Injection and Tracking of Micro Seismic Emitters to Optimize Unconventional Oil and Gas Development FE0024360

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U.S. Department of Energy
National Energy Technology Laboratory
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Presentation Outline

- Technical Status & Accomplishments to Date
- Paulsson, Inc. Introduction & Capabilities
- Surface Seismic vs. Borehole Seismic Imaging
- Tests with Fiber Optic Vectors Sensors (FOSVS)
- Injectable Micro Emitters (IME's)
- Lessons Learned
- Synergy Opportunities
- Project Summary

Technical Status & Accomplishments

- Developed a Robust Deployment System for Borehole Sensors
- Developed very sensitive Fiber Optic Seismic Vector Sensors
- Tested Fiber Optic Sensors with the Deployment System
- Manufactured ~400 Fiber Optic Seismic Vector Sensors (FOSVS)
- Manufactured 40 Sensor Pod Housings. In the process to manufacture 110 Sensor Pod Housings.
- Manufactured & Tested a FOSVS System to DD = 6,000 ft
- Tested 1st Version of Acoustic Micro Emitters: 2mm = too large
- Tested 2nd Version of Acoustic Micro Emitters: 60µm = right size. 60µm is equivalent of 40-70 mesh which is a common proppant size
- We are looking for a test site for the Fiber Optic Seismic Vector Sensors (FOSVS) and the Injectable Micro Emitters

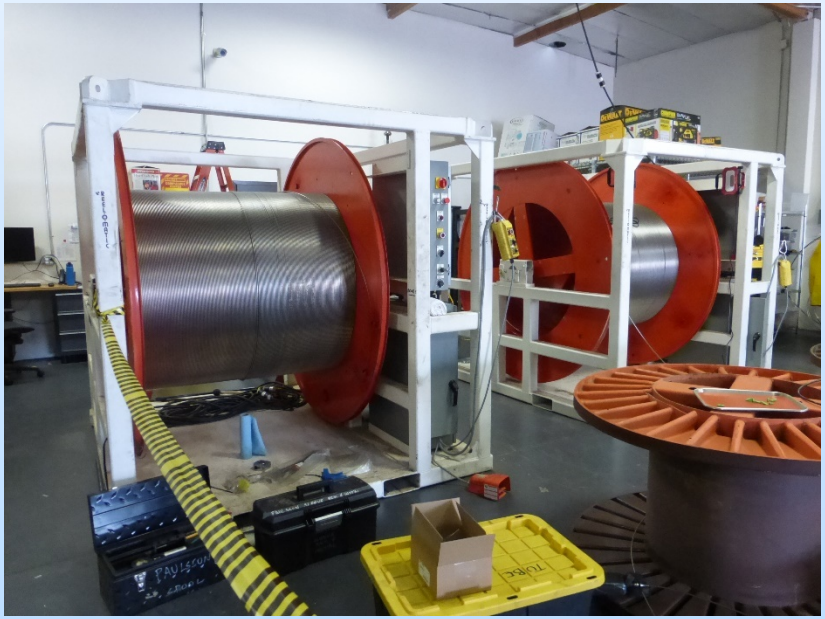
Paulsson, Inc. – The Company

Facility in Van Nuys, CA

ISO 1,000 Clean Room to build sensors

Machine Shop: Five state-of-Art CNC machines

15,000 ft Fiber Optic Cable with15 fibers



Paulsson Commercial Experience Made Possible by Past DOE Funding

- Recorded over 65 3D VSPs around the world
- Recorded the largest 3D VSP in the world using a 960 channel system (4 wells x 80 x 3C)
- Recorded VSP's with the largest number of 3C clamped stations: 160 3C levels & 8,000 ft long
- Recorded the first multi-well (8 wells) 3D VSP
- Recorded 3D VSP data in the USA, Canada, China and Middle East

A Critical Point:

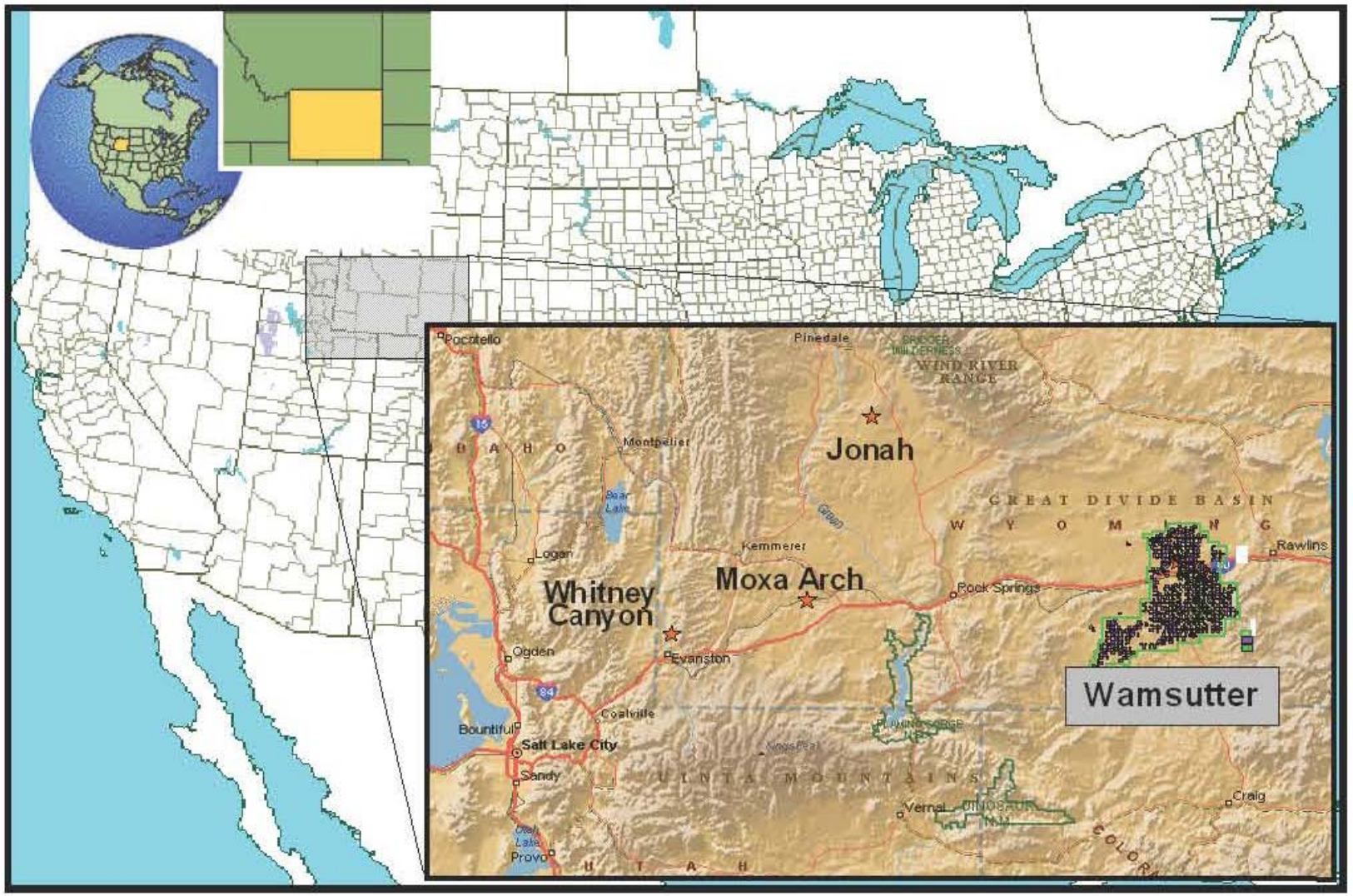
Before We Monitor the Injectable Micro Emitters We Must Image the Geology & Reservoirs In High Resolution!

Surface Seismic is not Sufficient!

Three Examples of 3D/4D VSP Imaging Results

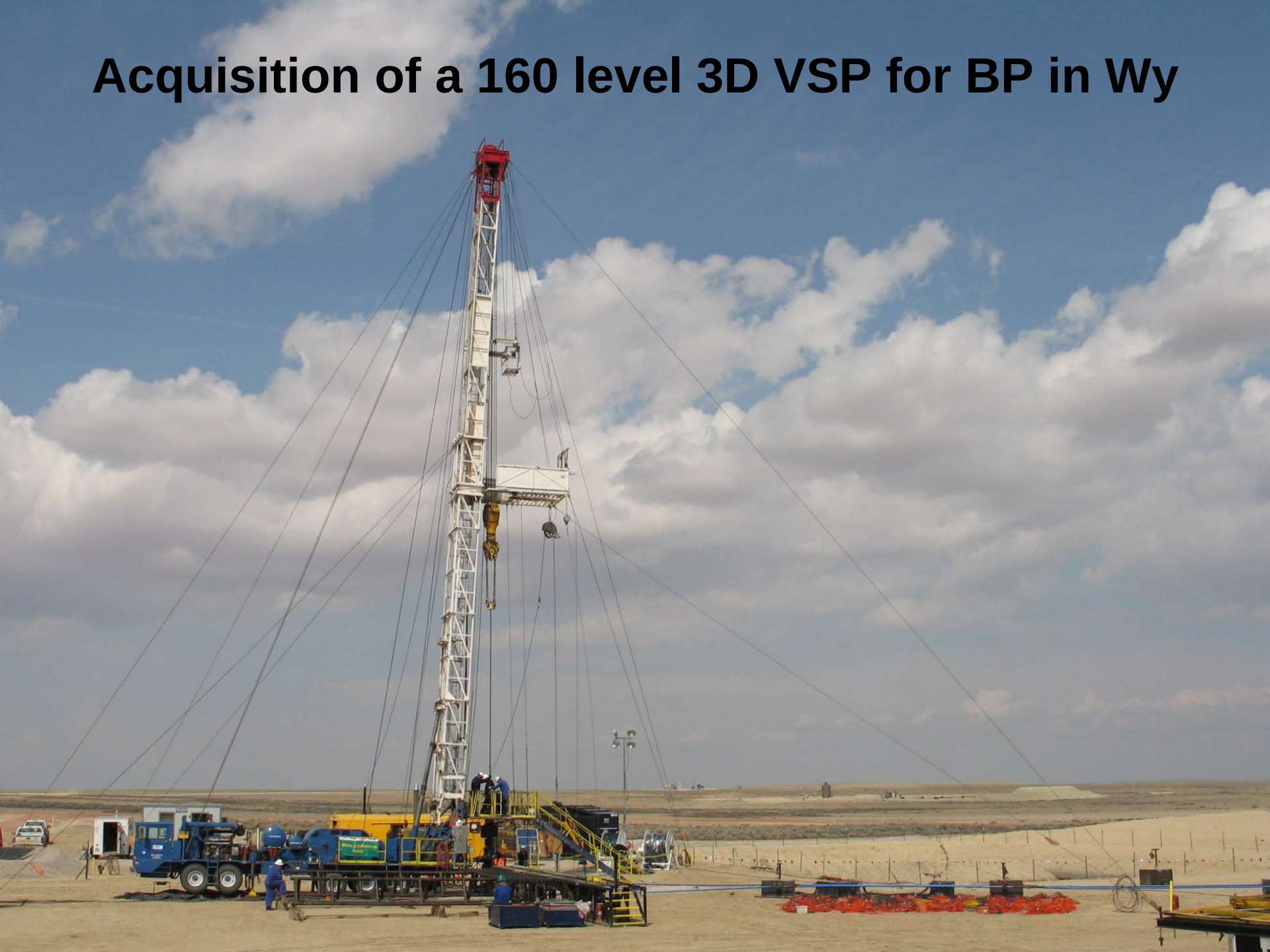
1st: Using a 160 level 3C array In the BP Wamsutter Field

Location of the Wamsutter Field, WY, USA
Test of Surface Seismic & 3D VSP Technologies

