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

U.S. DEPARTMENT OF ENERGY Fossil Energy OFFICE OF OIL & NATURAL GAS

NATIONAL ENERGY TECHNOLOGY LABORATORY

TEXAS A&M UNIVERSITY
Harold Vance Department of Petroleum Engineering

INPEX
INPEX CORPORATION

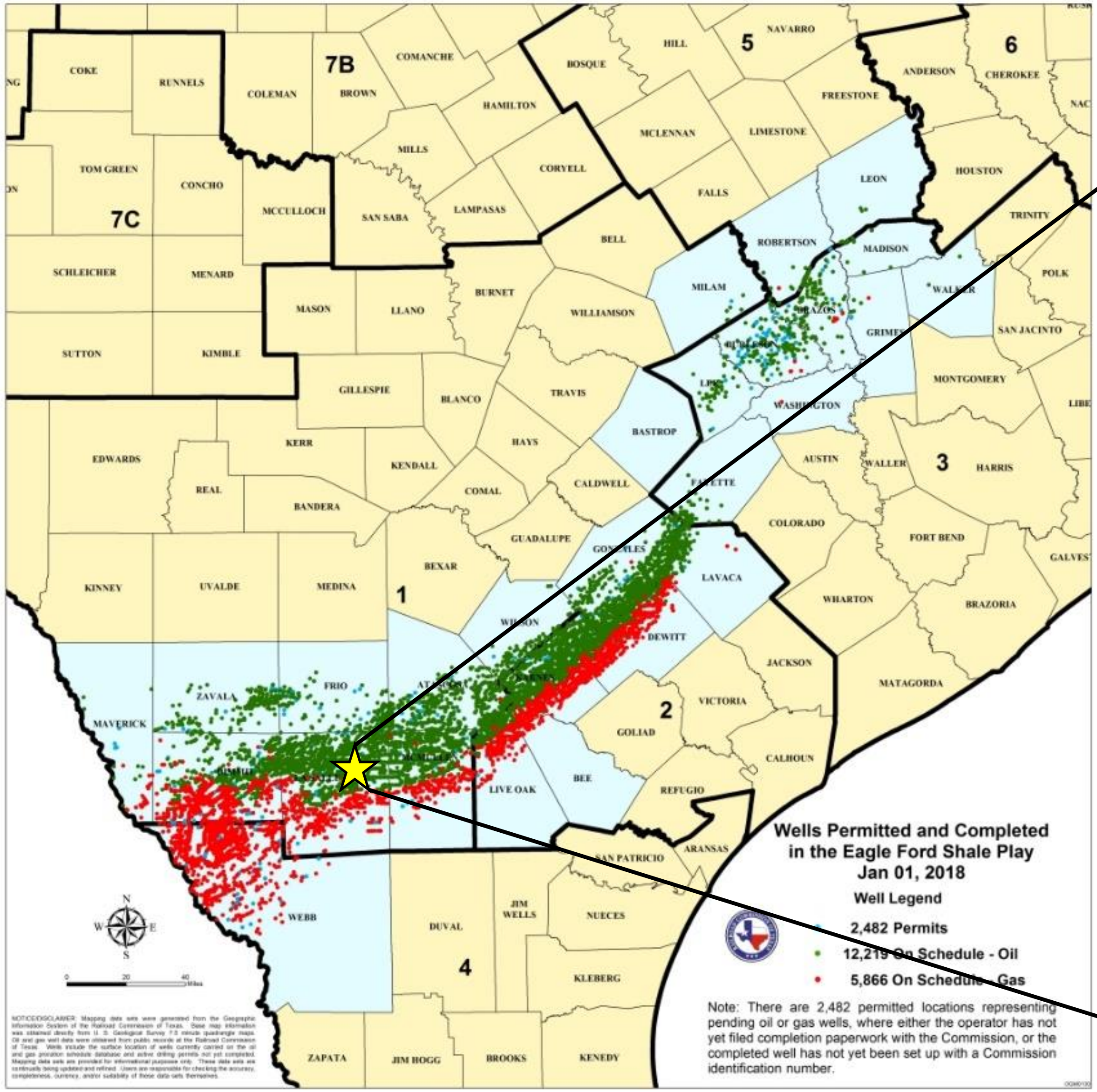
BERKELEY LAB
Bringing Science Solutions to the World

