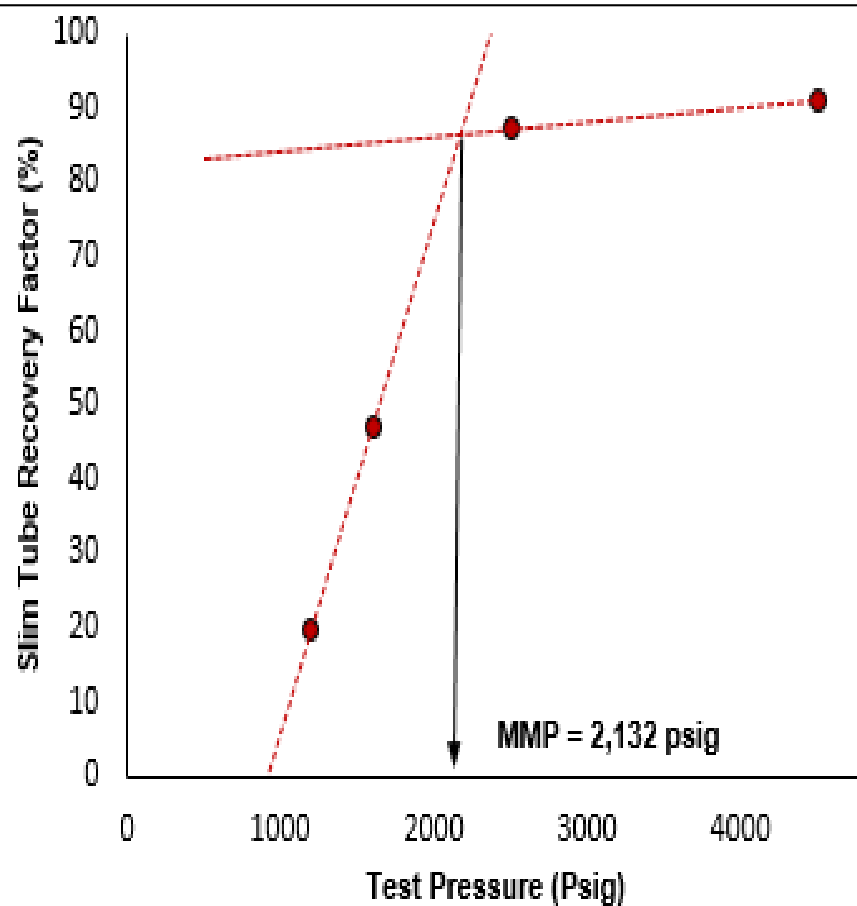
Measurement of Rock Properties with Drill Cuttings

- Nano-indentation
- Scratch tests



Gas Injection EOR Experiments

- Minimum Miscibility Pressure
- Wettability
- Spontaneous Imbibition

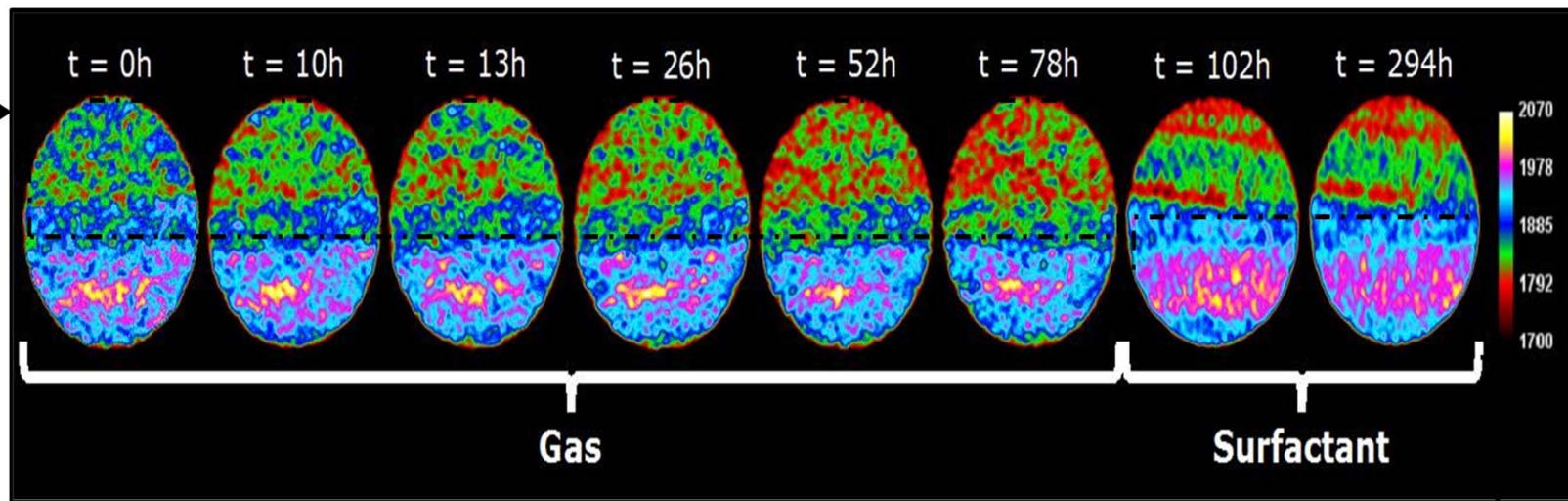


Miscibility Status
Miscible
Immiscible

Res Temp (°F)
MMP (psig)

Doped Eagle Ford Crude Oil	
Test Pressure (psig)	Oil Recovery (% of OOIP)
4500	91.3
2500	87.24
1600	47.23
1200	19.62

170
2,132



High CT #
Smaller pores

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