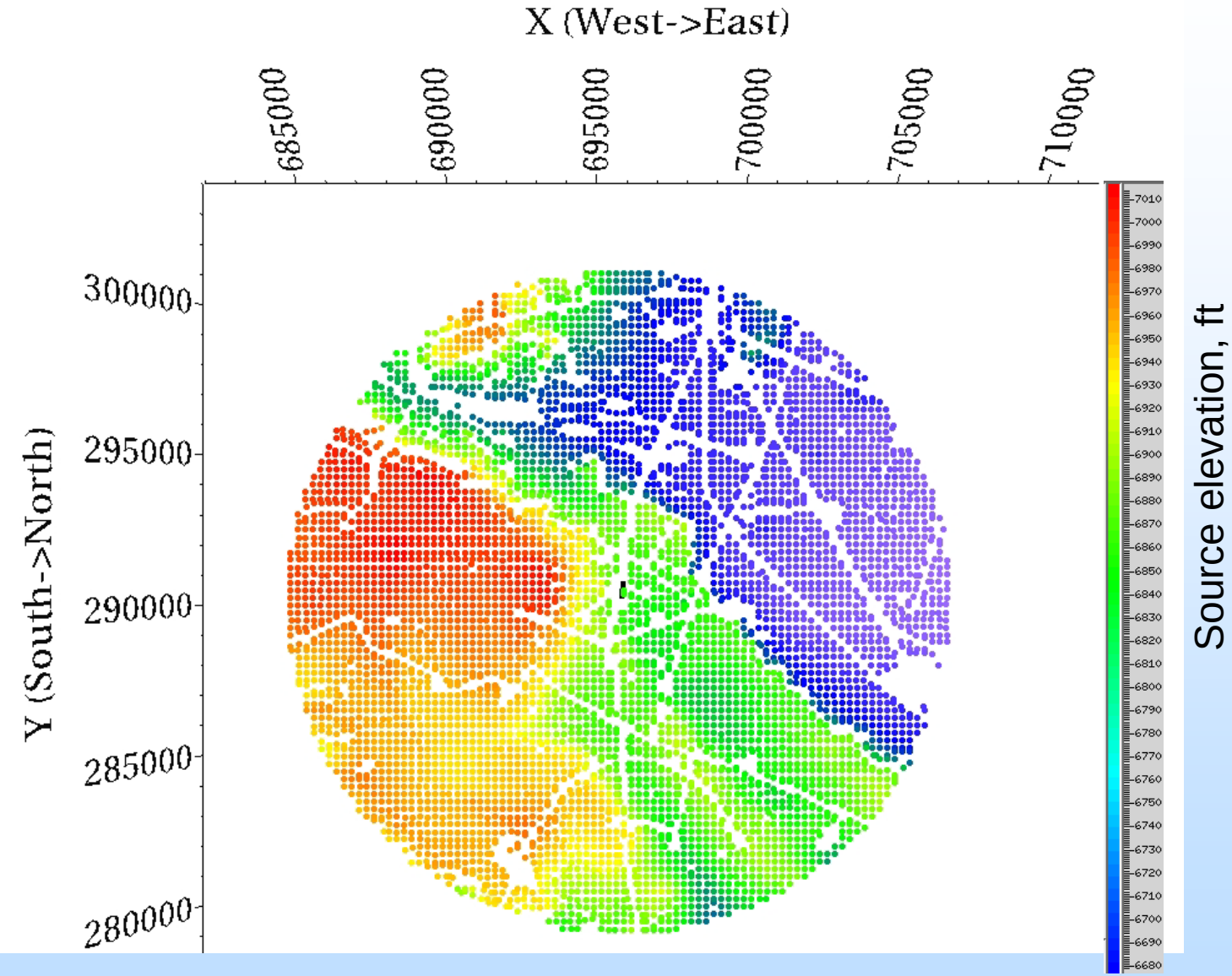


Ramkhelawan et al., 2008

Acquisition of a 160 level 3D VSP for BP in Wy

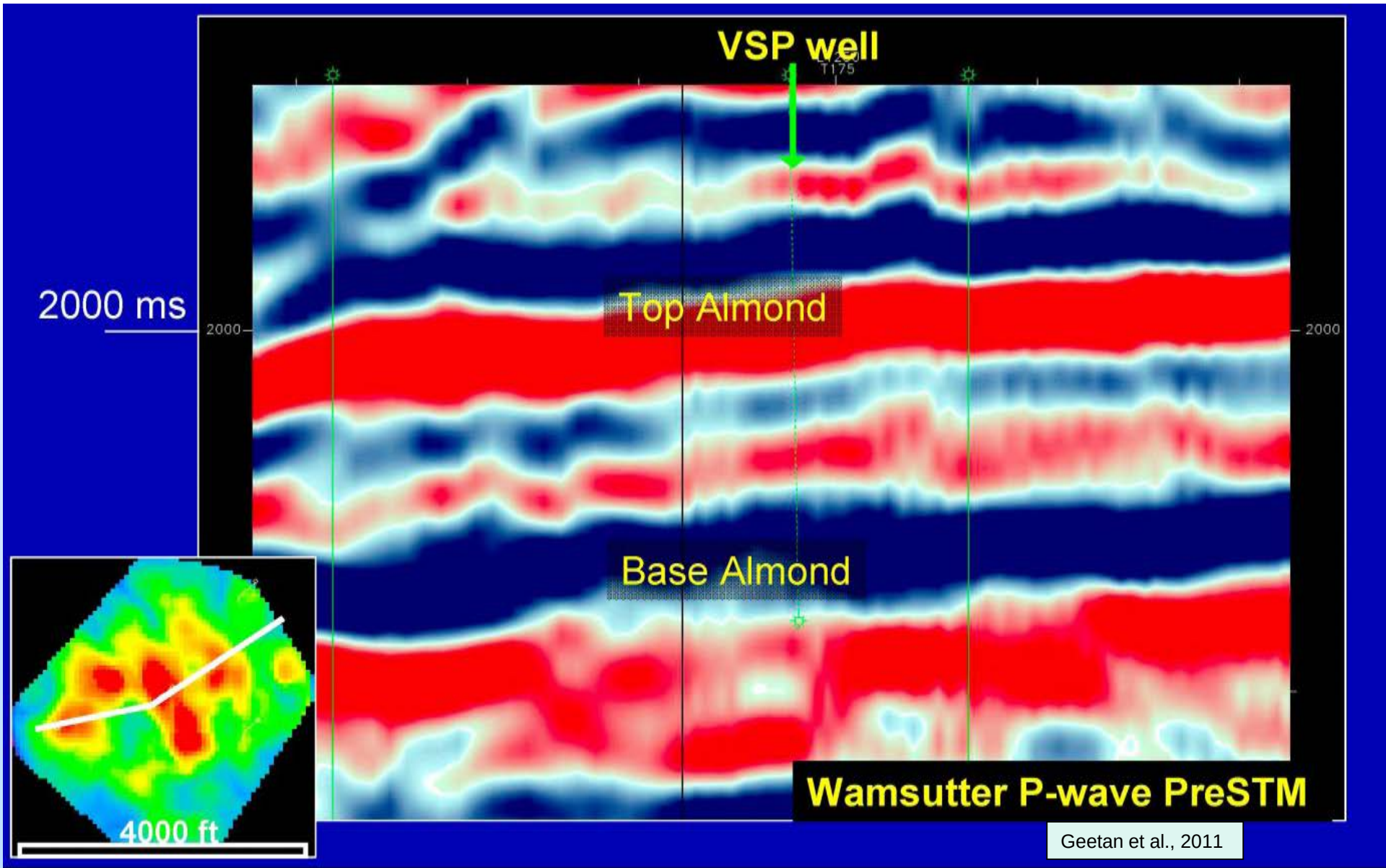


3D VSP, 6000 source pts, 160 levels 2,500 – 10,500 ft: 8,000 ft



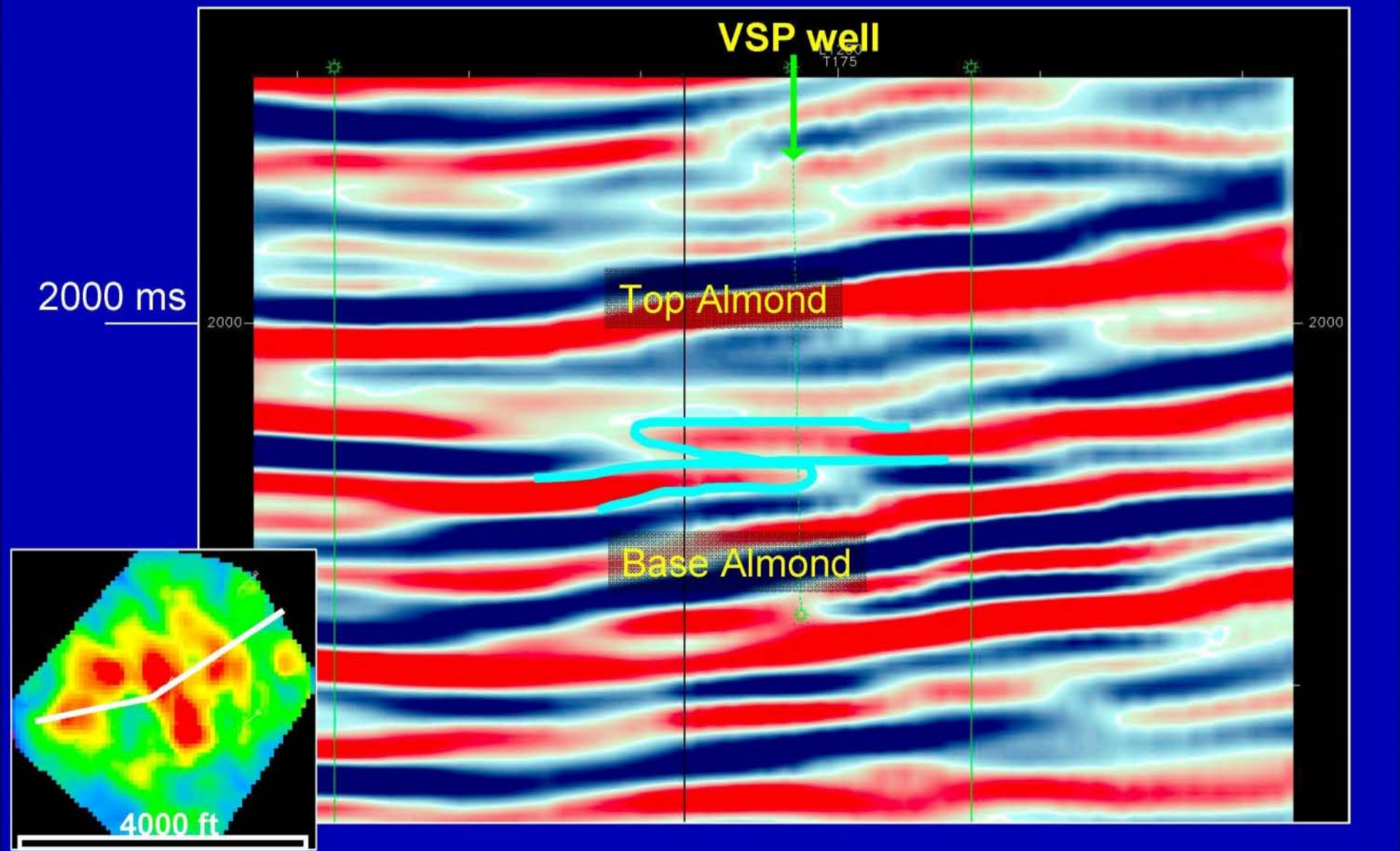
Ramkhelawan et al., 2008

A 3D Surface Seismic Image



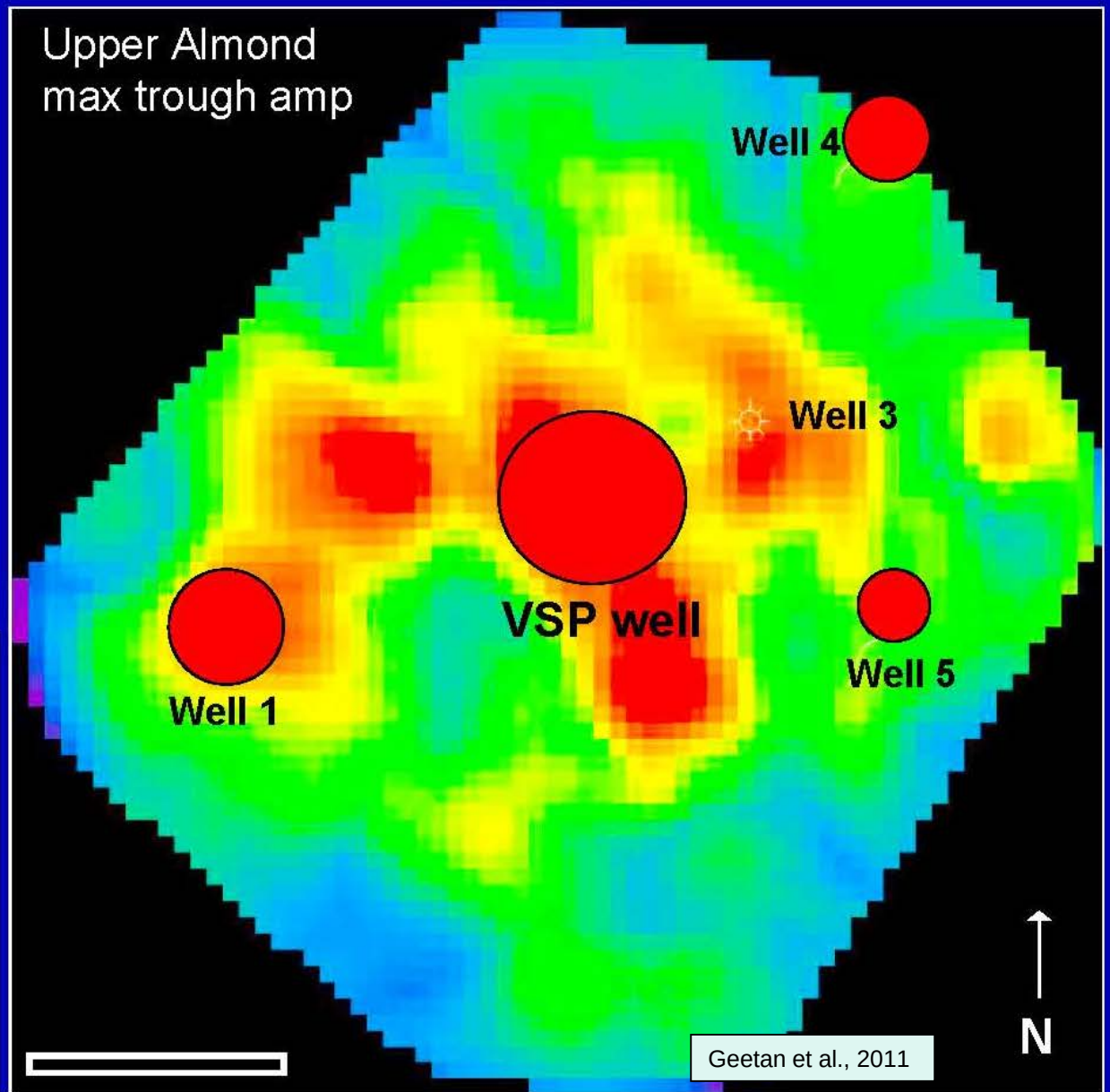
Geetan et al., 2011

A 3D Borehole Seismic Image
160 x 3C levels = 8,000 ft long



Almond reservoir 3D VSP and Production overlay

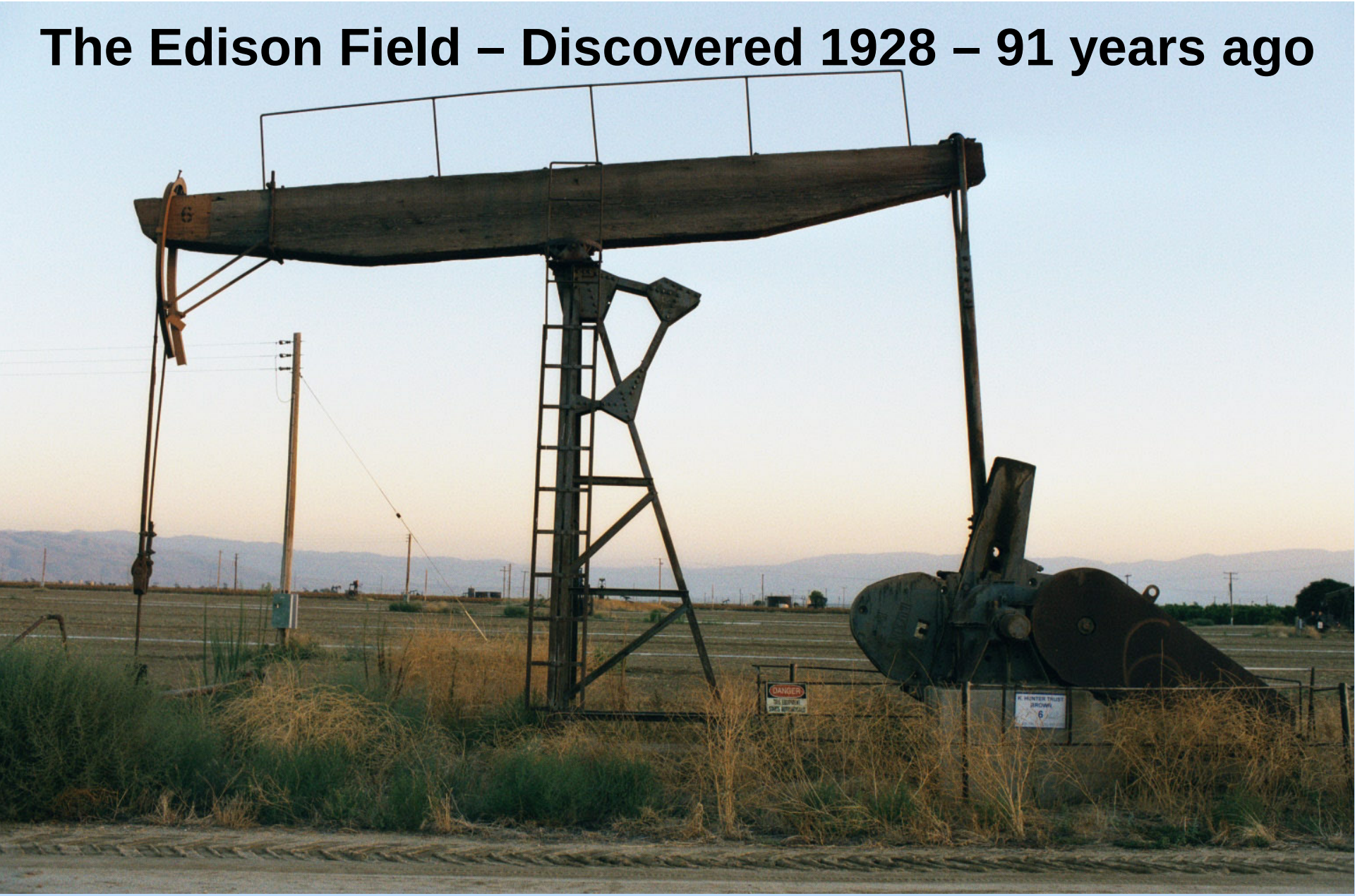
Areas of Large Gas Concentrations Mapped with 3D VSP technology. Not seen of Surface Seismic.