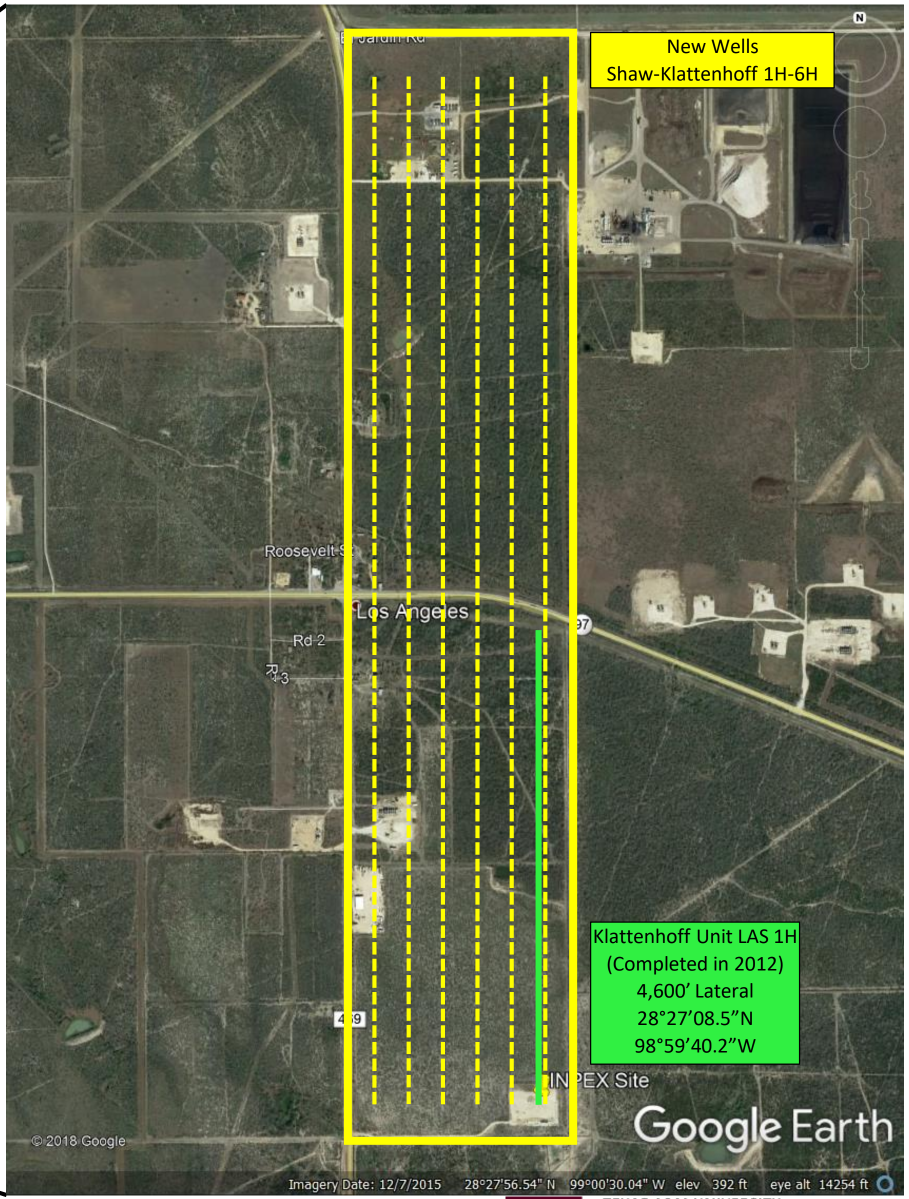
STANFORD UNIVERSITY

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

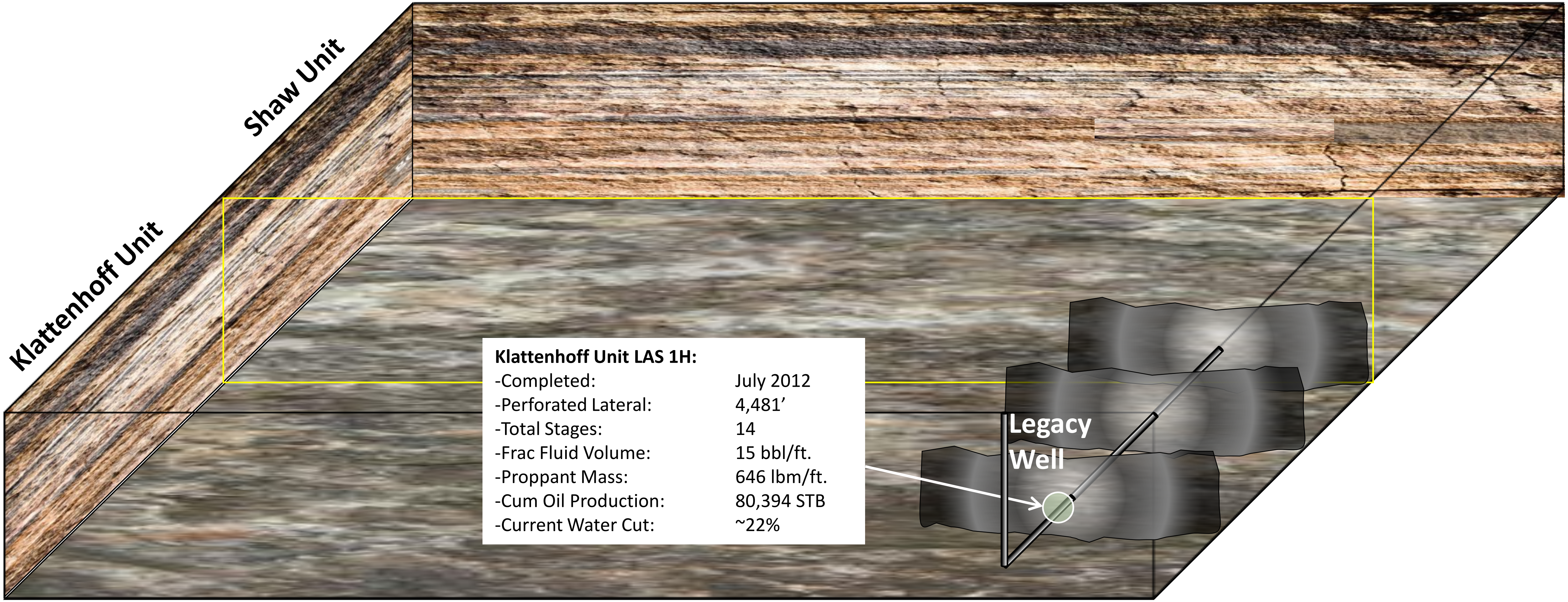
- Phase I : Re-fracture monitoring and evaluation
- Phase II: Monitoring, evaluation and optimization of multistage fracture stimulation (three new producers)
- Phase III: EOR pilot with gas injection

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 errosion**
- **Vertical well cores for supporting lab work**
- **Theoretical and numerical modeling**

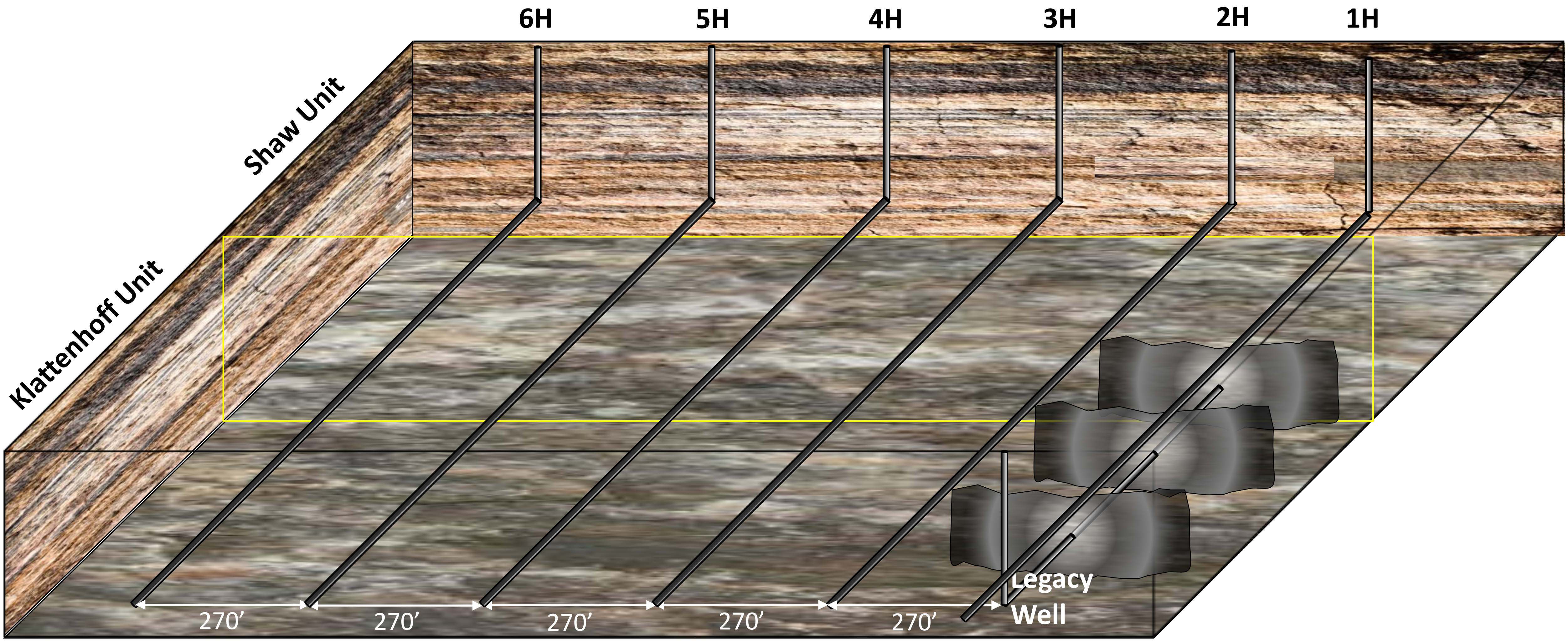
Existing Site and Legacy Well



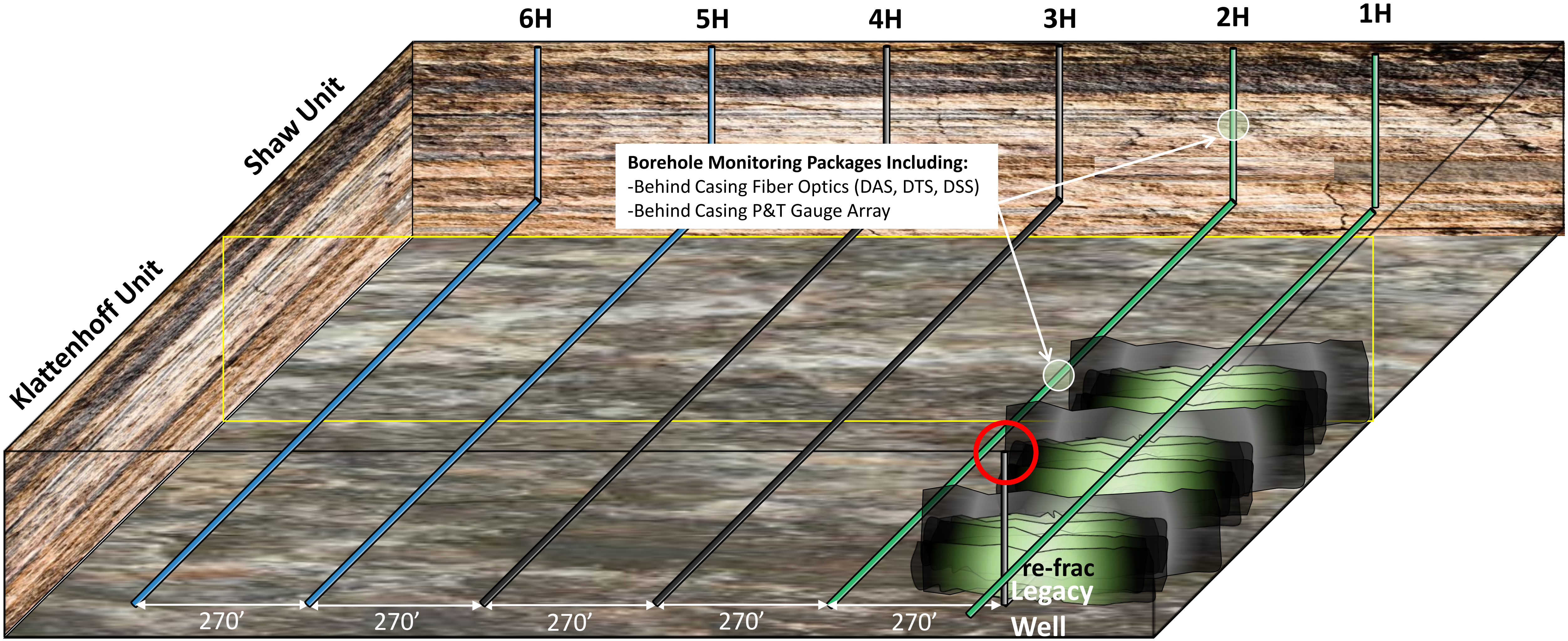
Klattenhoff Unit LAS 1H:

-Completed:	July 2012
-Perforated Lateral:	4,481’
-Total Stages:	14
-Frac Fluid Volume:	15 bbl/ft.
-Proppant Mass:	646 lbm/ft.
-Cum Oil Production:	80,394 STB
-Current Water Cut:	~22%

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 errosion

SOV/DAS for Seismic Monitoring

Target :

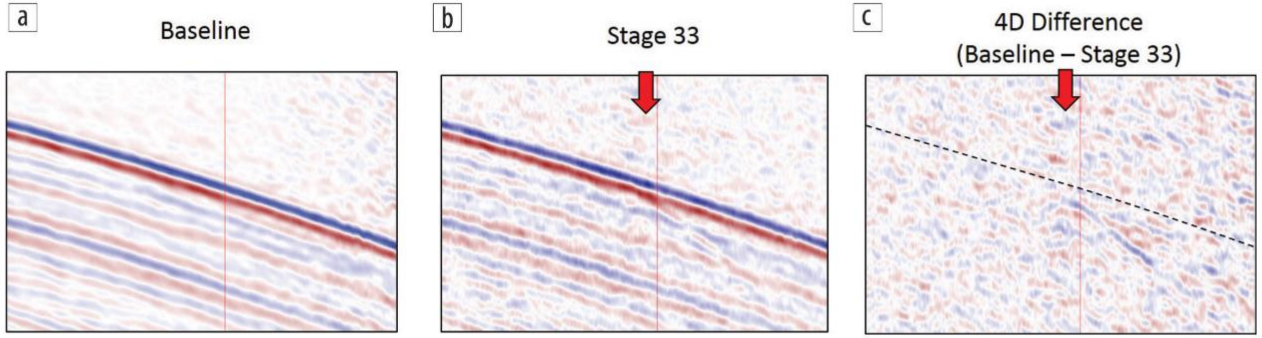
- High-repeatability time-lapse seismic for monitoring fracture opening and closure in space & time.
- Provide an active source approach for quantifying the SRV

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?



Byerley et al. (2018)

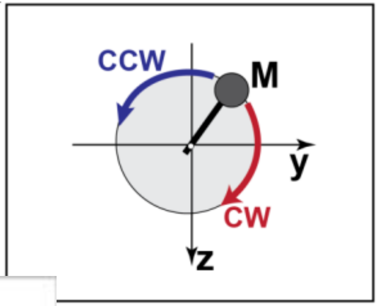
Figure 5. Zoom of north shot location shot gathers showing prefrac (a) baseline, (b) shot acquired after stage 33, and (c) the difference between the two. Black dashed line shows the timing of the direct P-wave arrival. Red arrow shows the location where stage 33 was fracked along the well.

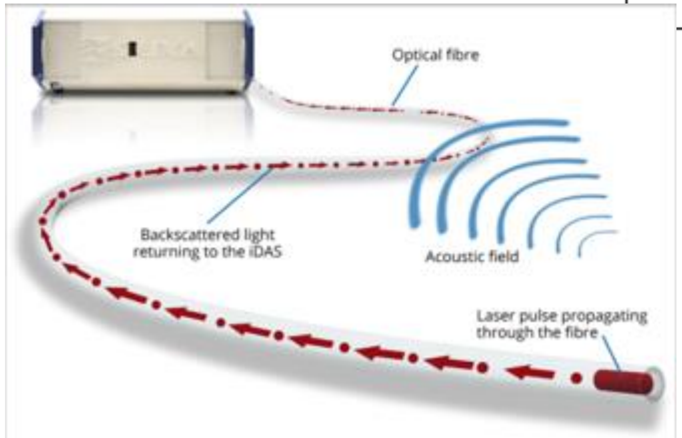
TEXAS A&M UNIVERSITY
Harold Vance Department of
Petroleum Engineering

