Fiber Optic Seismic Vector Sensors (FOSVS)™ and Underground Gas Storage (UGS)

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Paulsson, Inc.
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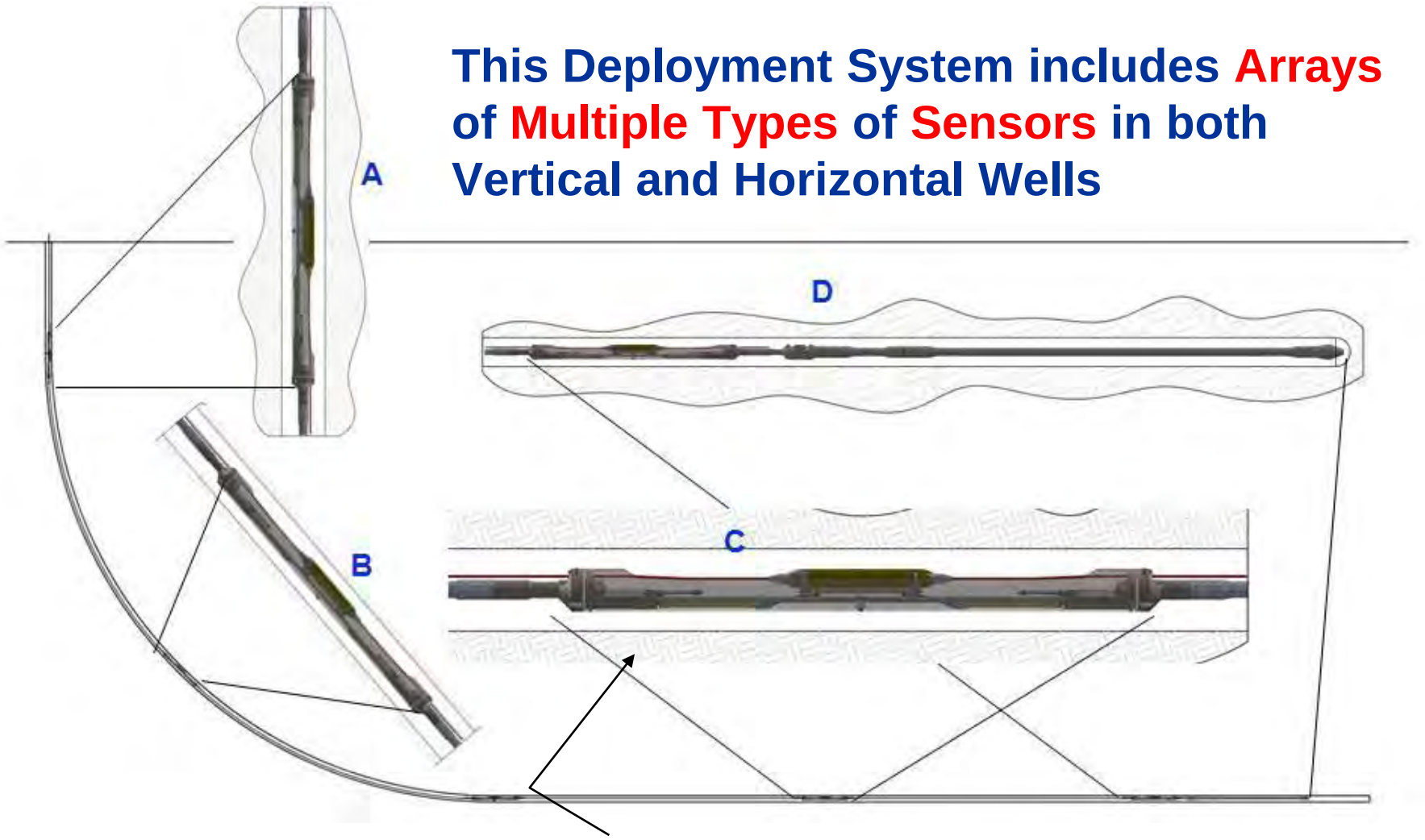
3C Optical Accelerometers + Hydrophones = 4C

Both Sensors are Point Sensors

We will only Discuss the Accelerometers Today

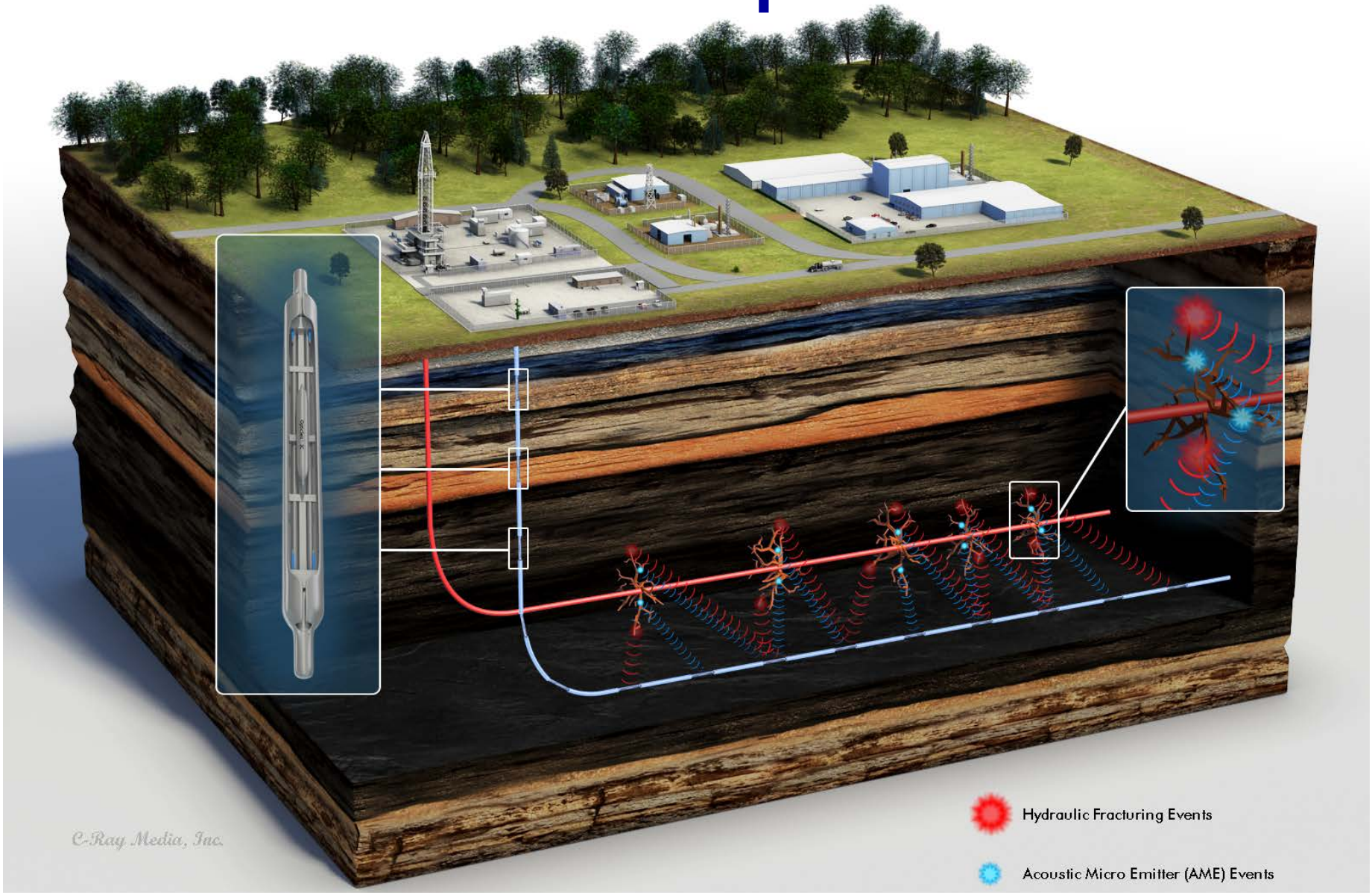
Drill Pipe Deployed System – Housing and Clamping