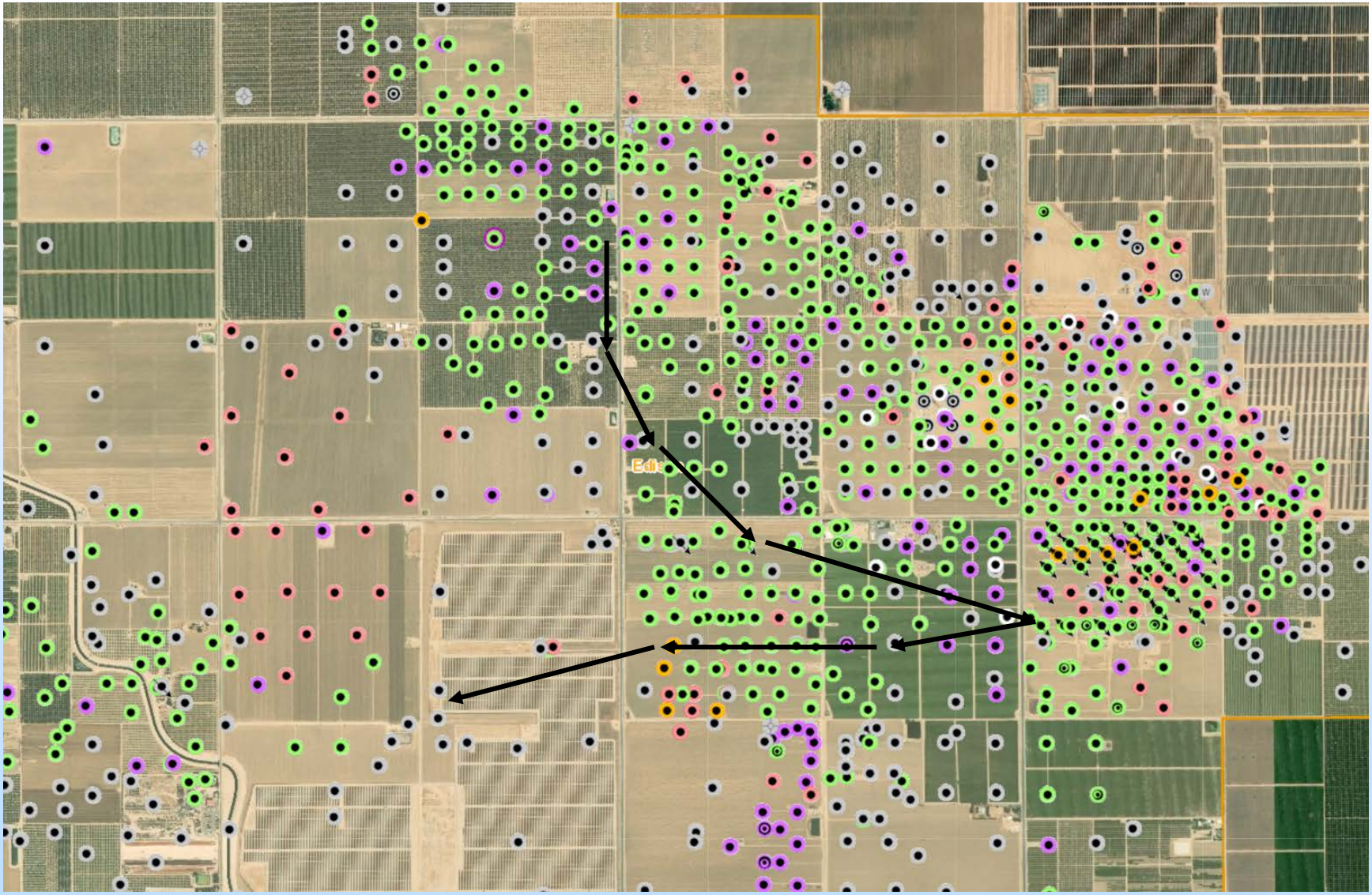
Geetan et al., 2011

2nd: Imaging an Old Oil Field in San Joaquin Valley, California using 3D Surface & Borehole Seismic Technology

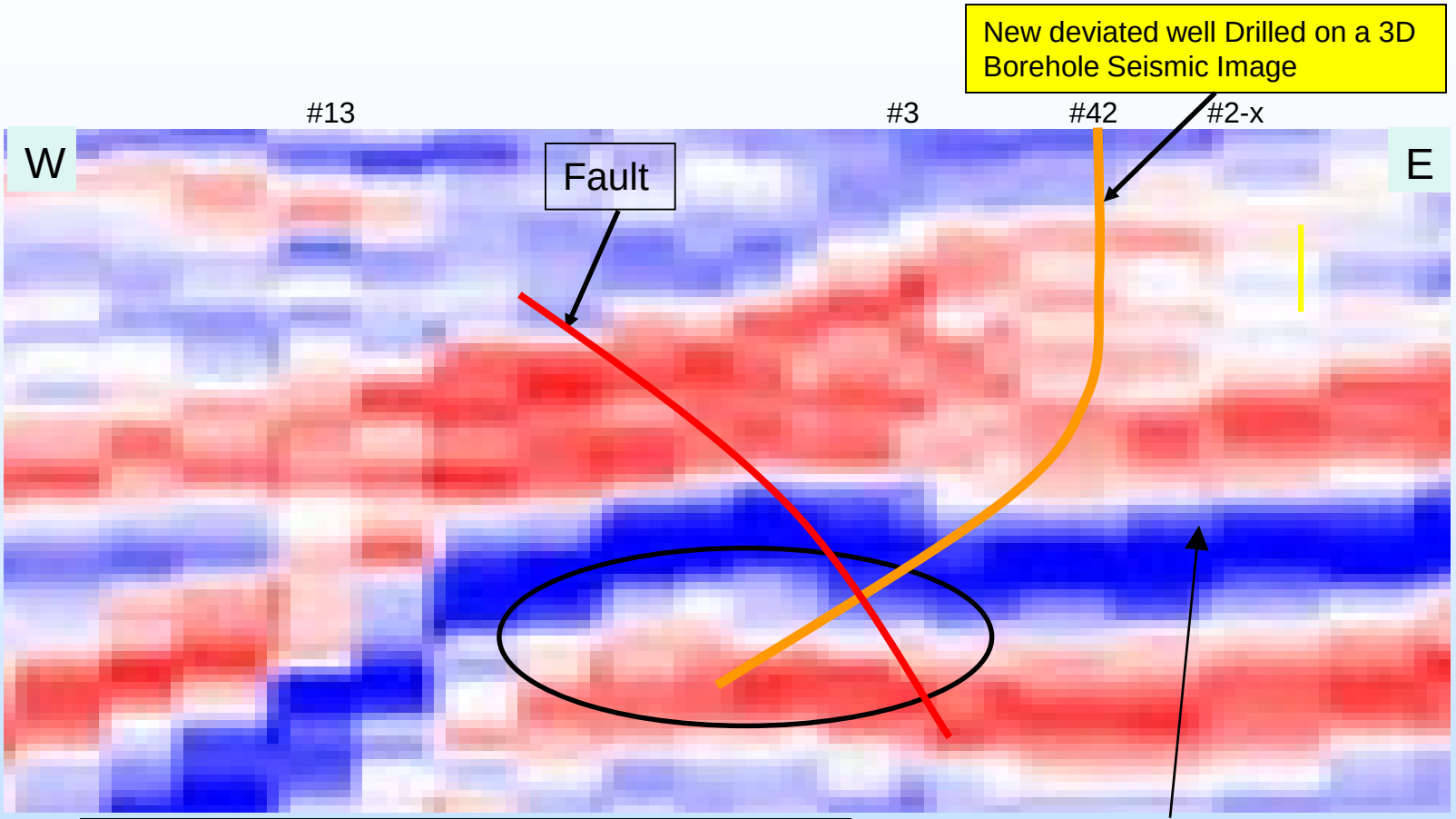
The Edison Field – Discovered 1928 – 91 years ago



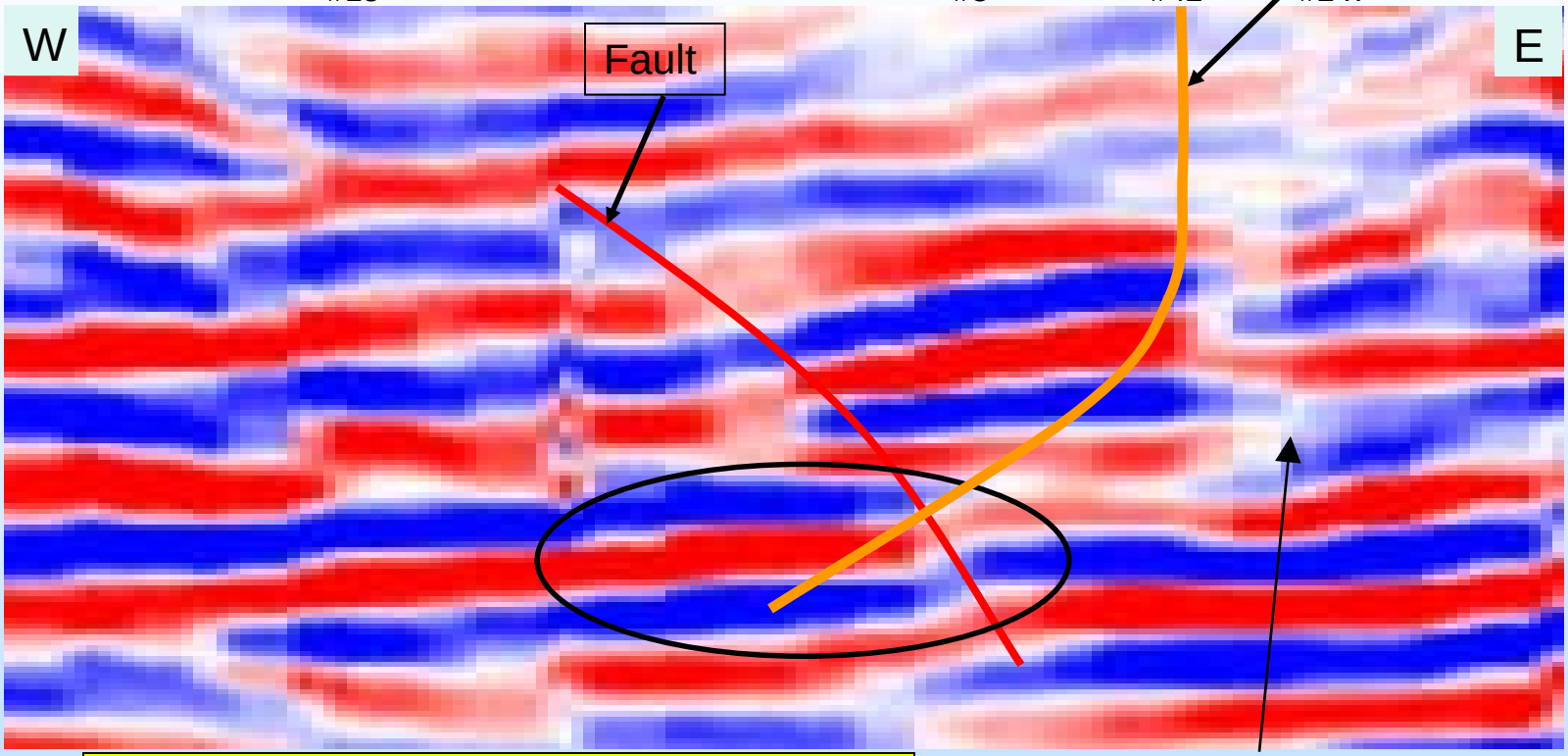
Wells Drilled in One Part of The Edison Field



3D Surface Seismic Technology (SST)



3D Borehole Seismic Technology (BoST)



Drilling result: The new well encountered 300 ft of oil and became the biggest producer in the field

Oil Sands in DS #2-X well doesn't make it over to the DS #3 well.

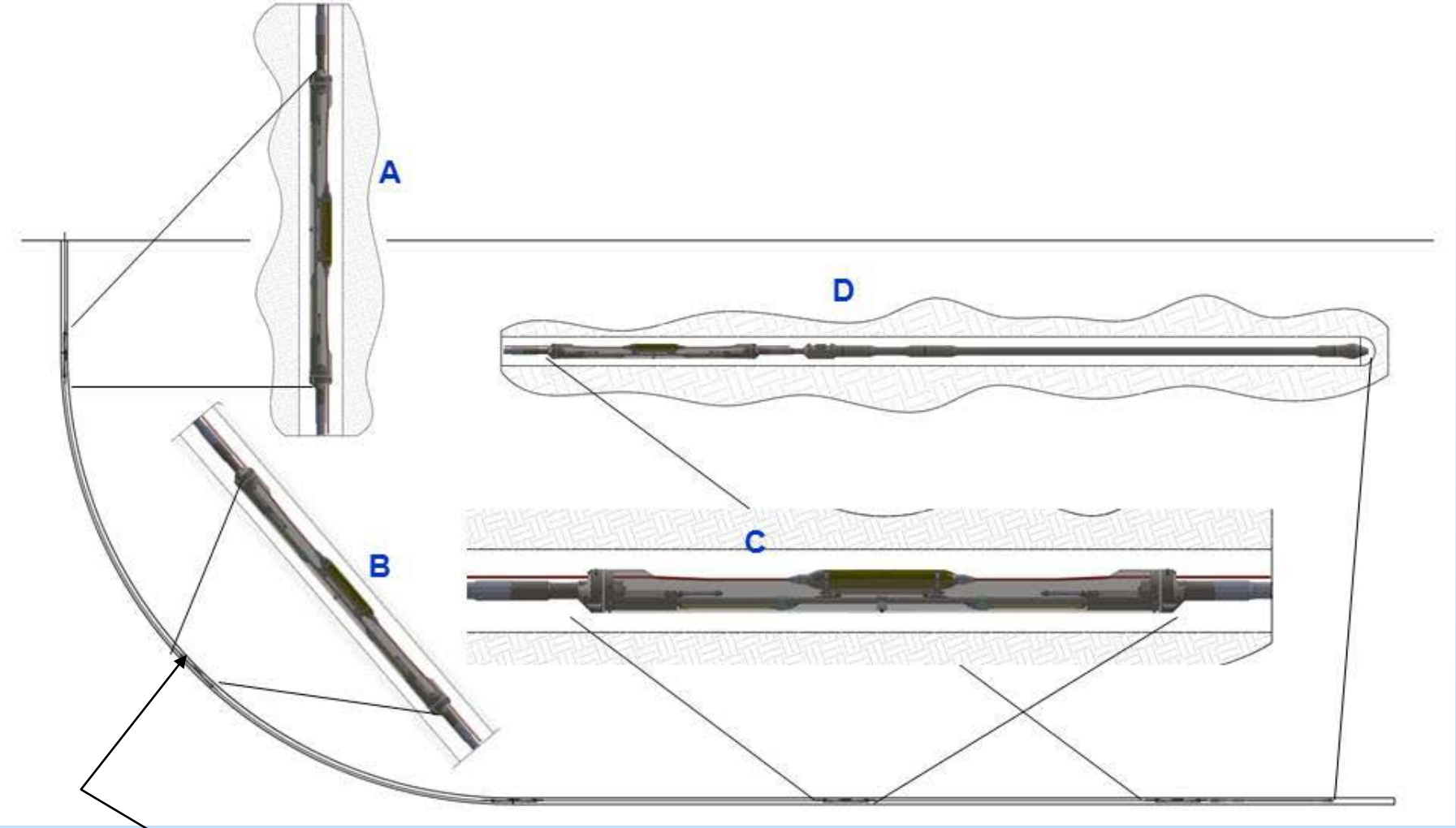
3rd: Monitor CO2 using Borehole Seismic Technology (BoST)