Conventional vs DAS Seismic Monitoring

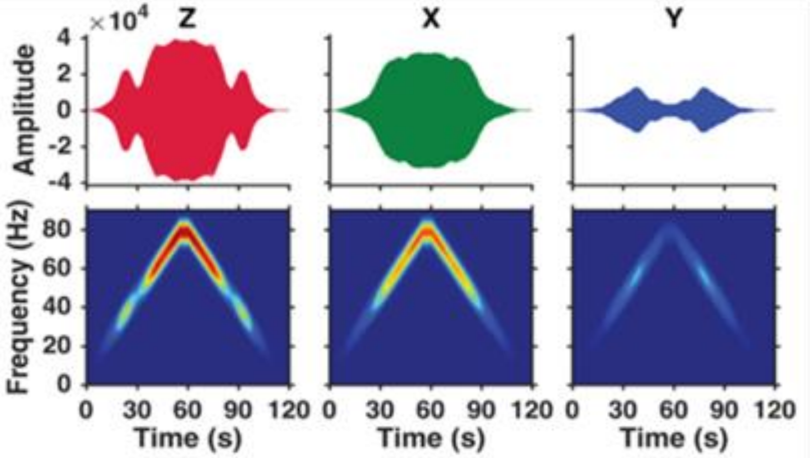
Conventional
campaign-based systems

SOV-DAS permanent monitoring system

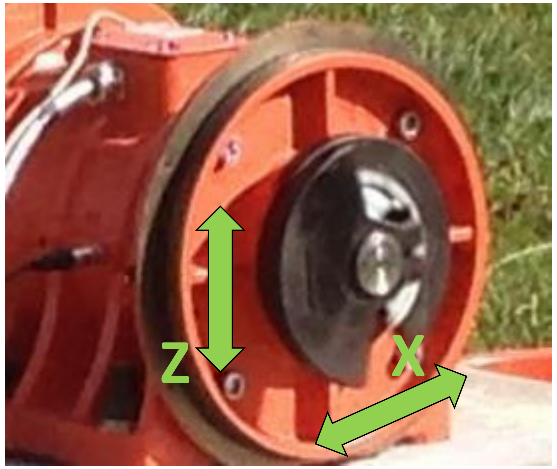




Surface Orbital Vibrator – VFD Controlled AC Induction Motor

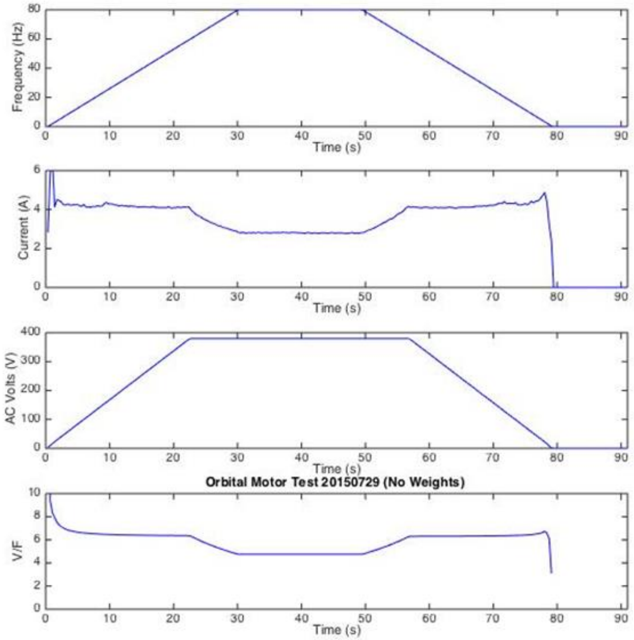


Max Frequency 80 Hz, Force (@80Hz) 10 T-f
Phase stability is not maintained

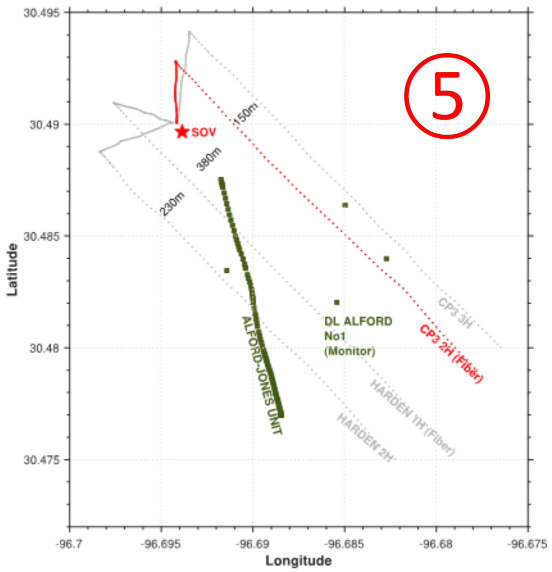


Force is adjustable

F=mω^2r



SOV Field Tests for EFSL



① WebDAQ geophone

② Foundation Installation

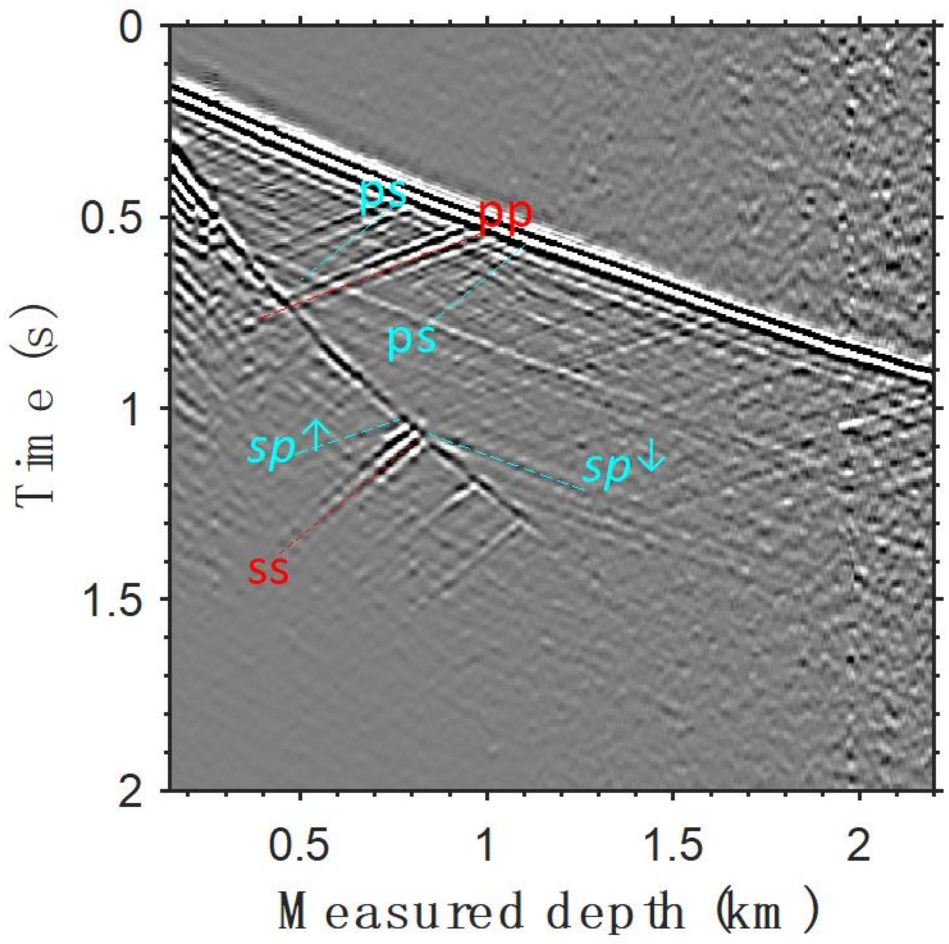
③ SOV

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.