This Deployment System includes Arrays of Multiple Types of Sensors in both Vertical and Horizontal Wells



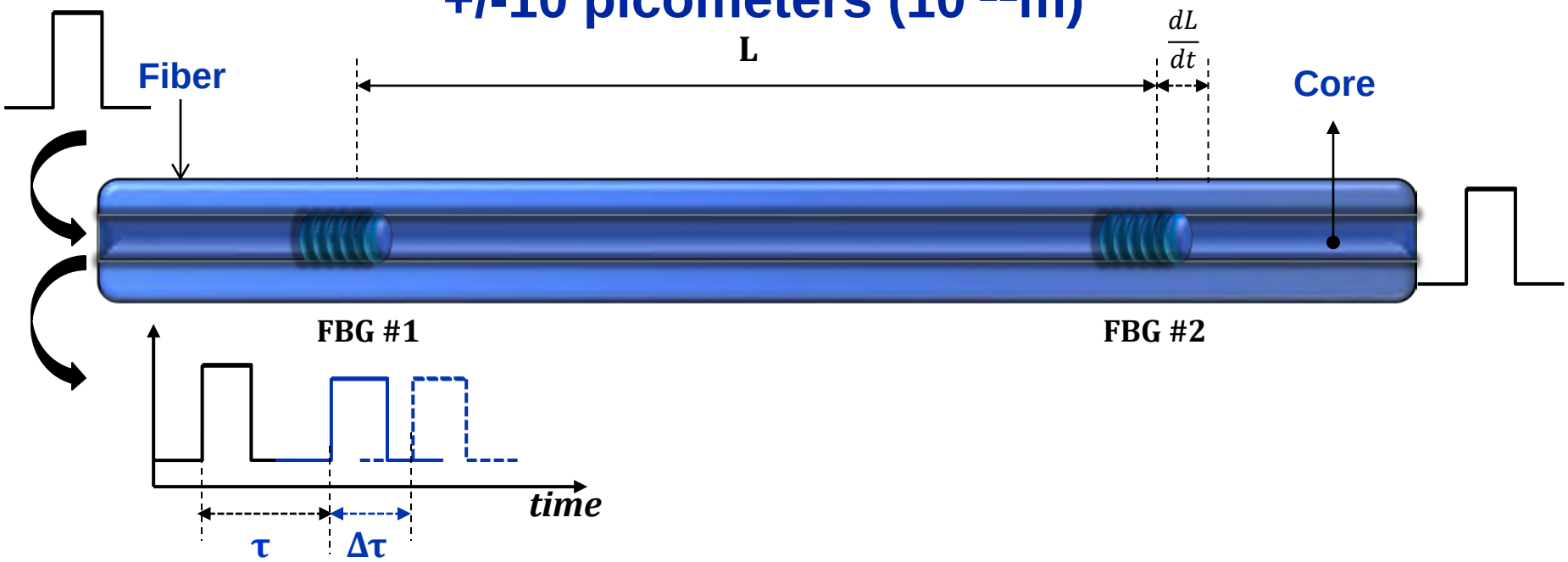
Clamping system operates by increasing pressure inside the drill pipe and manifolds using the borehole fluid as a pressurized medium