FOSVS Field System

Funded under

DE-FE00024360

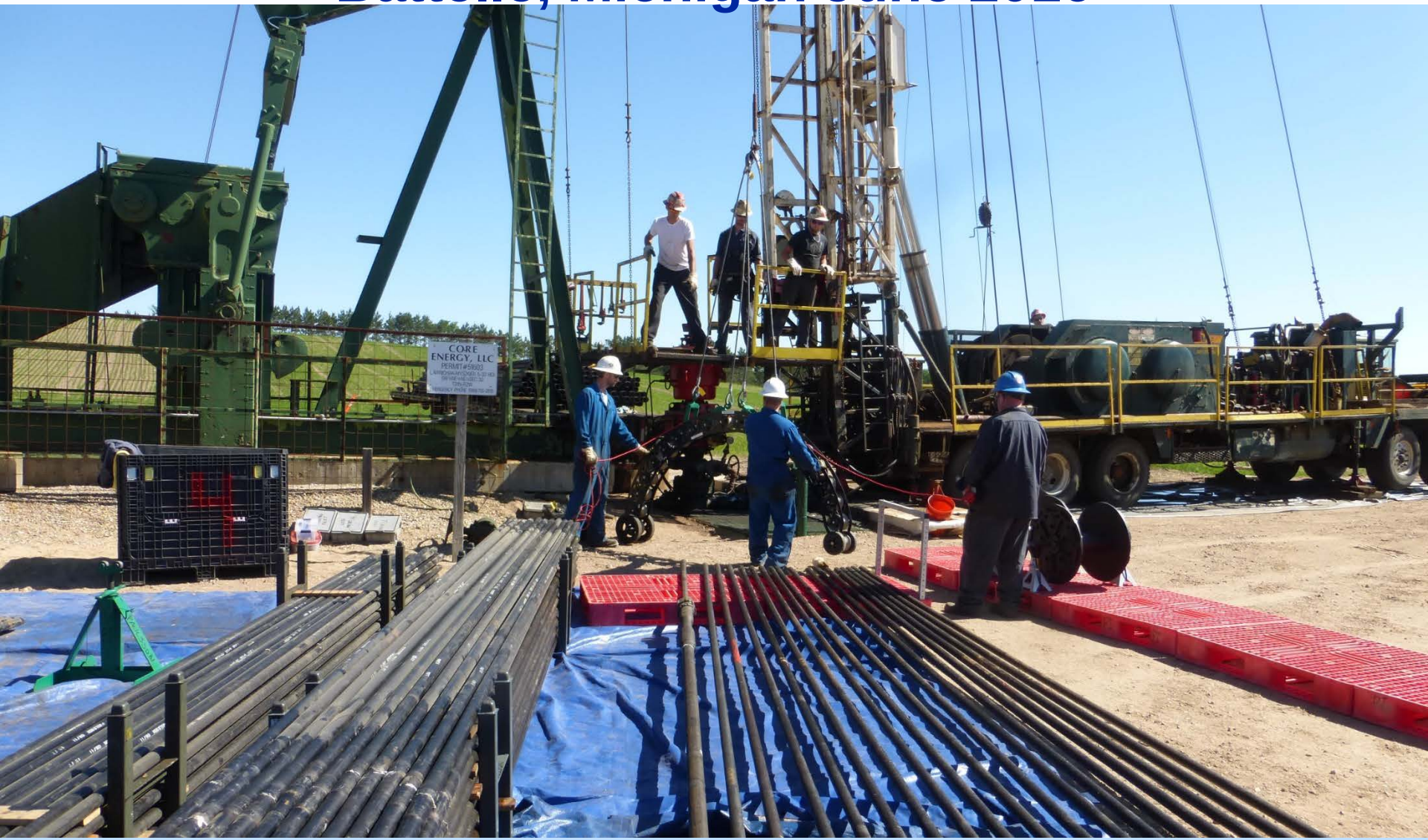
Drill Pipe Deployed System – Housing and Clamping



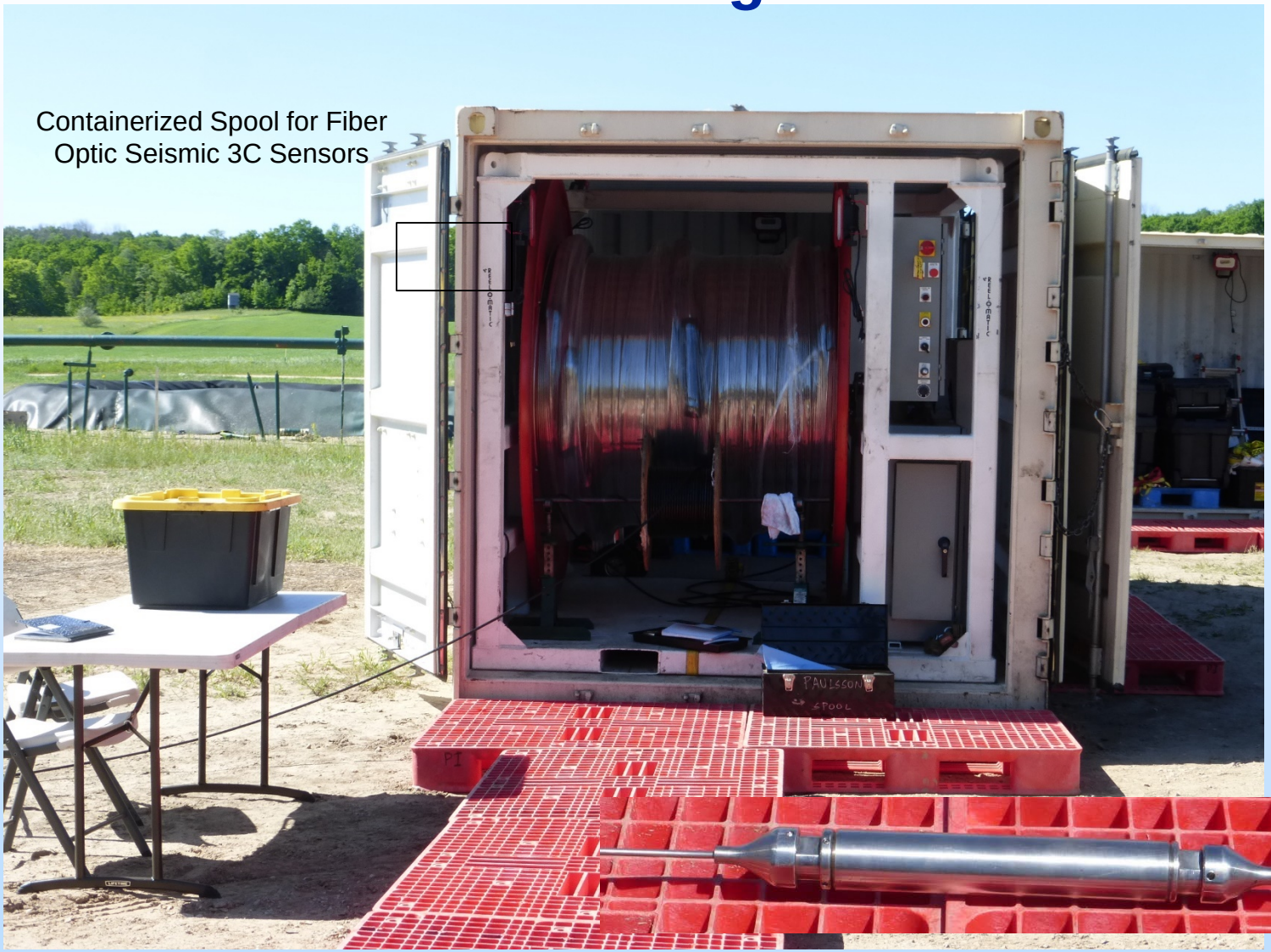
Clamping system operates by increasing the pressure inside the drill pipe and manifolds using the borehole fluid as the pressurized medium

Fiber Optic Seismic Sensor System Deployment
Battelle, Michigan June 2016

Fiber Optic Seismic Sensor System Deployment
Battelle, Michigan June 2016

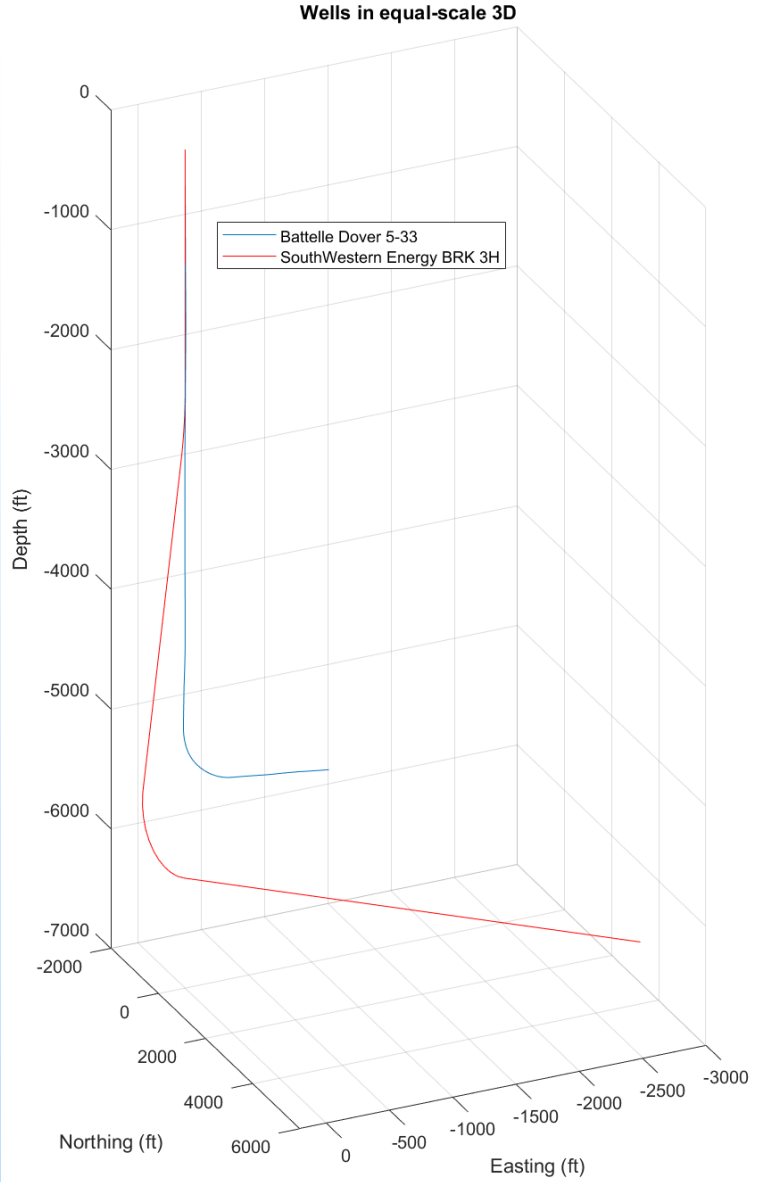


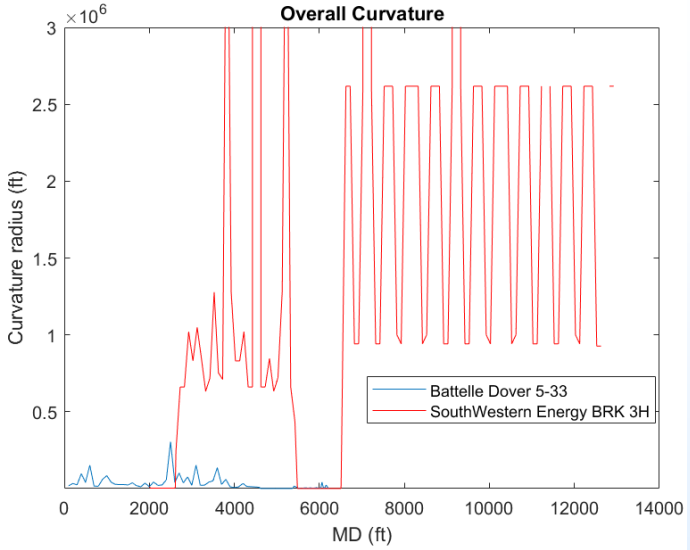
Fiber Optic Seismic Sensor System Deployment for Battelle in Michigan June 2016

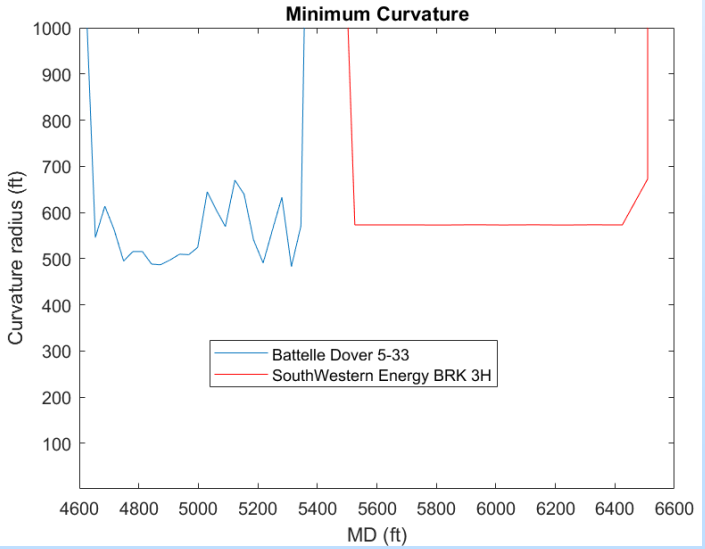


Fiber Optic Seismic 3C Sensor Pod

Deploying the FOSVS System into Horizontal Wells





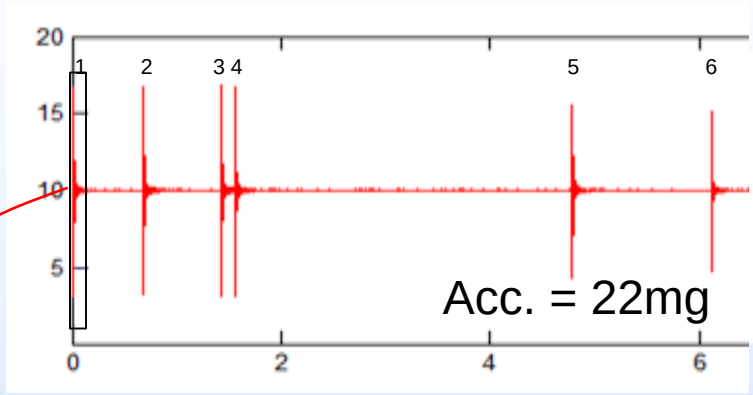


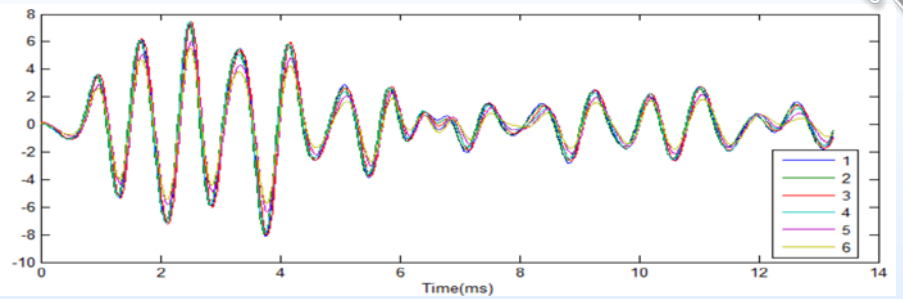
Fiber Optic Seismic Vector Sensors

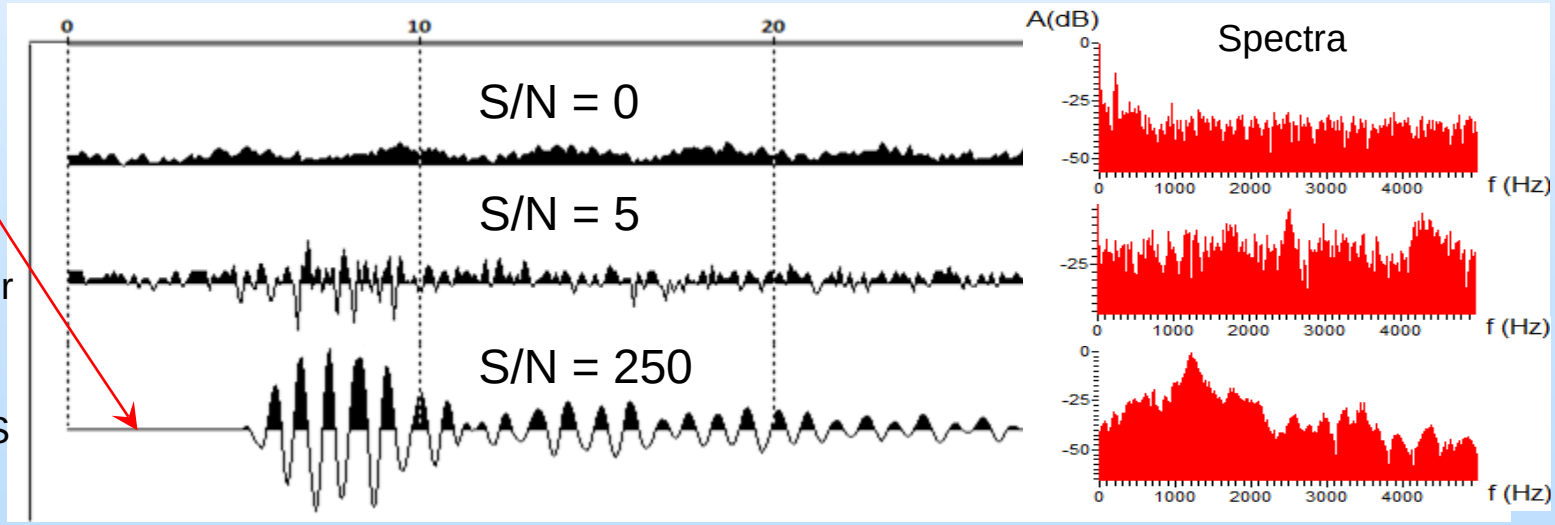
Test of Fiber Optic Seismic Vector Sensors (FOSVS) & AME