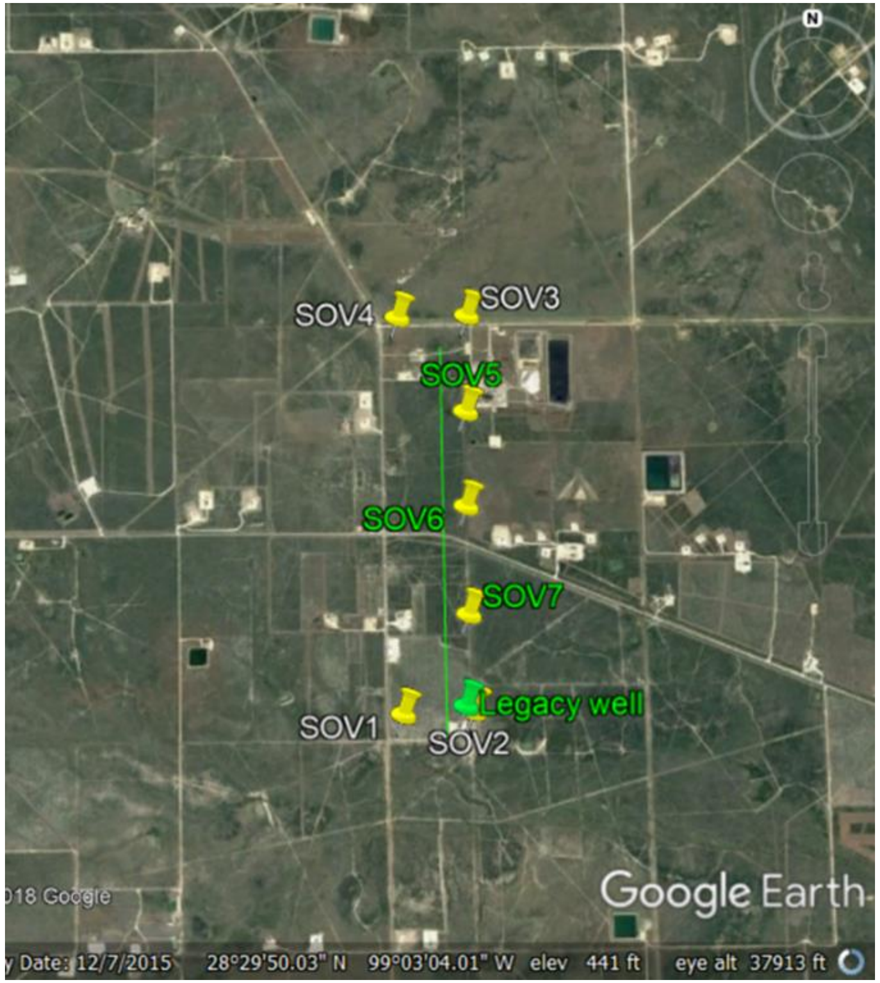


SOV monitoring status

- 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

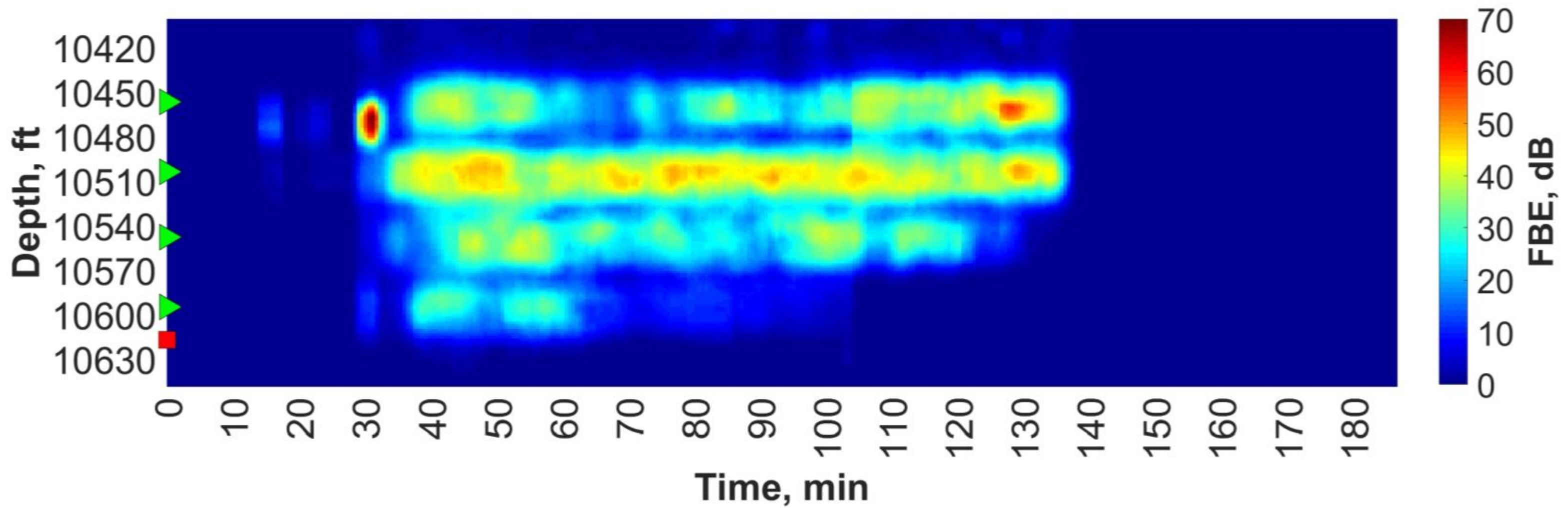
SOV Field Tests for EFSL

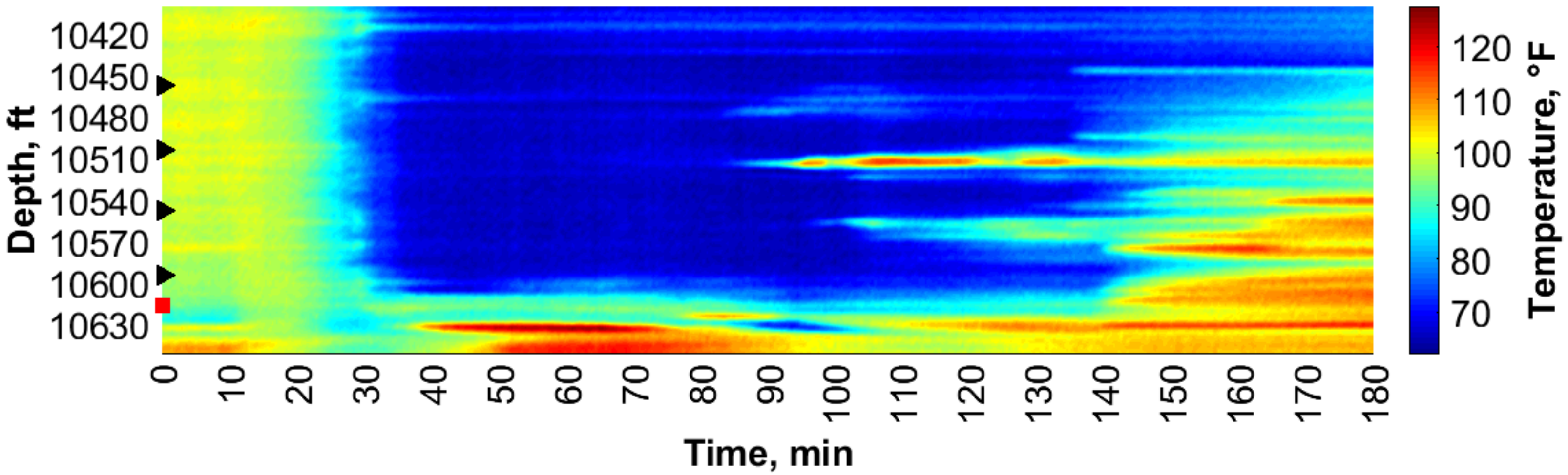
- Current SOV deployment plan
- Modeling work underway to optimize locations for reflection imaging



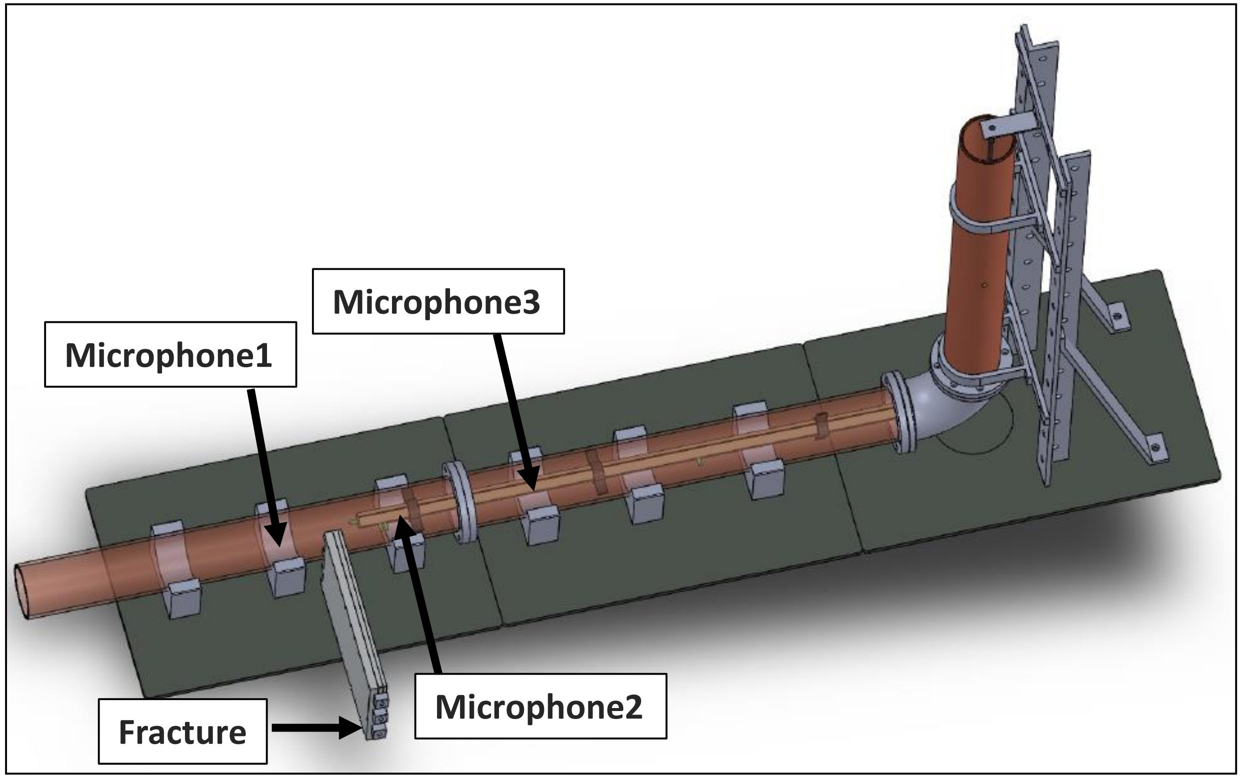
Interpretation of Distributed Acoustic Sensors (DAS) and Distributed Temperature Sensors to for Fracture Diagnosis

DAS and DTS Waterfall Plots





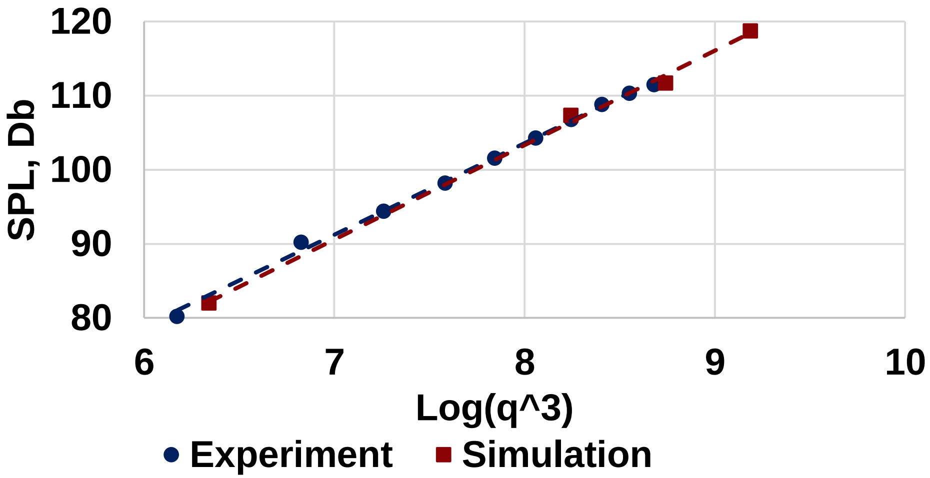
Laboratory Experiments and Computational Simulations



Correlation between acoustic signals and fluid flow rates:

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

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



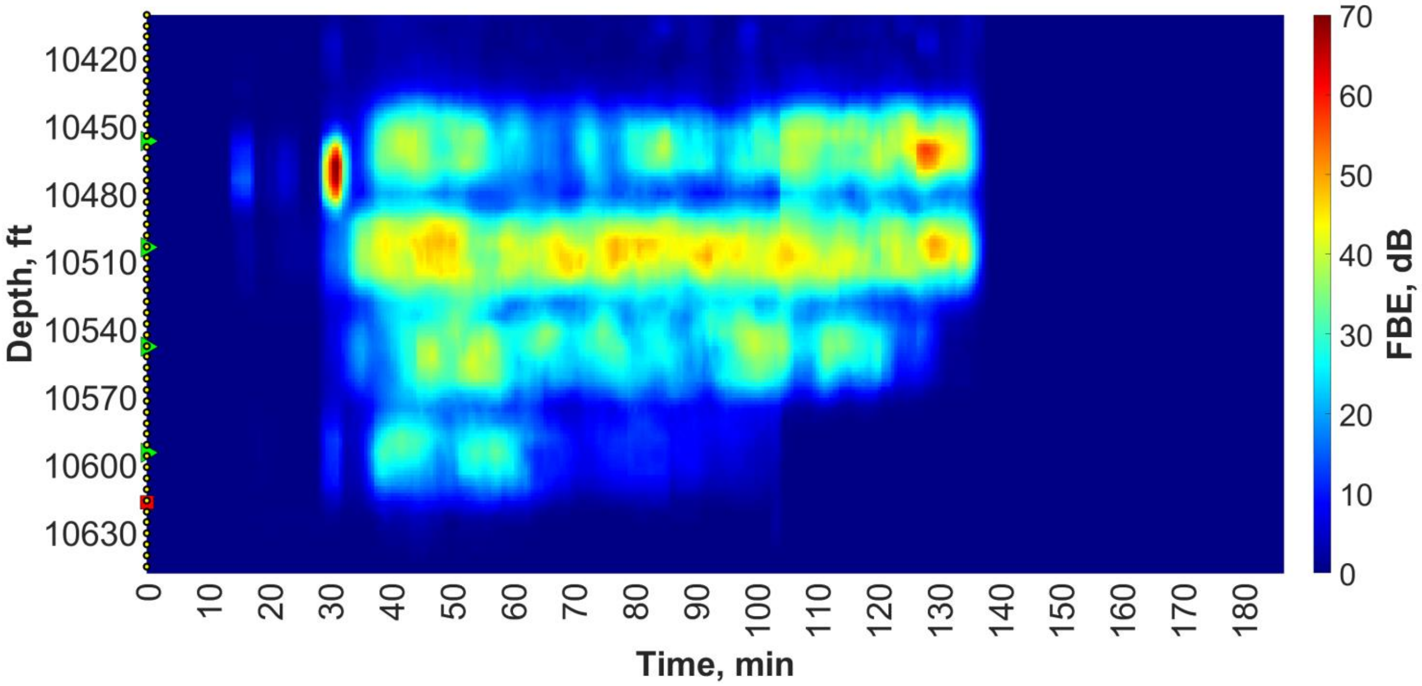
Energy Response of Acoustic Signal

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

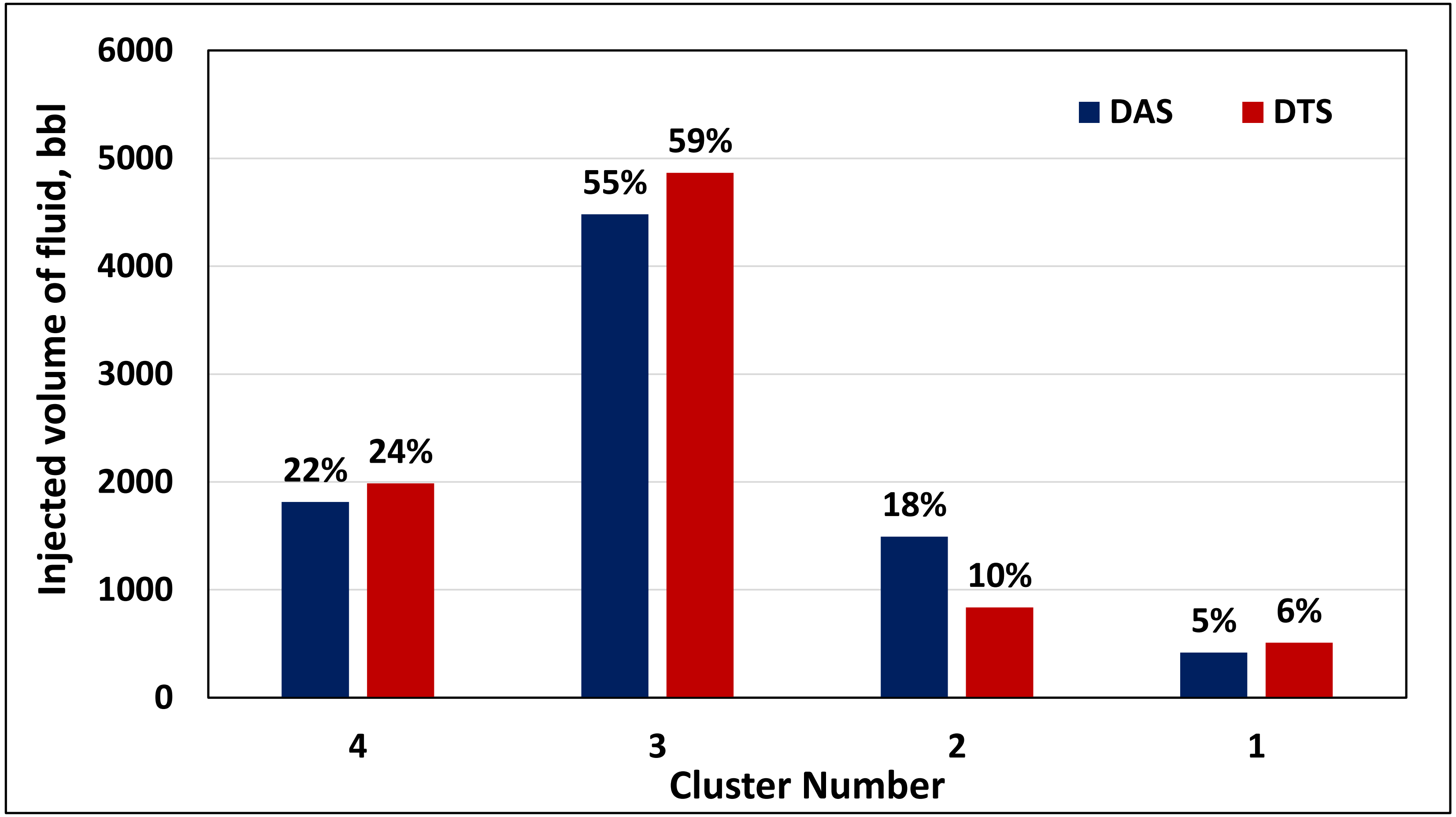
Frequency Band Energy (FBE):

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

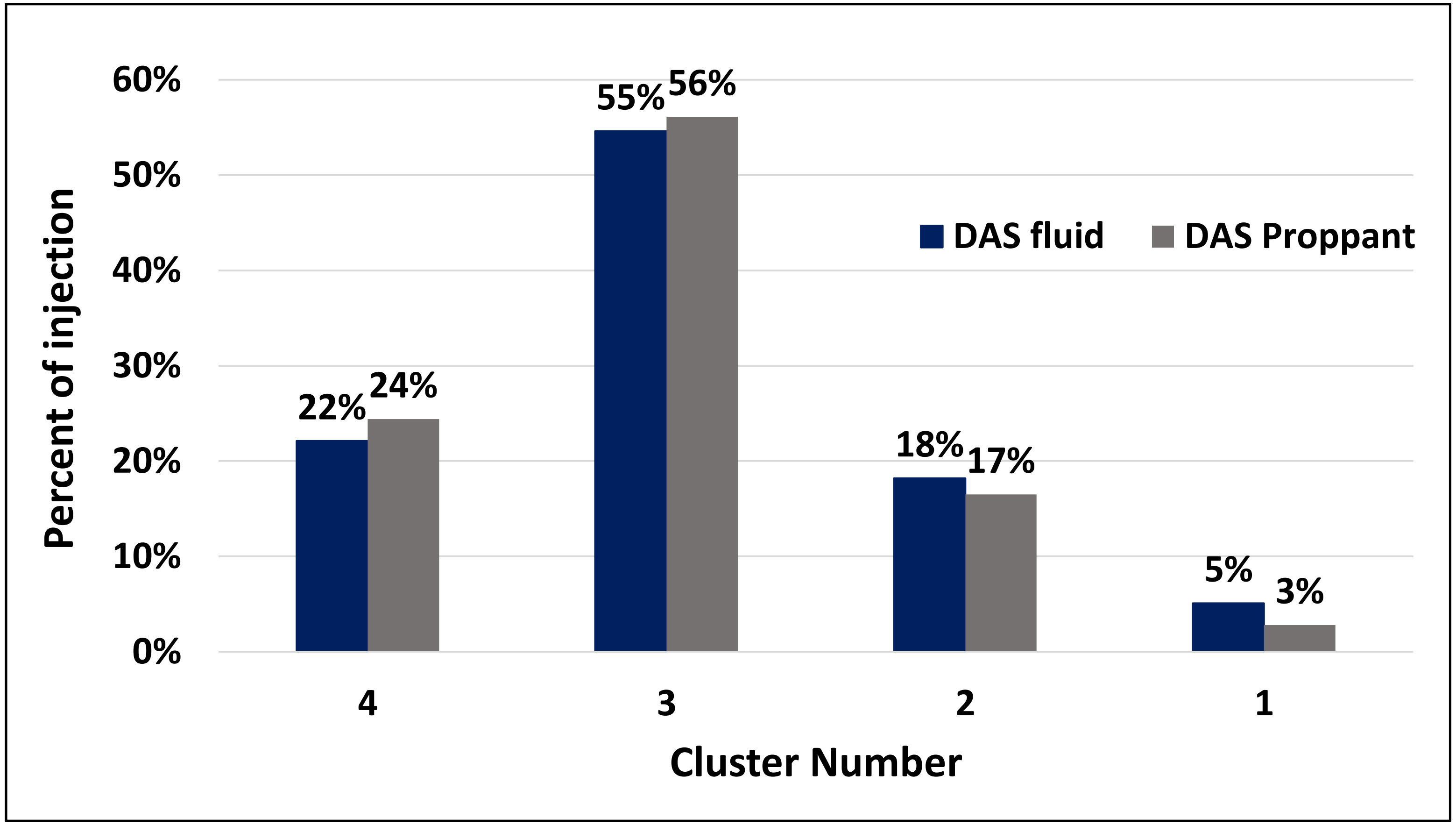
$x(j)$ **is sample** j **out of** N **samples in a fixed period of time (for example every 1 second).**