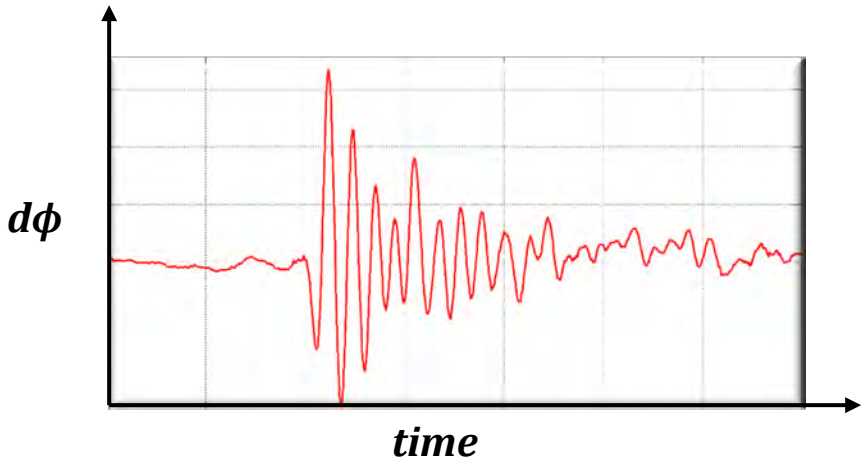
Effective & Accurate Operations of CCS

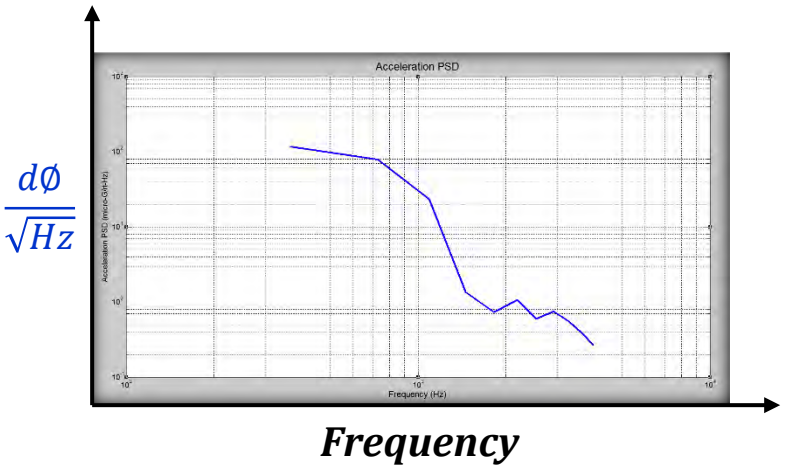


Fiber Optic Seismic Sensor System Deployment
Battelle, Michigan, June 2016

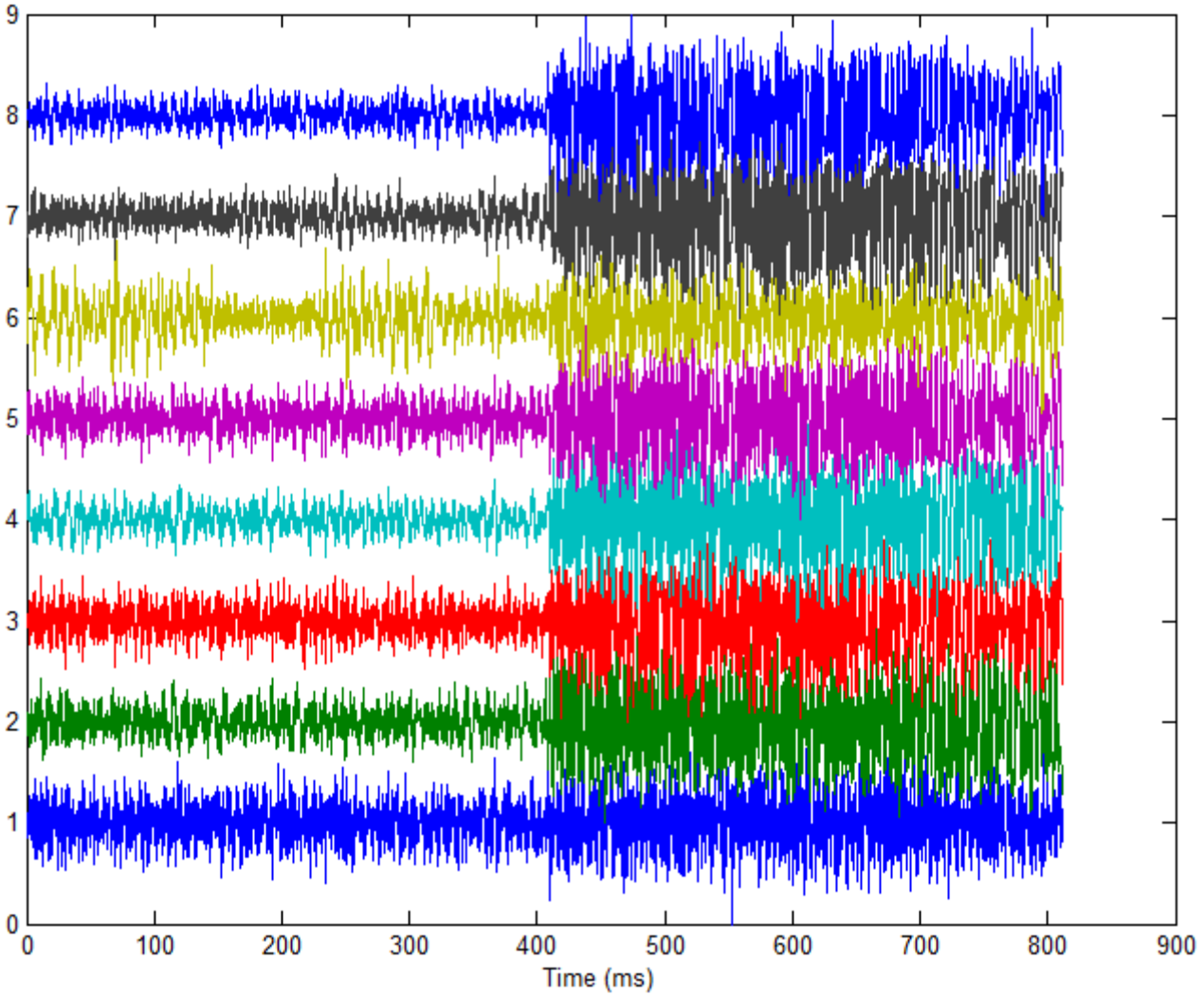
Fiber Bragg Grating: Interferometric Sensing – +/-10 picometers (10^{-11}m)