Fiber sensor, geophone and accelerometer are placed approximately 20 cm (8 inches) from the pressure vessel with AMEs

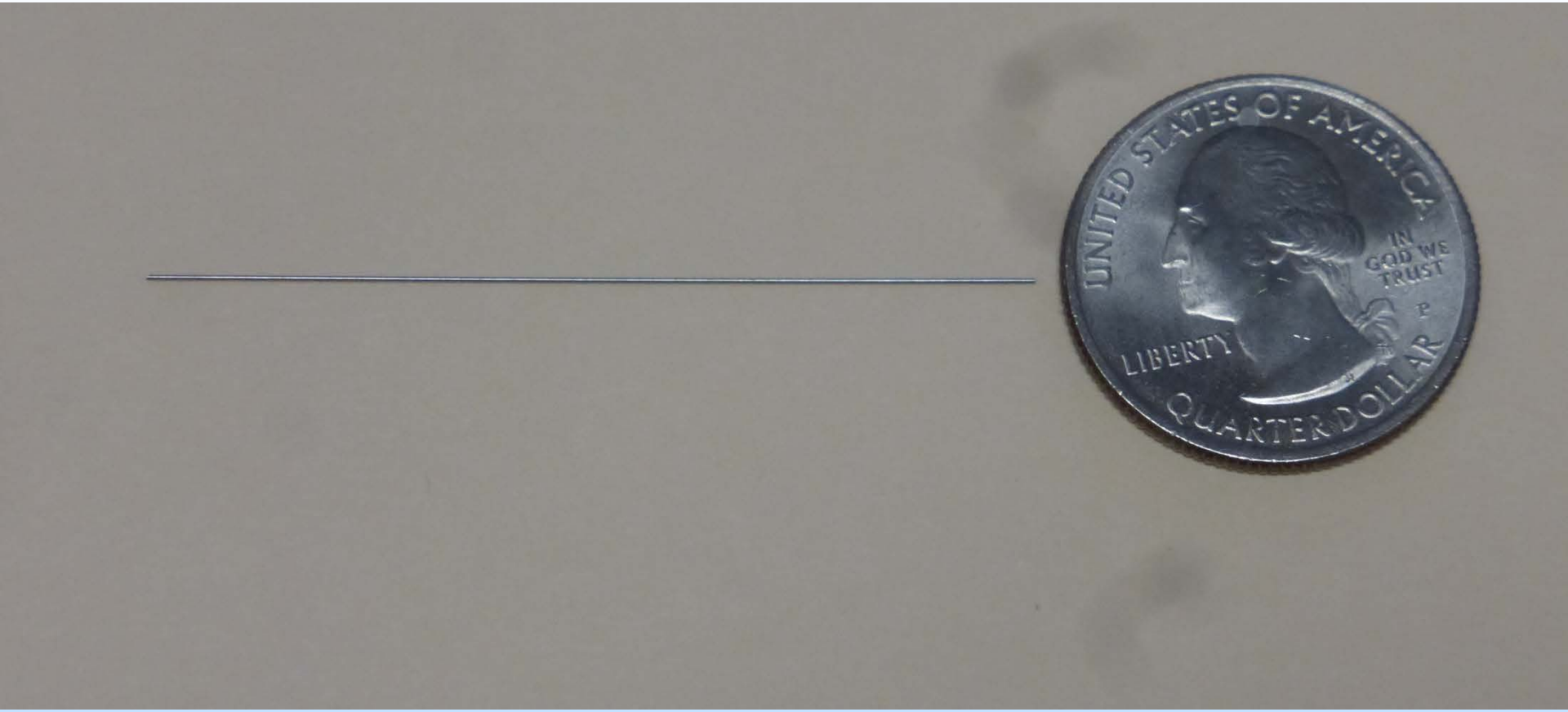
Repeatability Test: 6 AME's recorded on FOSVS: Outstanding Repeatability.
Allow extraction of arrivals in high noise environment. AME Energy Released: ~0.1 J = M-3.5





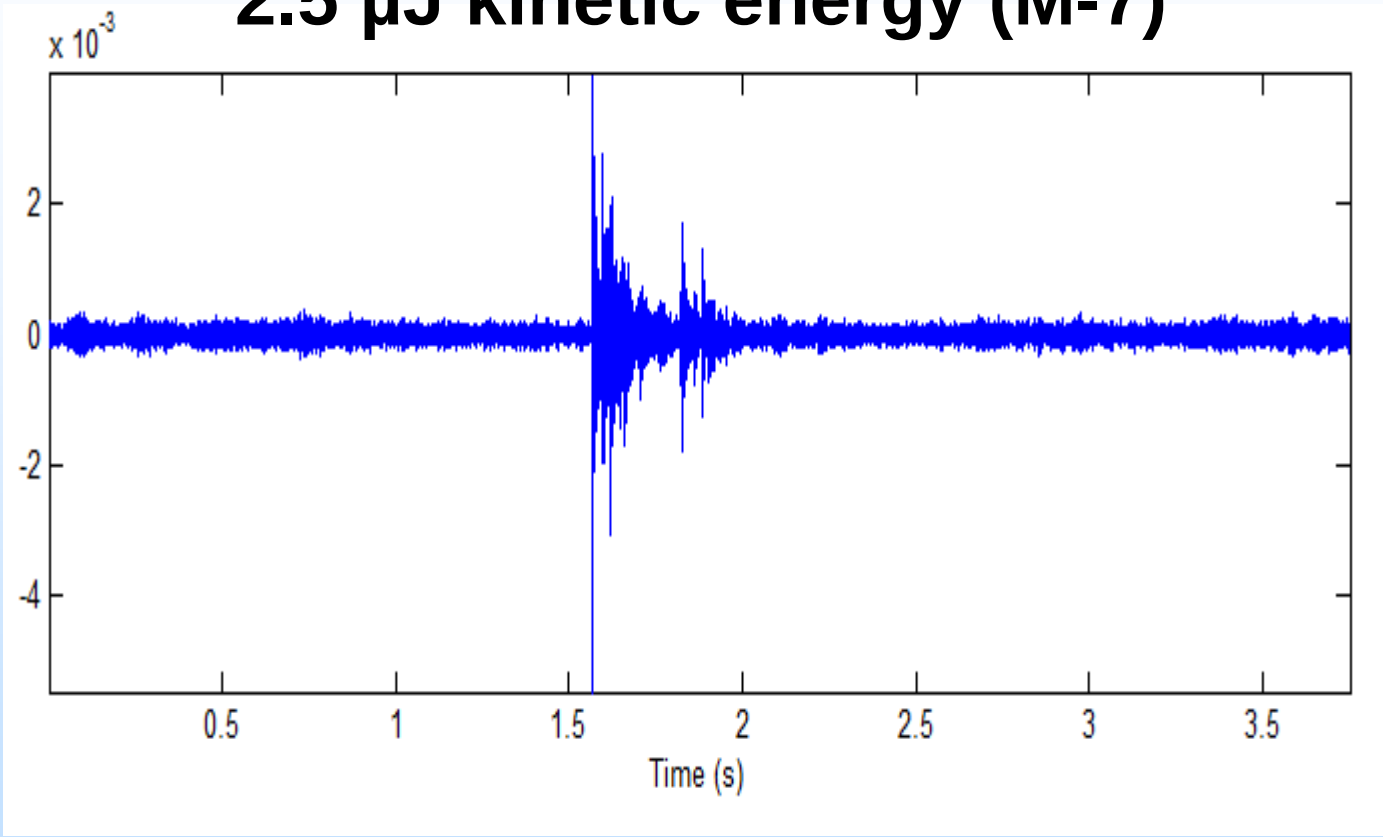


Can You Hear a Pin Drop?
Test Object: OD: 0.011”, 2” long, 24.8 mg



FOSVS Test: OD: 0.011”, 24.8 mg Pin Drop 1 cm:

2.5 µJ kinetic energy (M-7)



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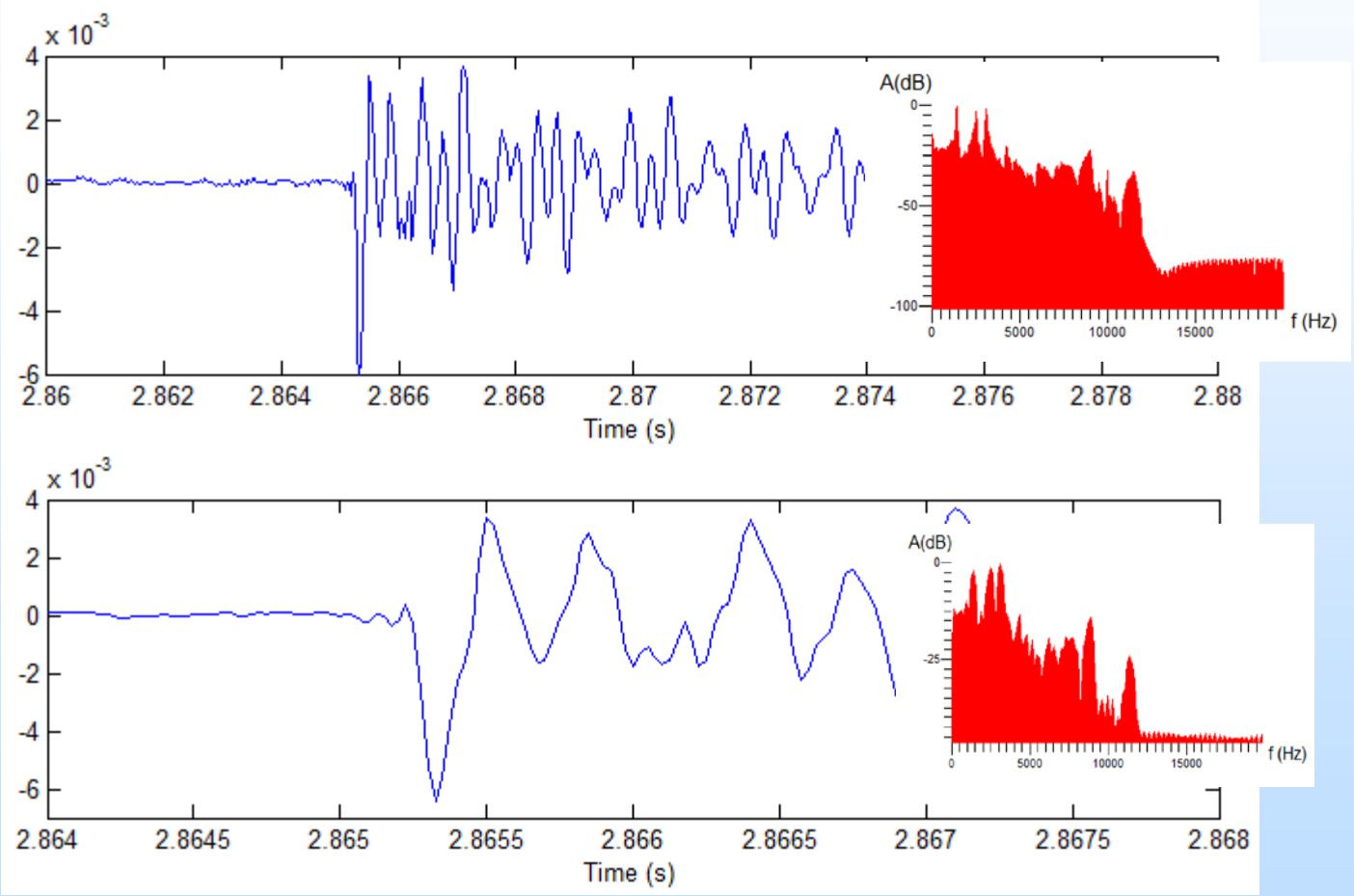
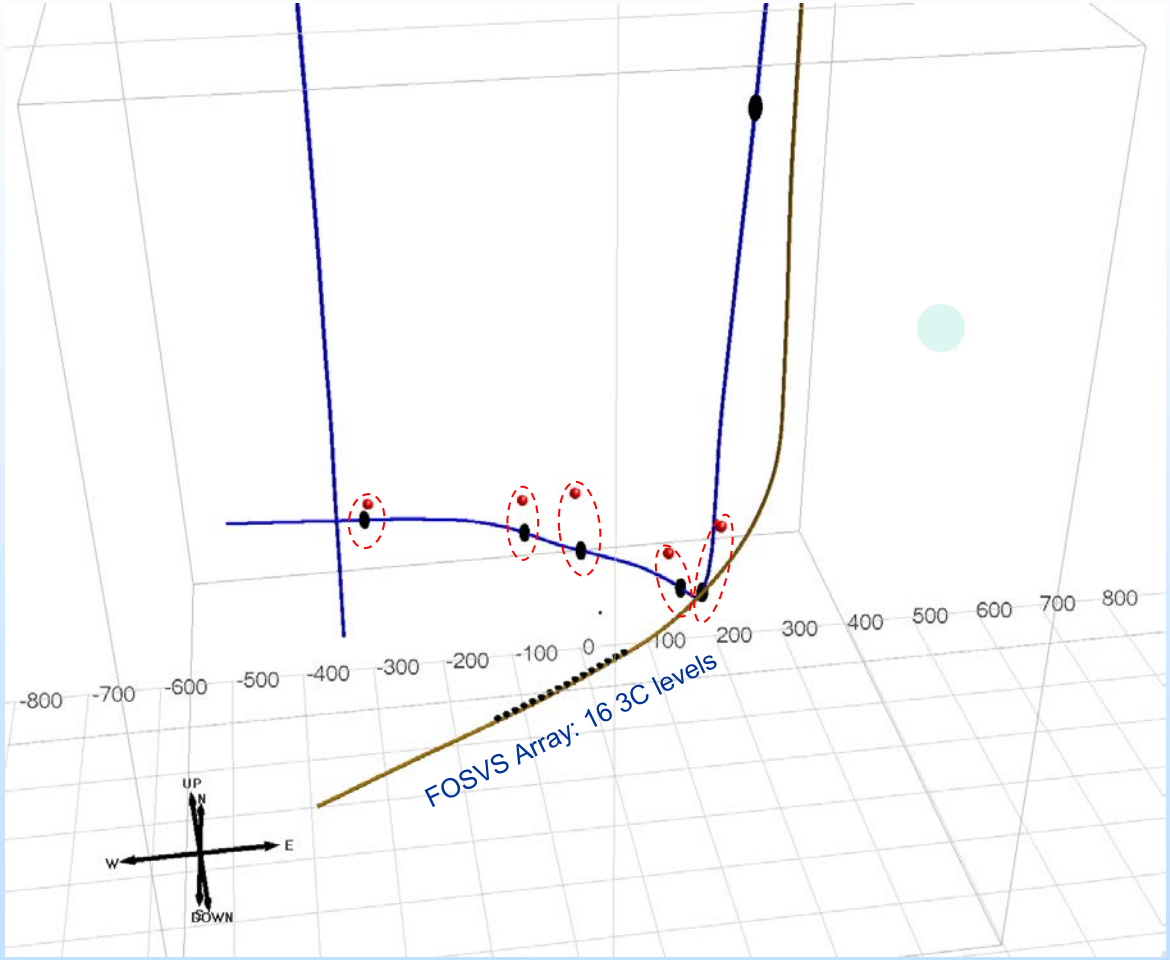