TEXAS A&M UNIVERSITY
Harold Vance Department of Petroleum Engineering

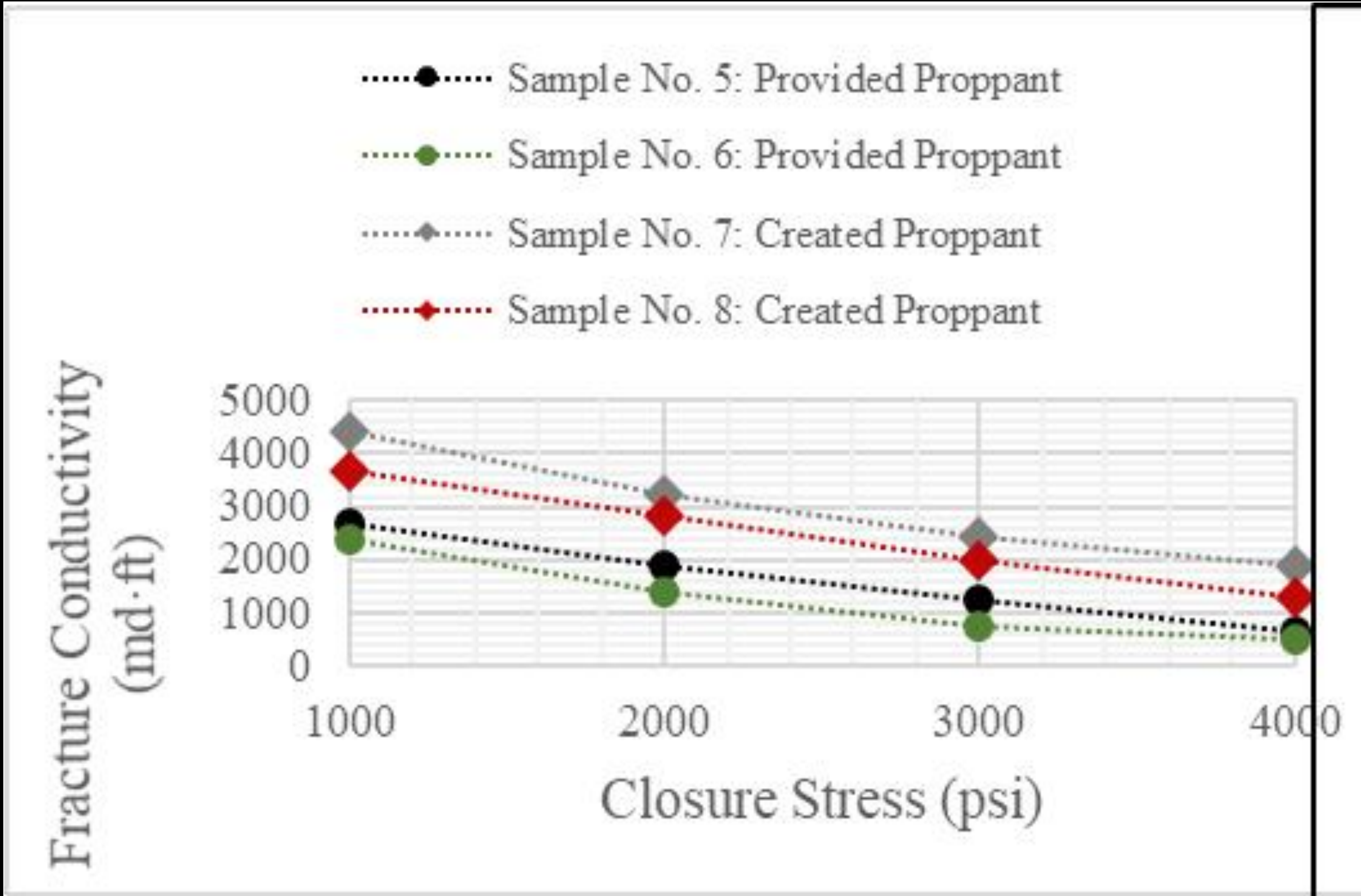


Injected volume of fluid, bbl
6000
5000
4000
3000
2000
1000
0
DAS
DTS
22%
24%
55%
59%
18%
10%
5%
6%
4
3
2
1
Cluster Number


60%
50%
40%
30%
20%
10%
0%
Percent of injection
55%
56%
22%
24%
18%
17%
5%
3%
DAS fluid
DAS Proppant
4
3
2
1
Cluster Number