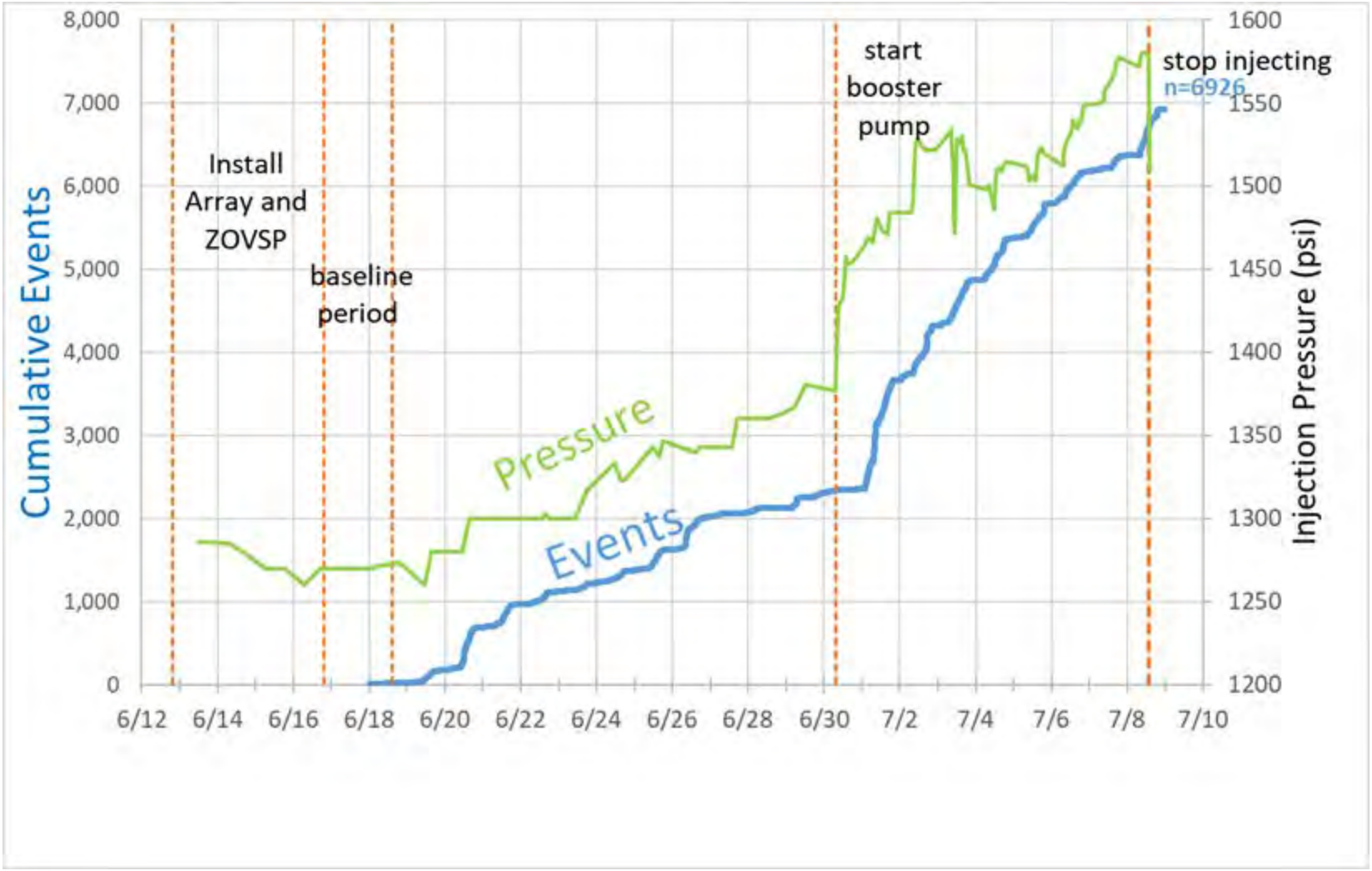




Sound of A Long Duration Event (~M-5.0) –Fluid Flow



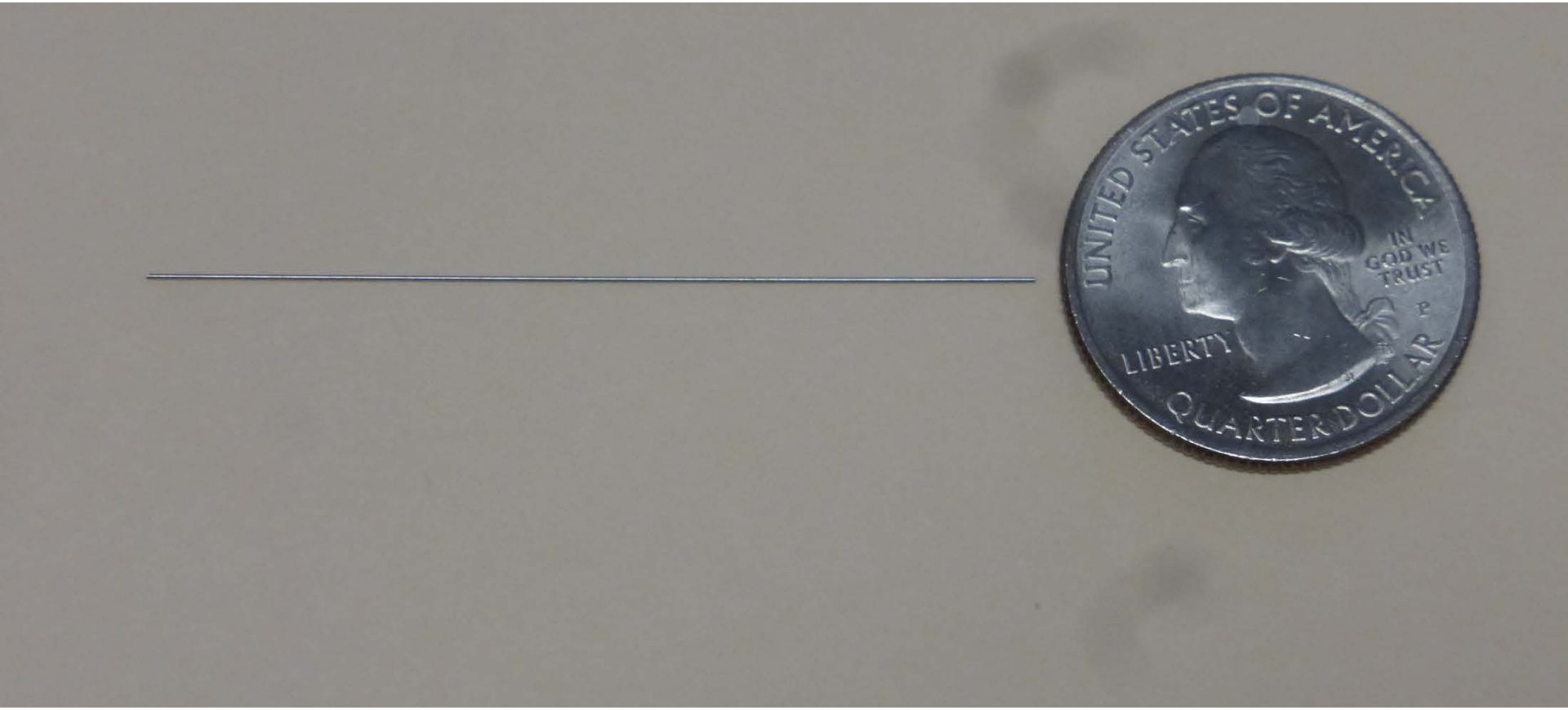
Micro Seismic Events as Function of Injected CO2



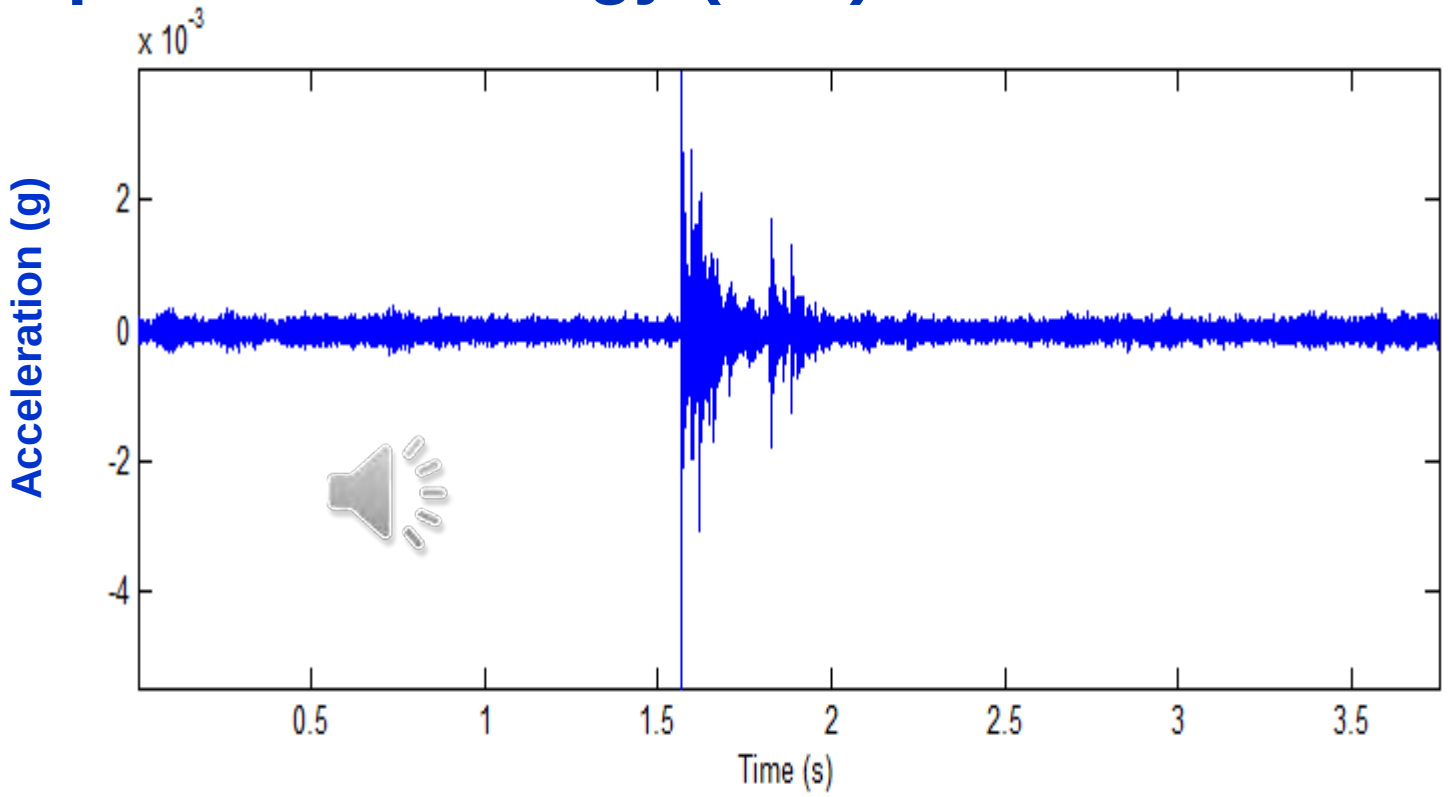
Microseismic data by Paulsson, Inc.; Pressure data by Battelle Memorial Institute