Field Test Data Recorded with Fiber Optic Seismic Vector Sensor (FOSVS)™ System

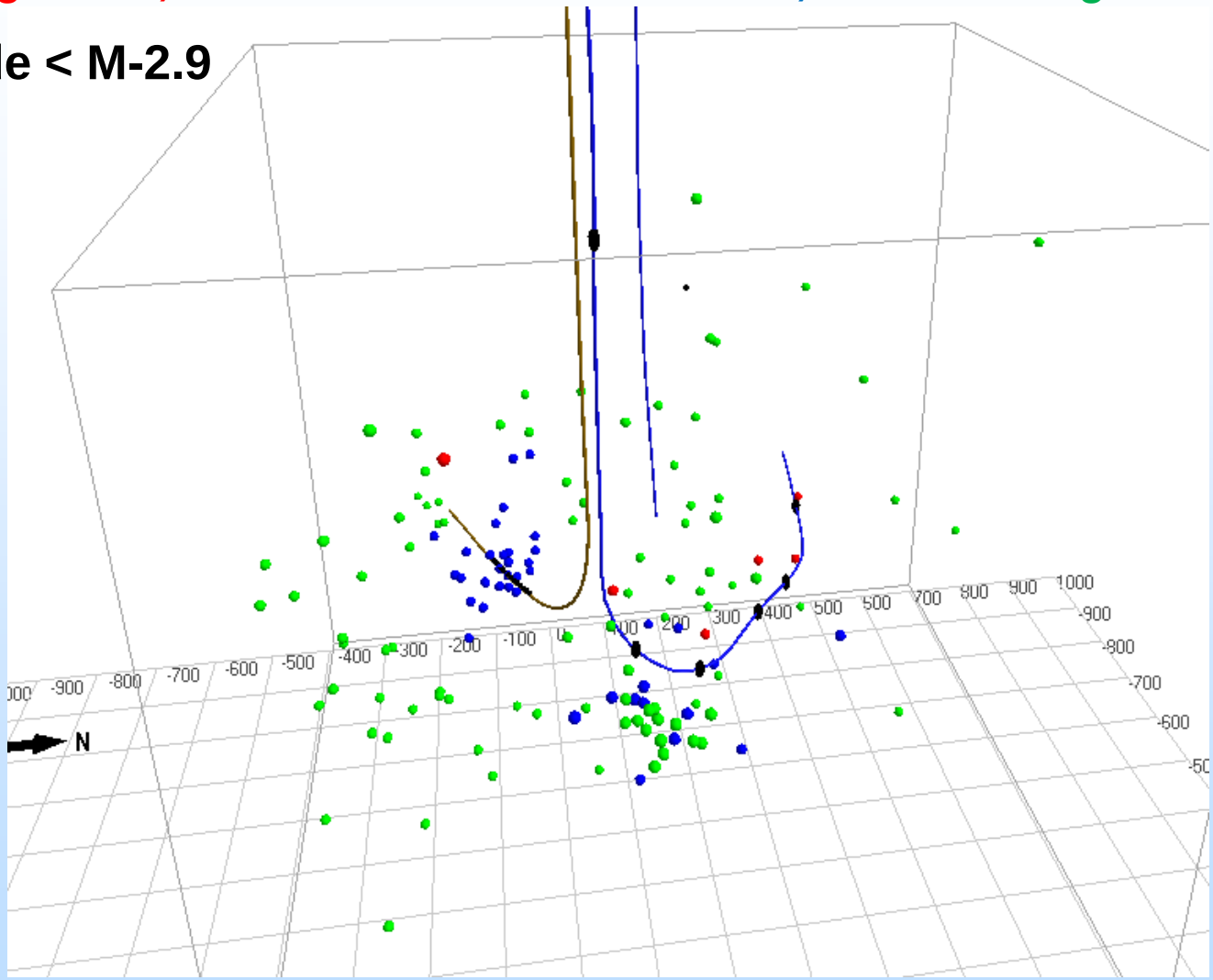
Results from Locating 0.5 gram String Shots During a Survey Recorded for Battelle in June 2016



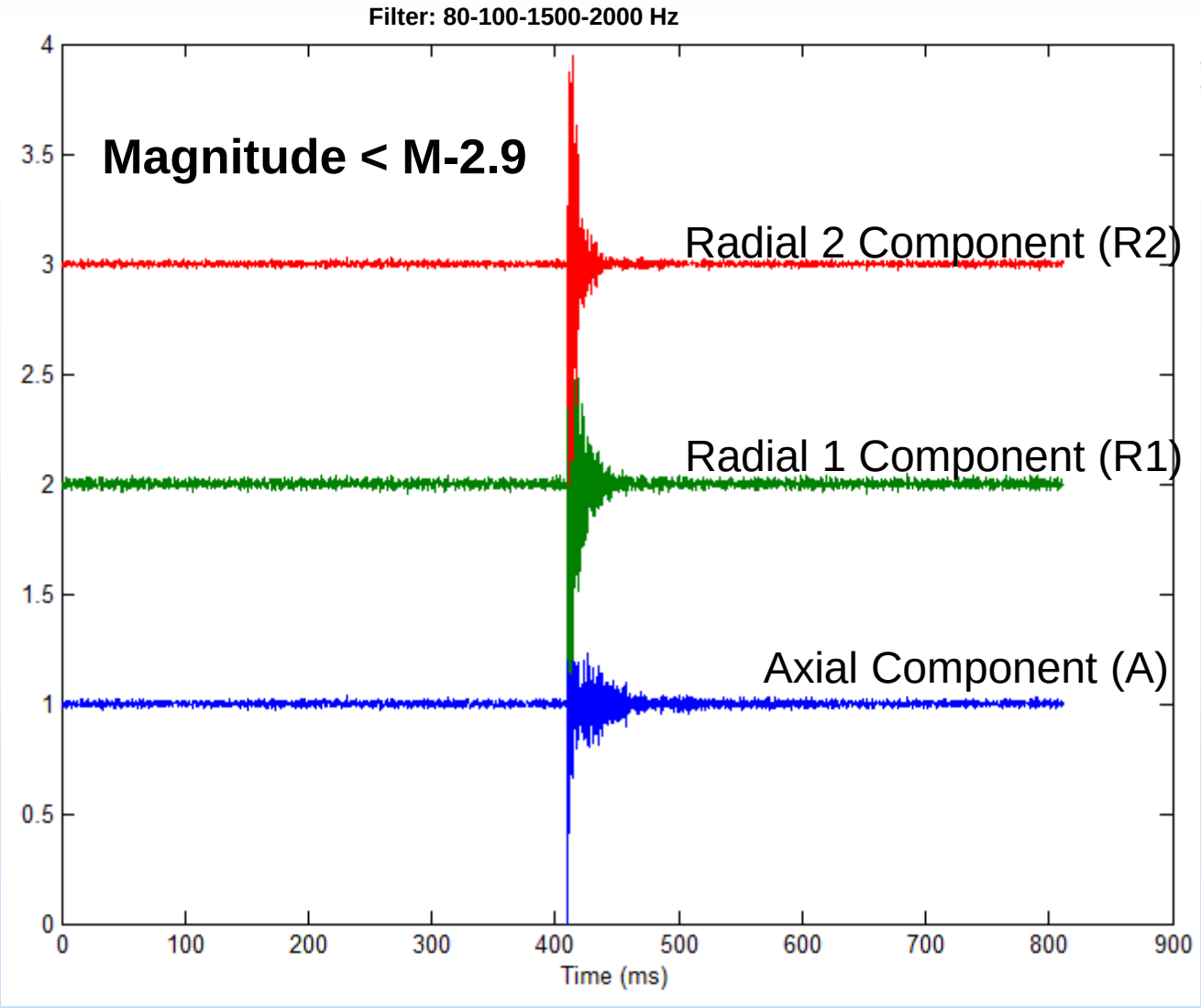
Survey for Battelle - Locating String Shots and Micro Seismic Events
Recorded >20,000 events in four weeks. Displayed here are 130 events.

Red: String Shots; Blue: Focused Micro Seismic; Green: "Long Period" Events

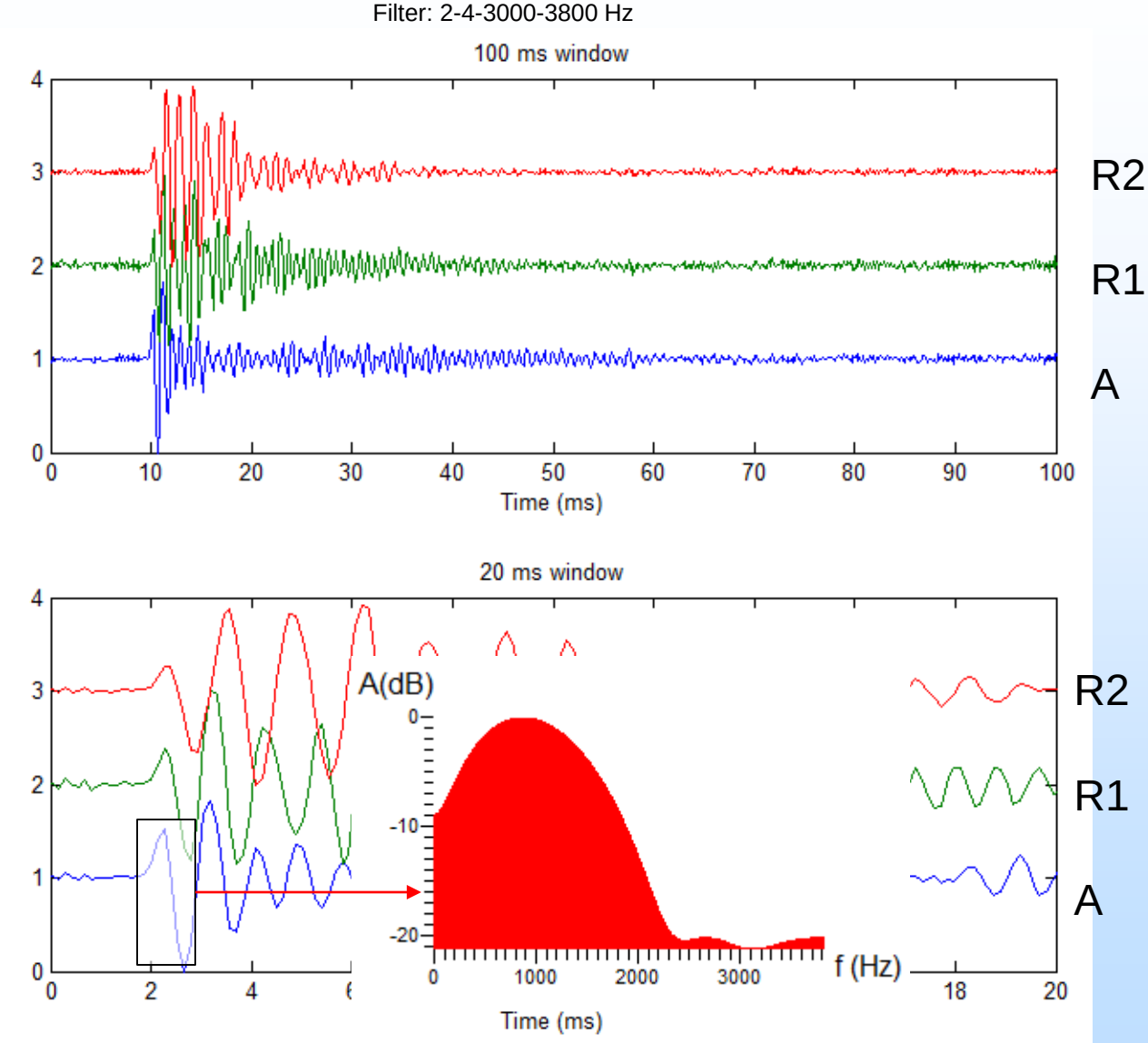
Magnitude < M-2.9



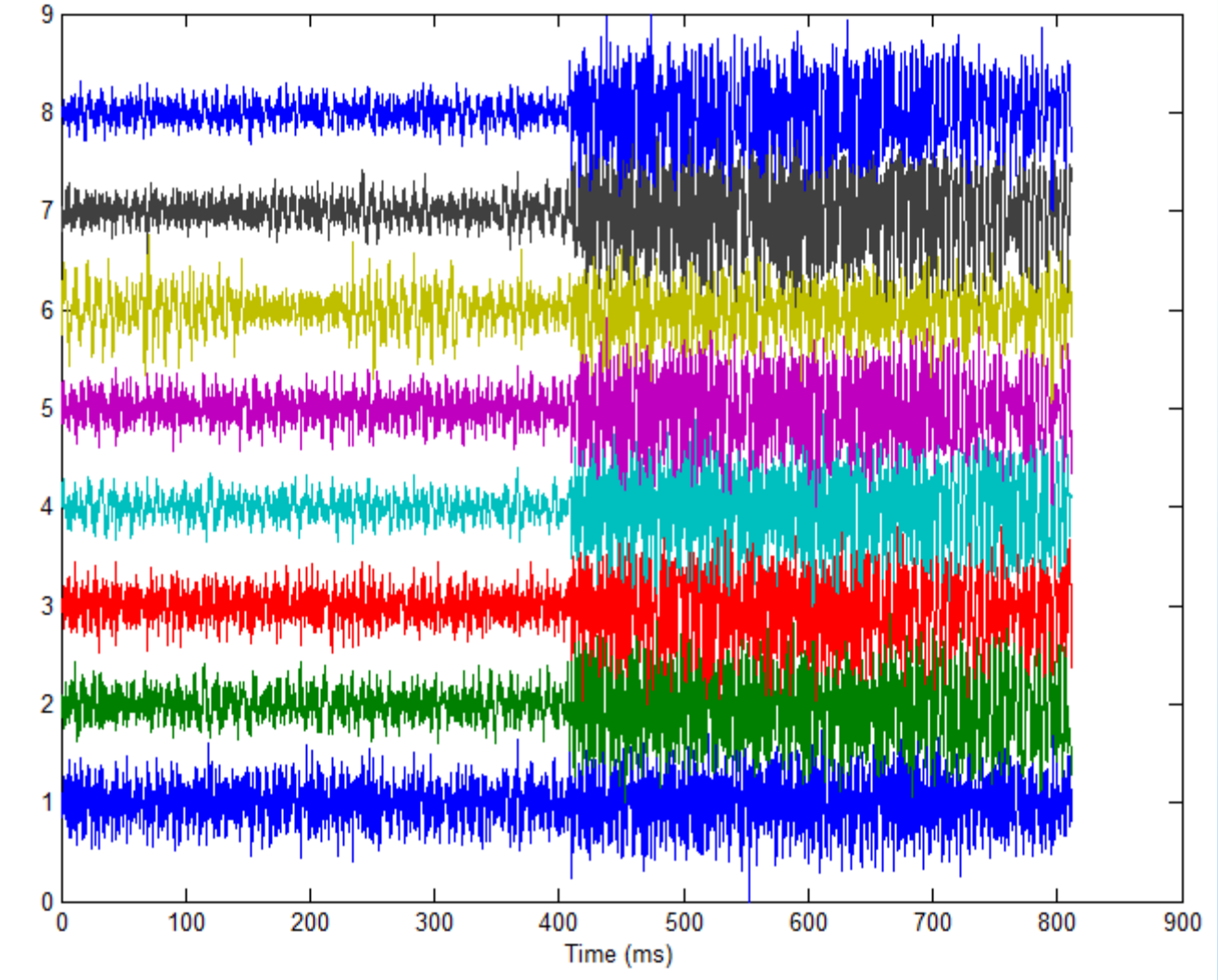
Sound of A Focused MS in 3C, Survey for Battelle, June 2016