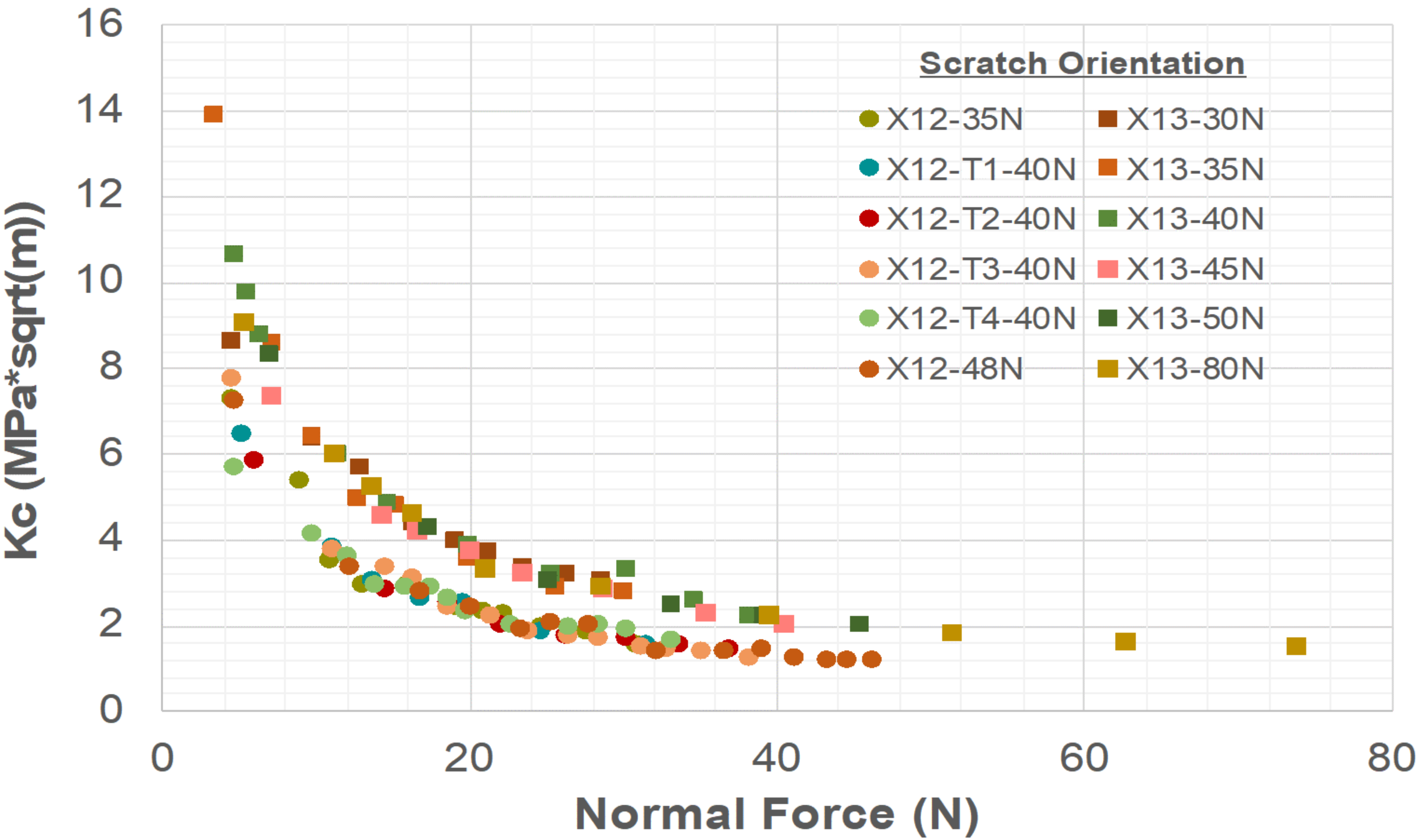
Laboratory Measurements of

- Propped Fracture Conductivity
- Relative Permeability


Sample No. 5: Provided Proppant
Sample No. 6: Provided Proppant
Sample No. 7: Created Proppant
Sample No. 8: Created Proppant
Fracture Conductivity (md·ft)
5000
4000
3000
2000
1000
0
1000
2000
3000
4000
Closure Stress (psi)

Measurement of Rock Properties with Drill Cuttings

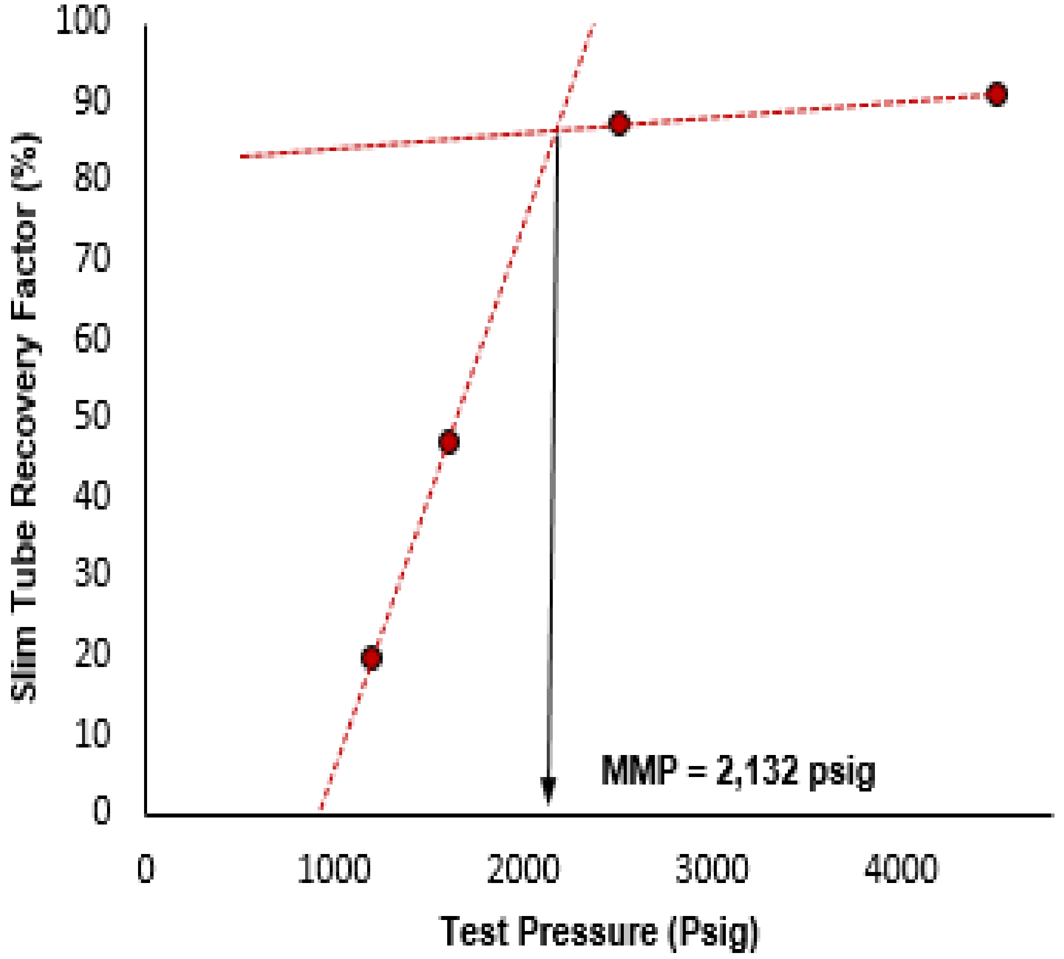
- Nano-indentation
- Scratch tests



Scratch Orientation
X12-35N
X12-T1-40N
X12-T2-40N
X12-T3-40N
X12-T4-40N
X12-48N
X13-30N
X13-35N
X13-40N
X13-45N
X13-50N
X13-80N
Kc (MPa*sqrt(m))
Normal Force (N)
0
2
4
6
8
10
12
14
16
0
20
40
60
80

Gas Injection EOR Experiments

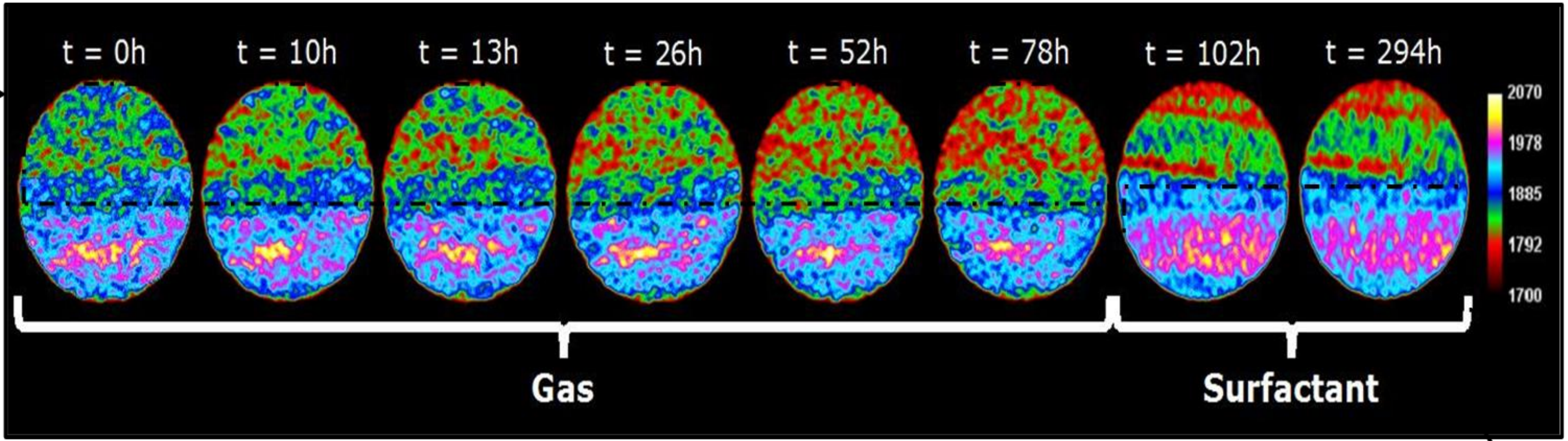
- Minimum Miscibility Pressure
- Wettability
- Spontaneous Imbibition



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

Res Temp (°F)	170
MMP (psig)	2,132

Low
Porosity
CT #



High CT #
Smaller pores

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

U.S. DEPARTMENT OF ENERGY | Fossil Energy
OFFICE OF OIL & NATURAL GAS

NATIONAL ENERGY TECHNOLOGY LABORATORY

TEXAS A&M UNIVERSITY
Harold Vance Department of Petroleum Engineering

INPEX
INPEX CORPORATION

BERKELEY LAB
Bringing Science Solutions to the World

STANFORD UNIVERSITY