Lab Tests

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

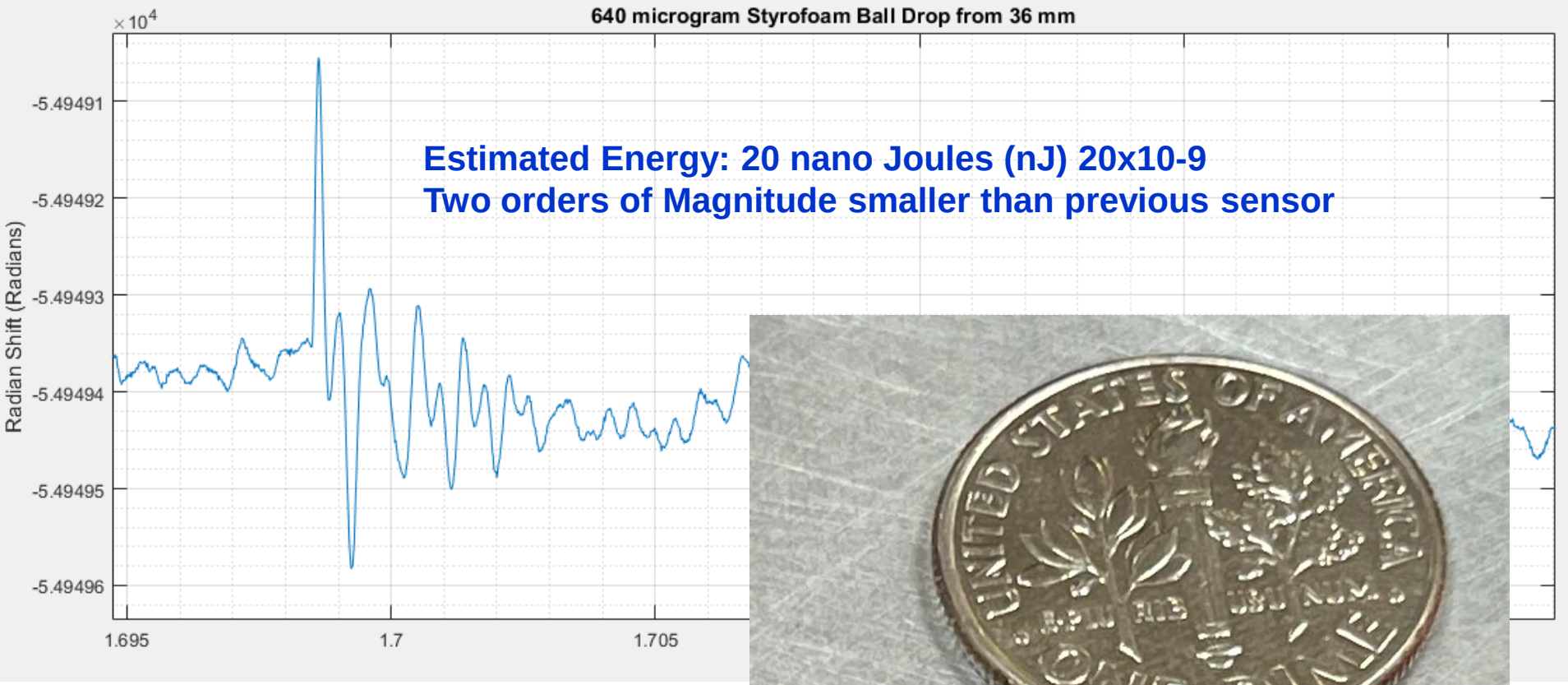


3rd Gen FOSVS Test:
Pin OD: 0.011”, 24.8 mg Pin Drop 1 cm:
2.5 µJ kinetic energy (M-7) for 1st of 8 hits of Pin



The FOSVS recorded 8 bounces of the pin = <<M-7

4th generation Fiber Optic Accelerometer by Paulsson



Estimated Energy: 20 nano Joules (nJ) 20x10-9
Two orders of Magnitude smaller than previous sensor

Drop a 0.6 mg Styrofoam Ball 4 mm

We Deployed
Enhanced Distributed Acoustic Sensors (EDAS),
Distributed Strain Sensors (DSS)
&
Distributed Temperature Sensors (DTS)

We will show data from 2,500 EDAS sensor and 1,700 DTS sensors deployed in a 5,300 ft Deviated Well

There are many Common Elements of Methane (CH4) Underground Gas Storage (UGS), Carbon Dioxide Storage (CO2 - CCS) and Hydrogen, H2 (UHS). The UGS and CCS markets are big - adding Hydrogen will make the UGS, CCS, UHS, Market even bigger – The US numbers are:

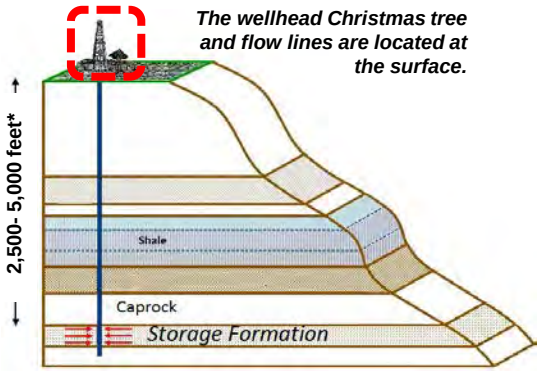
- **UGS: 15,000 wells. At least 3,000 are at risk.**
- **UGS operates 412 sites**
- **UGS is today a $500B industry - $760B (2026)**
- **CCS Needs to drill 42,000 wells before 2050**
- **CCS needs 100s of Storage Sites for the CO2**
- **CCS needs to invest ~$1T to store CO2!**

Gas Storage Landscape in Northern California

STORAGE IMPACT STATS

70% Approx. 70% of PG&E's gas system has been supplied by PG&E and Independent Storage Provider (ISP) storage gas during historical high-demand periods

20% Approx. 20% of gas used in the U.S. during winter now comes from storage fields, according to the American Gas Association



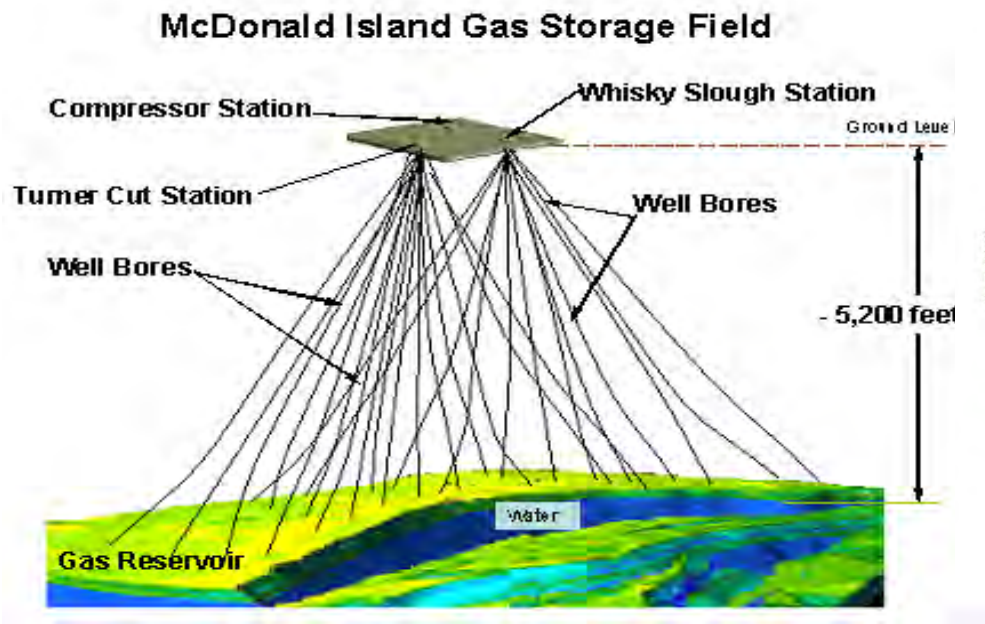
The wellbore casing extends several thousand feet below ground to the storage reservoir.

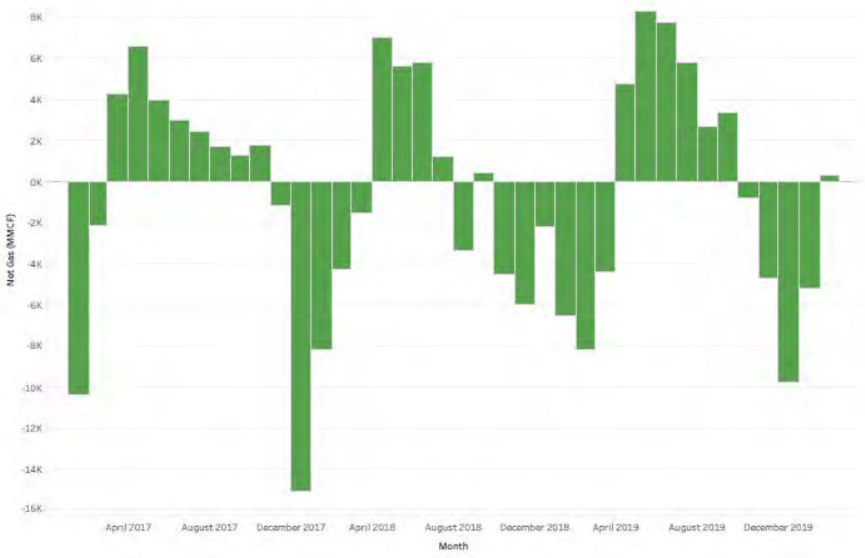
**Depth range of PG&E storage formations*

Why and when do we store Green Hydrogen?
Storing Green Hydrogen is an Energy Storage technology far superior to Batteries for Large Scale Energy Storage

PURPOSE OF UNDERGROUND STORAGE

- Enables large volumes of natural gas to be stored and later withdrawn during high-demand periods
- Provides the ability to purchase natural gas and inject into storage, taking advantage of seasonal gas pricing as well as market fluctuations