Zoomed-In Focused MS in 3C- Filter: 2-4-3000-3800 Hz



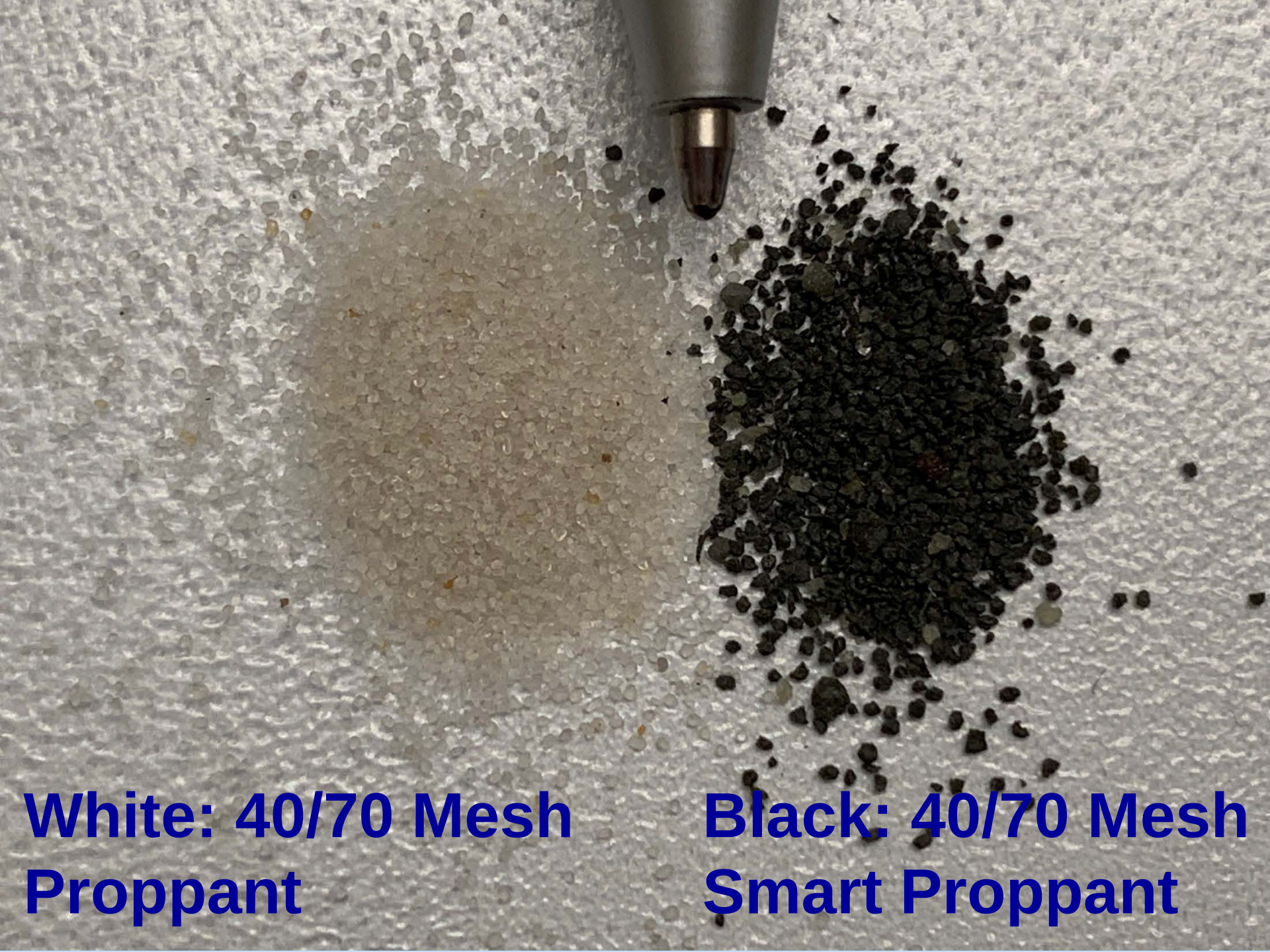
Sound of A Long Duration Event (~M-5.0) – Maybe Fluid Flow



Injectable Micro Emitters (IME)

Size: Core 60 µm: With Coating: 200 µm

Matches 40/70 proppant


White: 40/70 Mesh Proppant
Black: 40/70 Mesh Smart Proppant

Pool Test of Micro Spheres as IME

Size: 60 µm

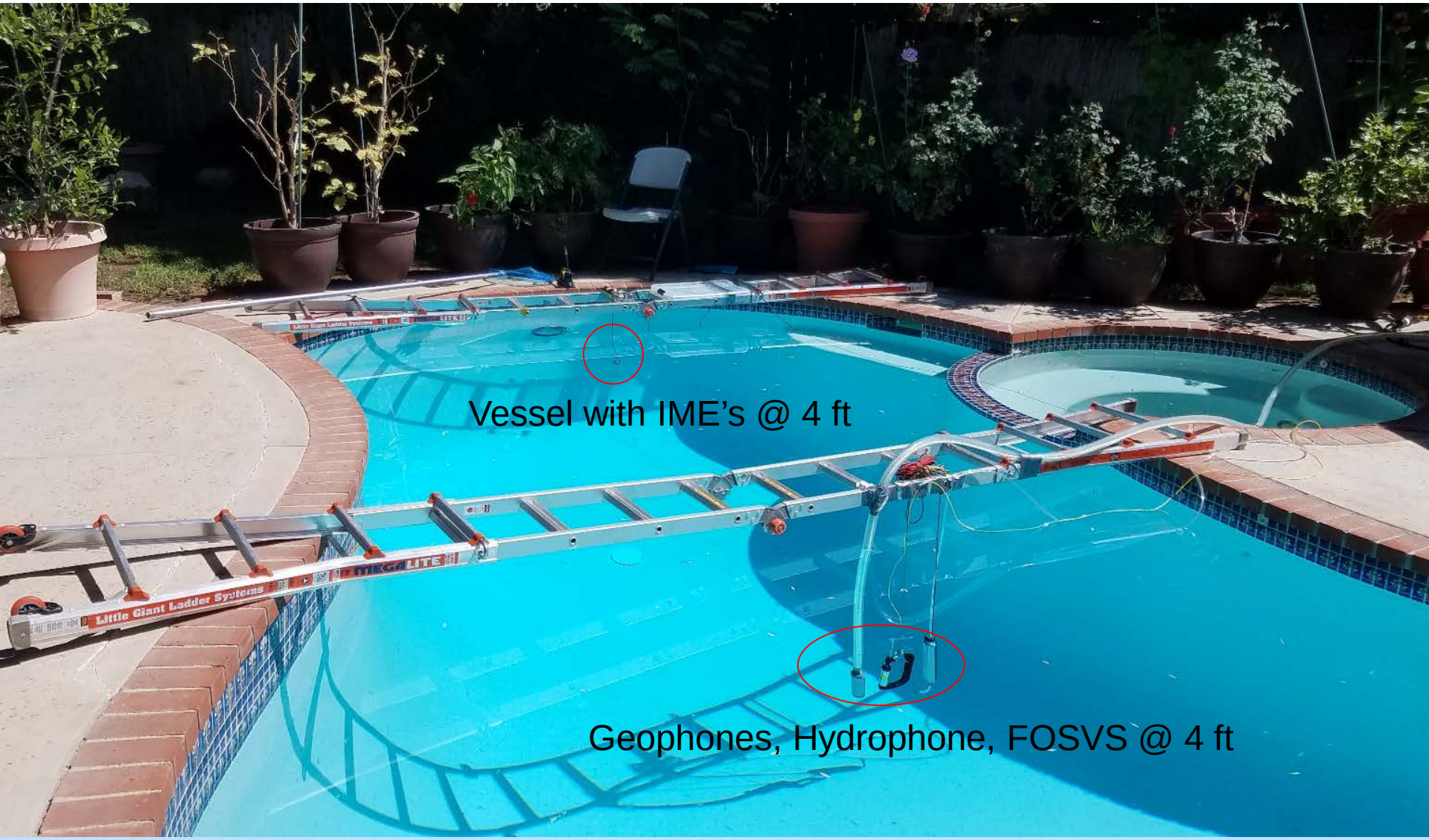
Matches 40/70 proppant

Pool Test Summary

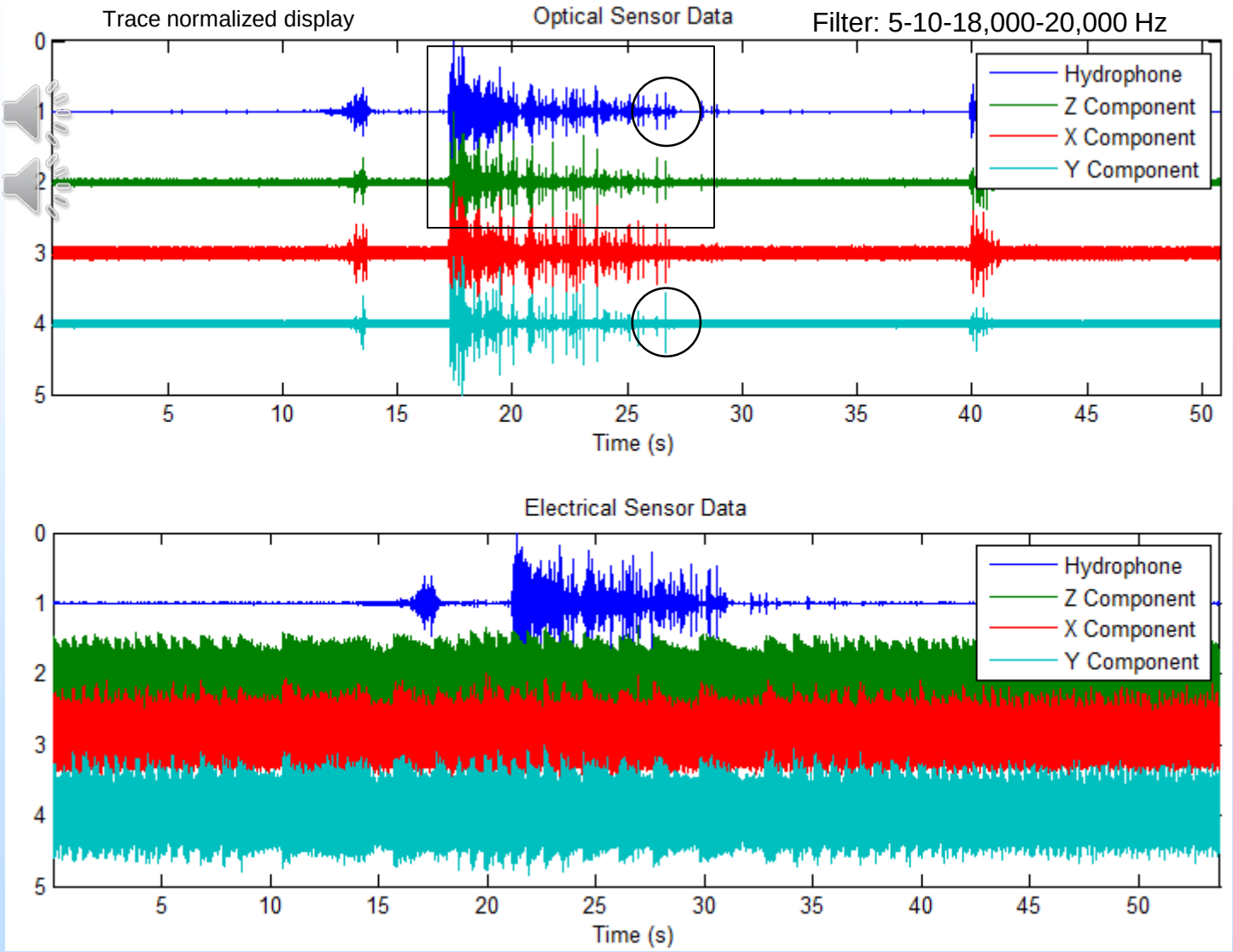
- **Location: Pool**
- **Source-Receiver Distance: 20 ft**
- **Receivers:**
  - **Optical: FOSVS and Fiber Optic Hydrophone (FOH)**
    - **Sampling rate: 150 kHz**
  - **Electrical: Geophone and Hydrophone**
    - **Geophone: Omni-2400**
    - **Hydrophone: Aquarian Scientific AS-1**
    - **Sampling rate: 40 kHz**

- **Sources:**
  - **Micro Emitters: 1 – 60 µm, Rated 2,000 psi (~ 4 grams)**
  - **Micro Emitters: 1 – 60 µm, Rated 4,000 psi (~ 4 grams)**

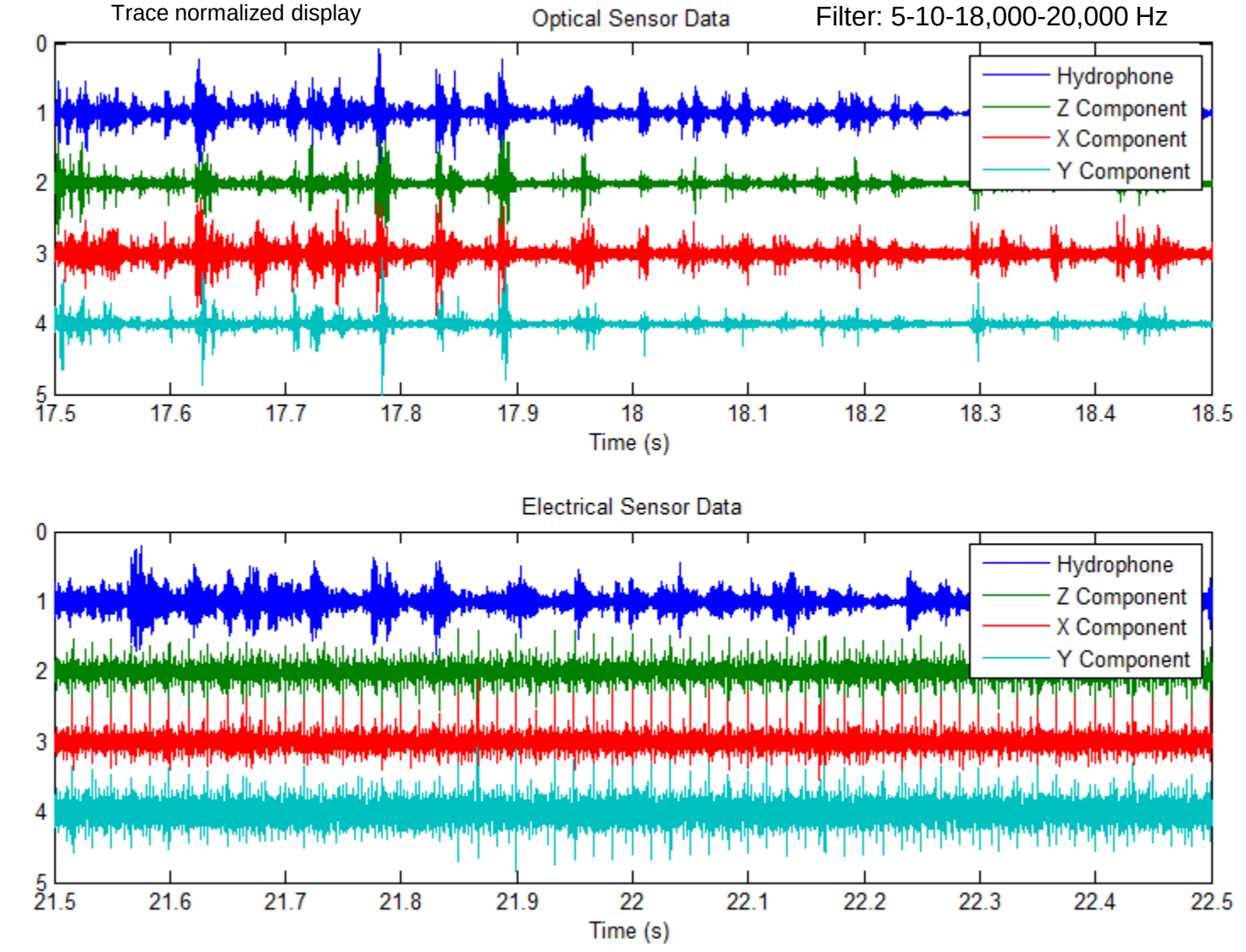
Micro Emitters Data Recorded on Several Different Sensors



Pool Test 8: ~ 4gm Micro-Sphere at 4,000 psi at 20 ft



Zoom in on Test 8: ~ 4gm Micro-Sphere at 4,000 psi



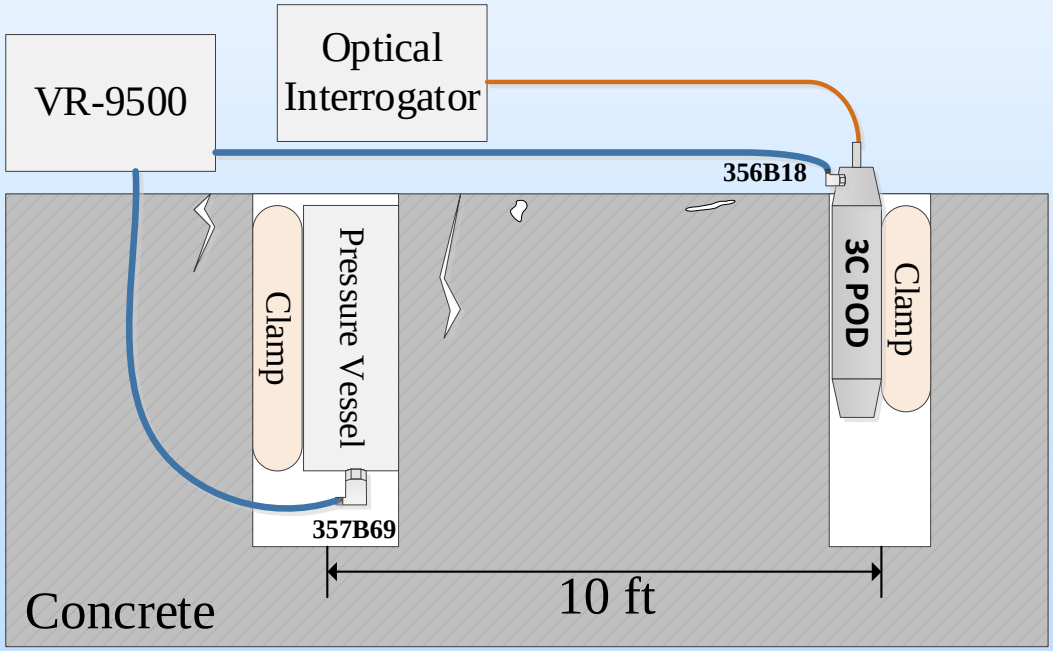
2019 Laboratory Tests of Micro Spheres as IME

Size: 60 µm

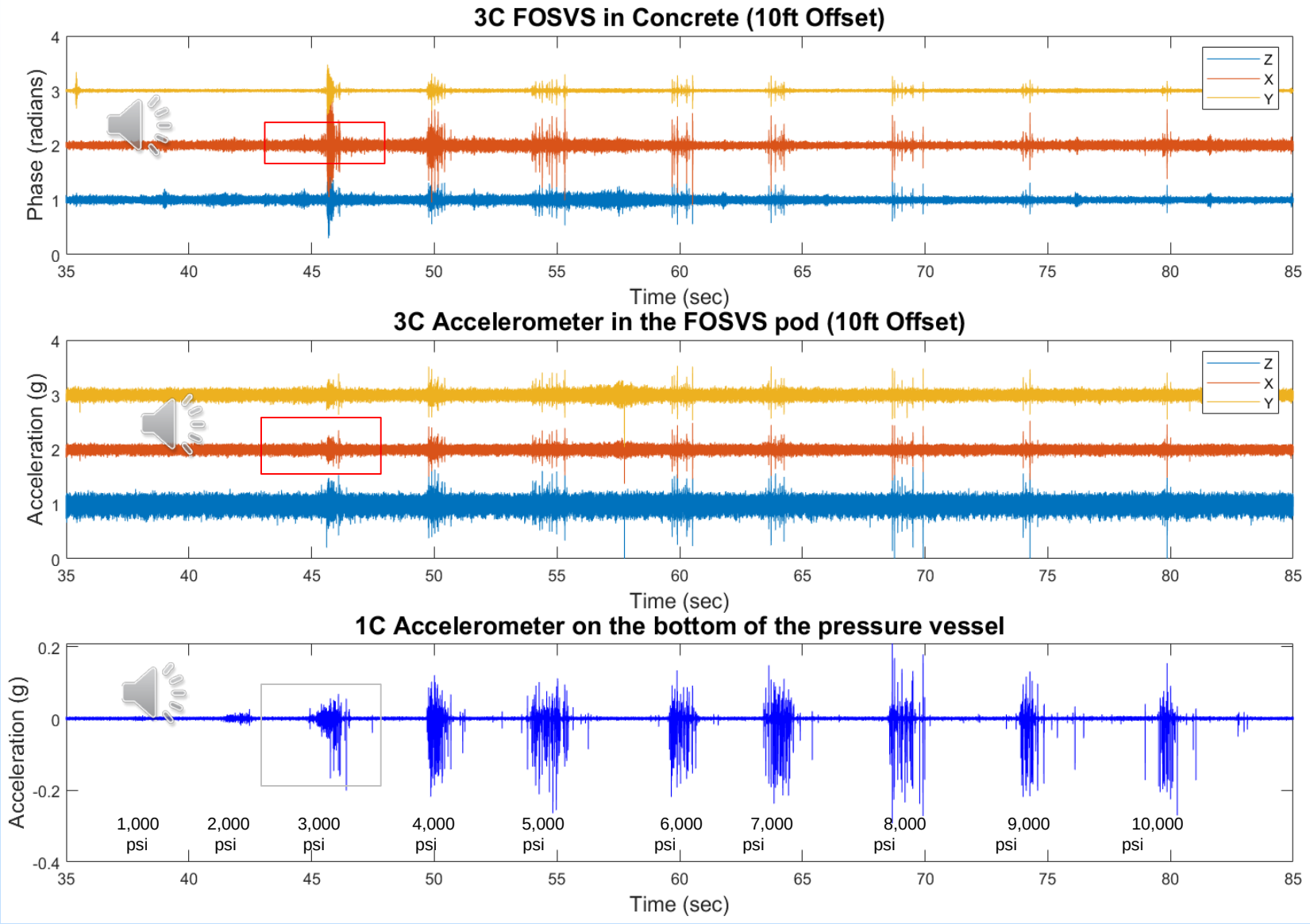
Matches 40/70 proppant

Lab Test Setup

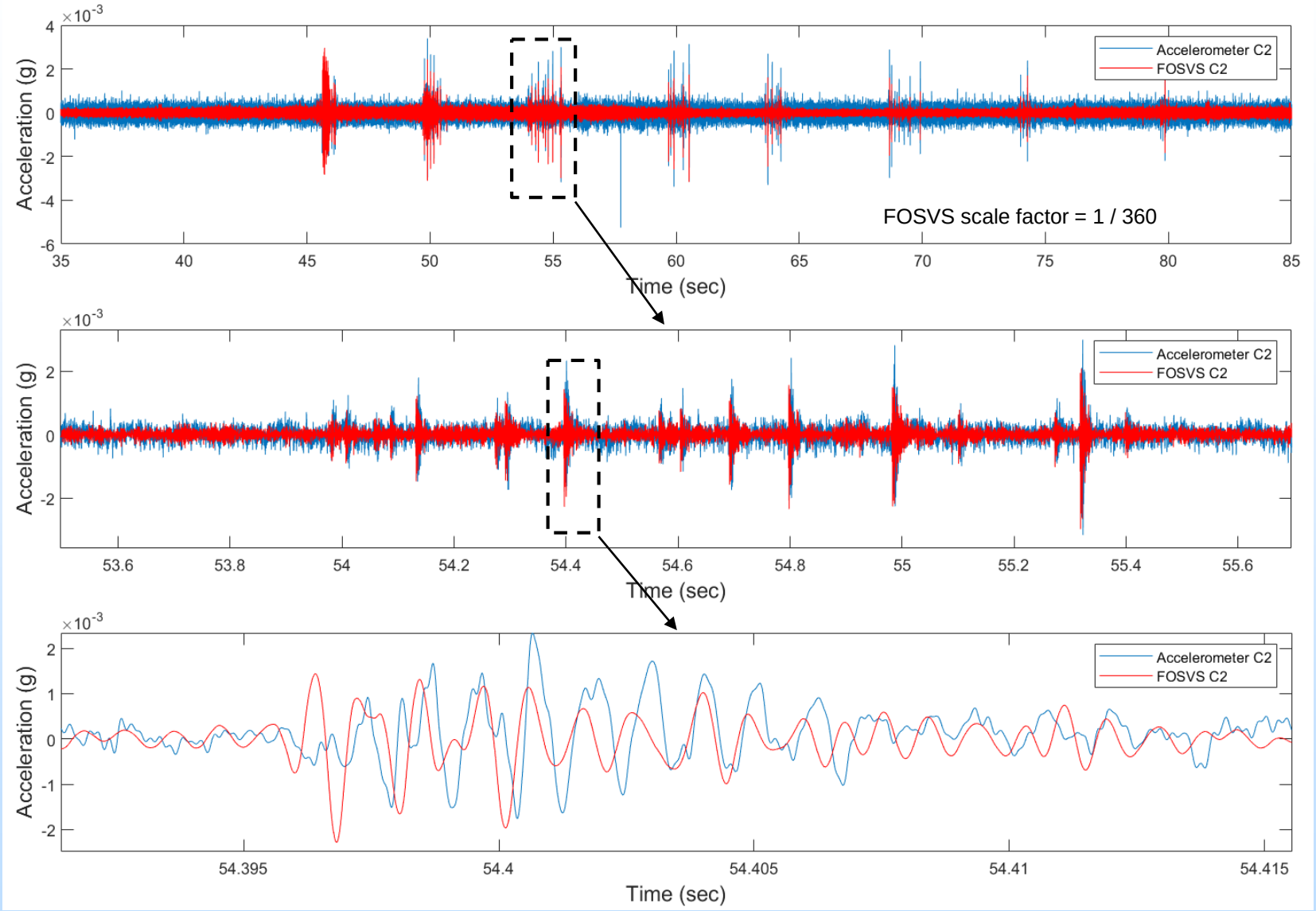
- **Date: July 15 2019**
- **Mixture: 10% of popper**
- **Offset: 10 ft**
- **Receivers:**
  - **1C accelerometer on the bottom of the pressure vessel**
  - **3C FOSVS and 3C accelerometers in the same pod in concrete 10 ft away**



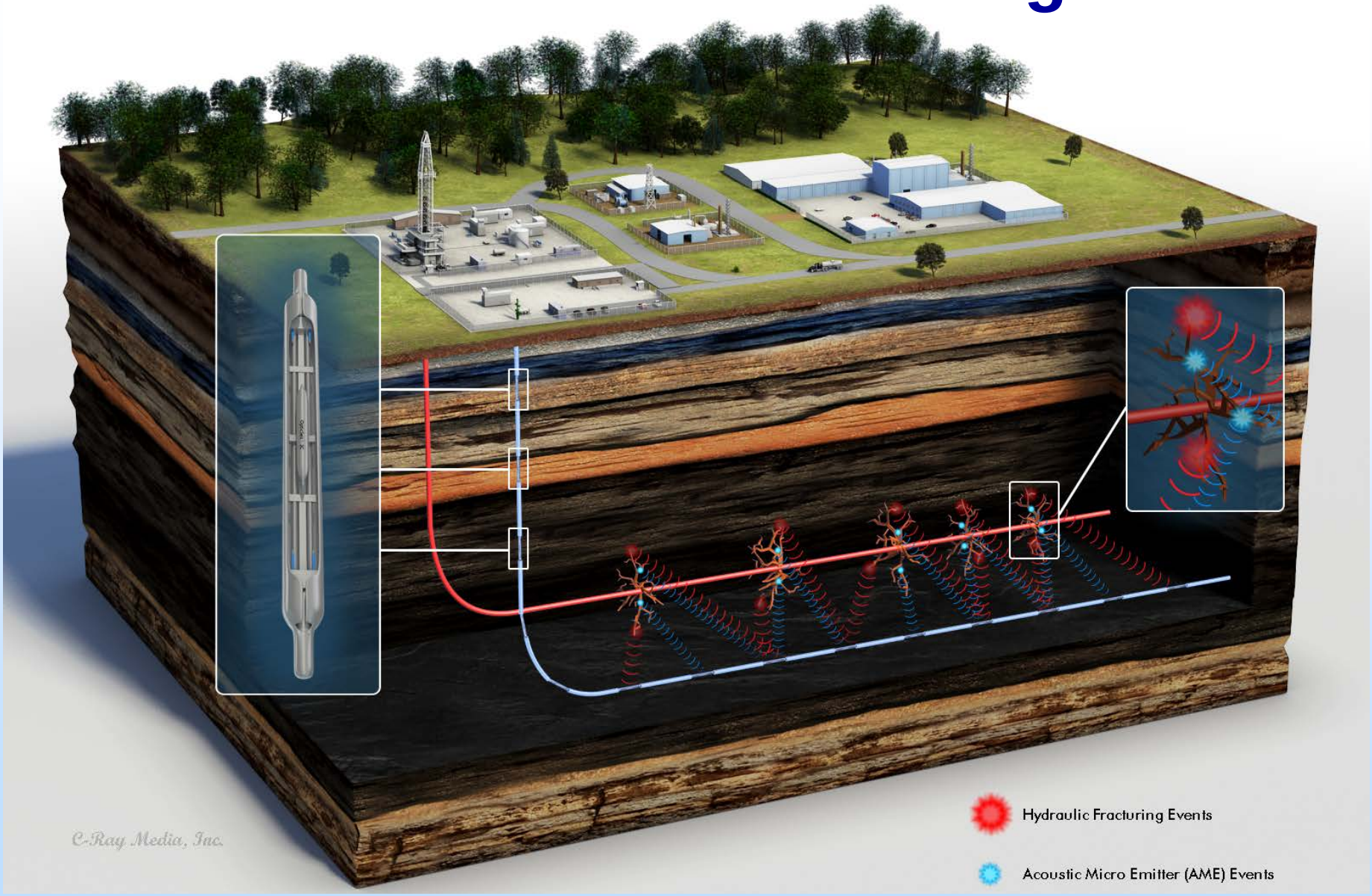
Filtered Data ([5 10 20k 30k] Hz)



FOSVS Filtered R1 VisionFrax Data ([5-10-5k-6k] Hz)



Effective & Accurate Monitoring of UOG



Injectable Micro Emitters (IME)

- Compliments standard micro seismic monitoring
- Allow localization of flowing fractures and fracture proppant
- Can produce valuable information on
  - fracture width vs. position
  - fracture orientation and size
  - number of fractures per fracking zone
- In combination with effective monitoring technology the IME technology allows for effective fracture optimization

Synergy Opportunities

- Application Areas Include
  - Oil & Gas: Conventional Primary, Secondary, Tertiary Recovery (now 35%)
  - Oil & Gas: Unconventional (~8% recovery; Where is the 92%?)
  - CCUS – Must secure a 99% compliance. Where is the CO2?
  - Geothermal – today NO geothermal rated seismic tools in existence.
  - Infrastructure – Pipelines, Dams, Other.
- The Developed Technology can be Used for Many of the Currently 17 Funded DOE Field Experimental Sites
  - Provide High Resolution Images to Better Understand the Geology of the Field Sites. Without Accurate Images the Knowledge Gained is Incomplete.
  - Provide High Resolution Monitoring of Small Seismic Events, M-5.0 and smaller. E.g. this will Allow Tracking of the Fracture Tips and the Fluid Flow.
  - Monitoring the Propagation of Micro Emitters is Potentially a Game changer

Acknowledgement

- The research discussed in this presentation has been supported by the following grants:
  - DOE Contract DE-FE0004522 (2010)
  - RPSEA Contract 09121-3700-02 (2011)
  - DOE Contract DE-EE0005509 (2012)
  - California Energy Commission Contract GEO-14-001 (2013)
  - DOE Contract DE-FE0024360 (2014)
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  - DOE SBIR II Grant DE-SC0018613 (2018) Downhole Source

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Thank You!

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