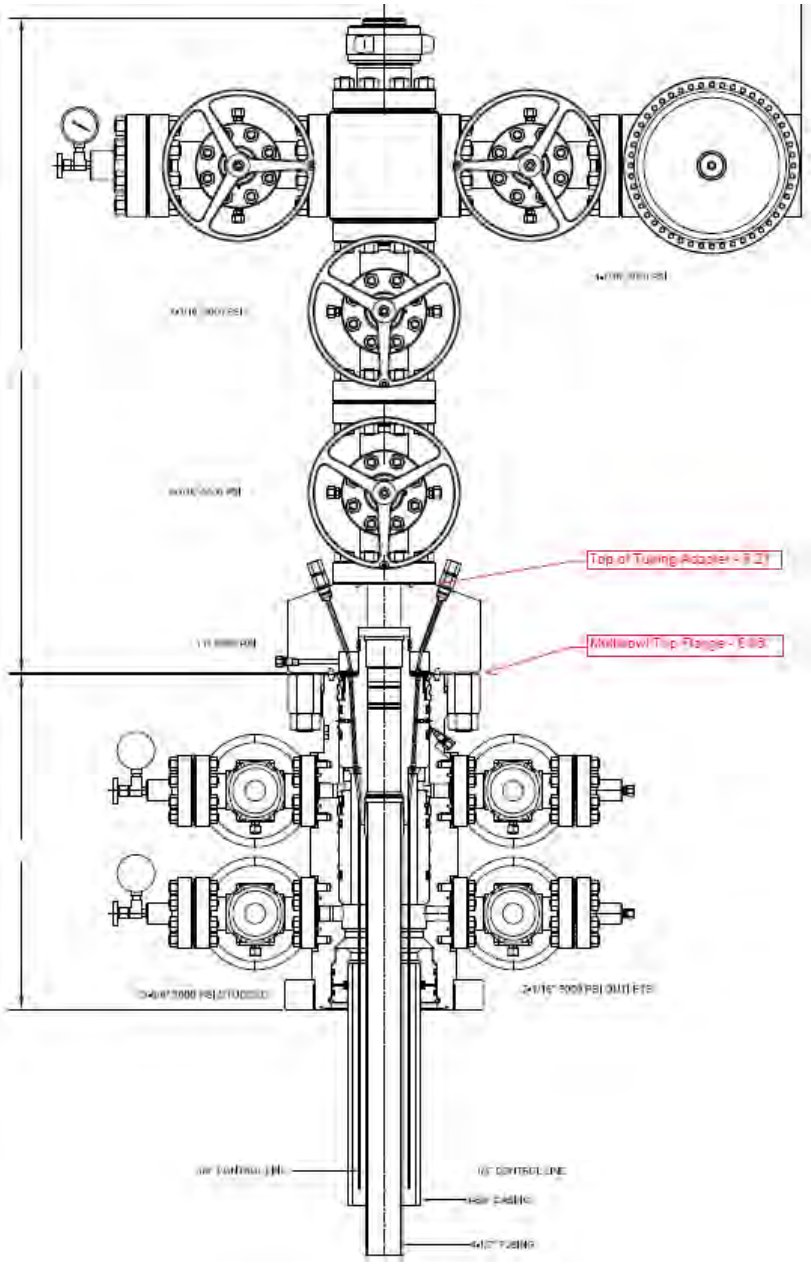




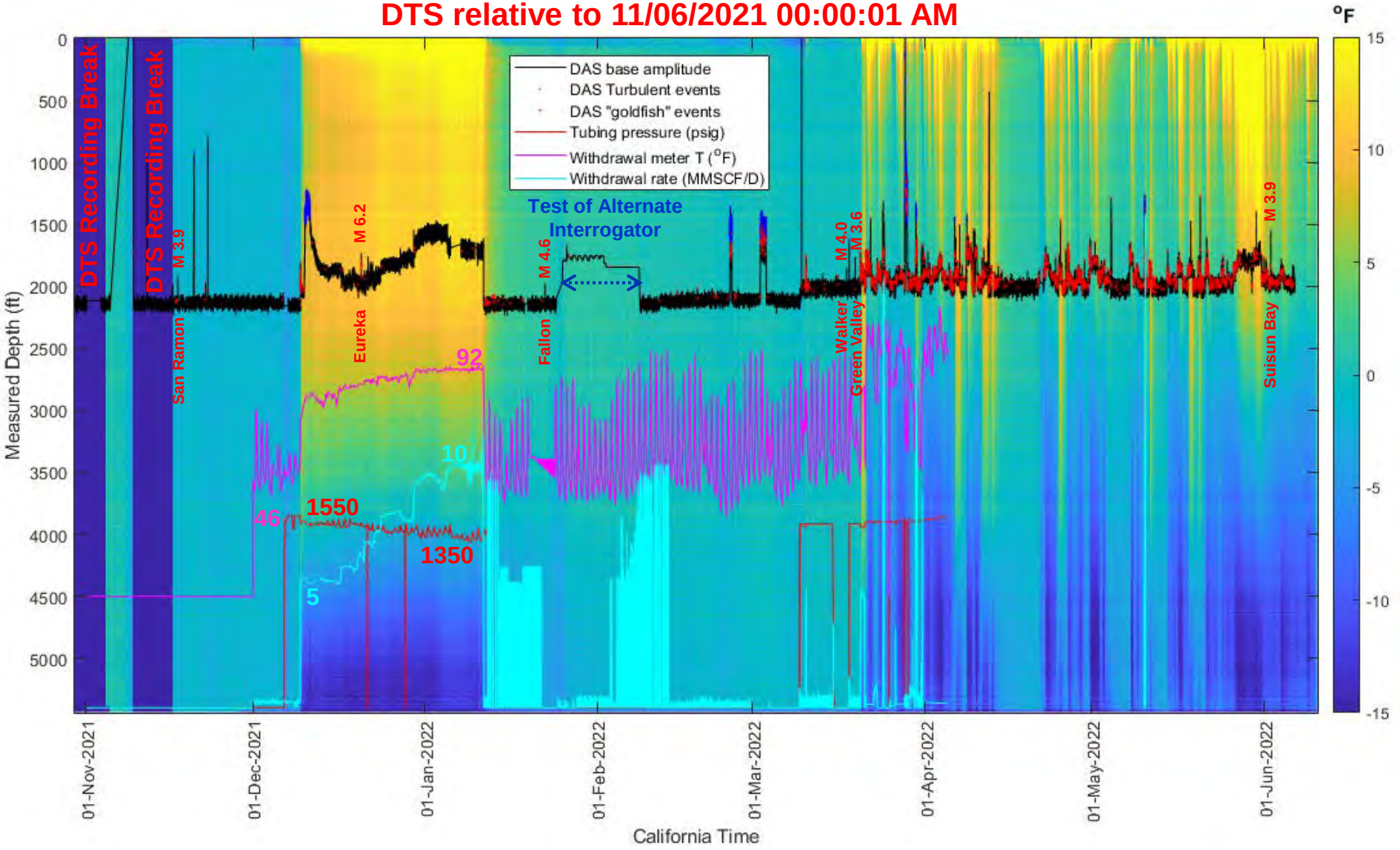
The McDonald Island UGS – The Survey Site: 84 wells

McDonald Island – The Survey Site during Sensor Installation

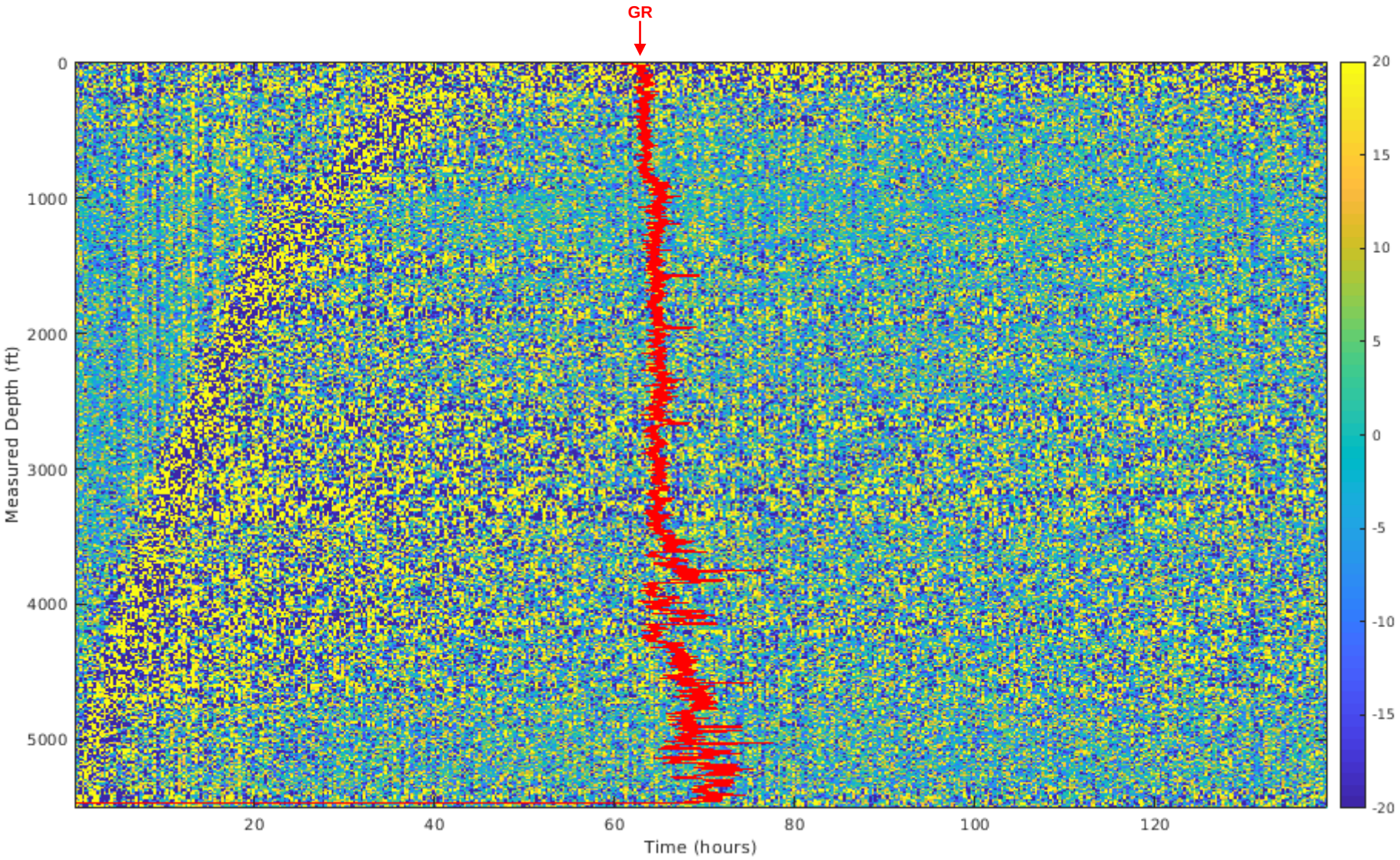
Wellhead of the TC 8S well



EDAS and Relative DTS Data: Overall ~7 Months (out of ~8)



Fluid Flow EDAS Events for 6 Days during Fluid degassing



Bubble effect of seismic air gun in underwater photos. Same effect is recorded when Gas is Leaking through tool joints

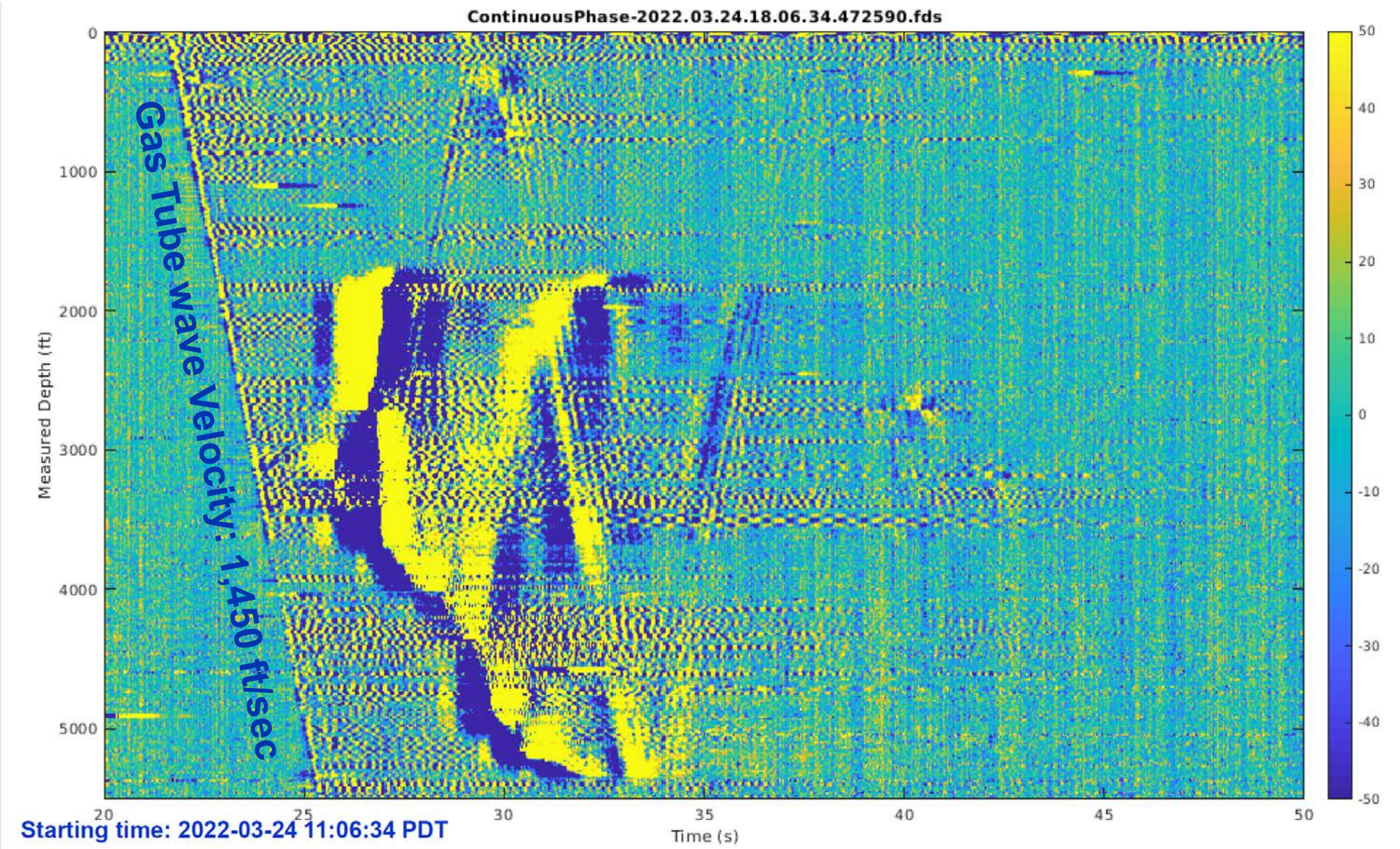
Link to video: https://youtu.be/WpblB3xToZ4

Bubble effect of seismic air gun in underwater photos. Same effect is recorded when Gas is Leaking through tool joints

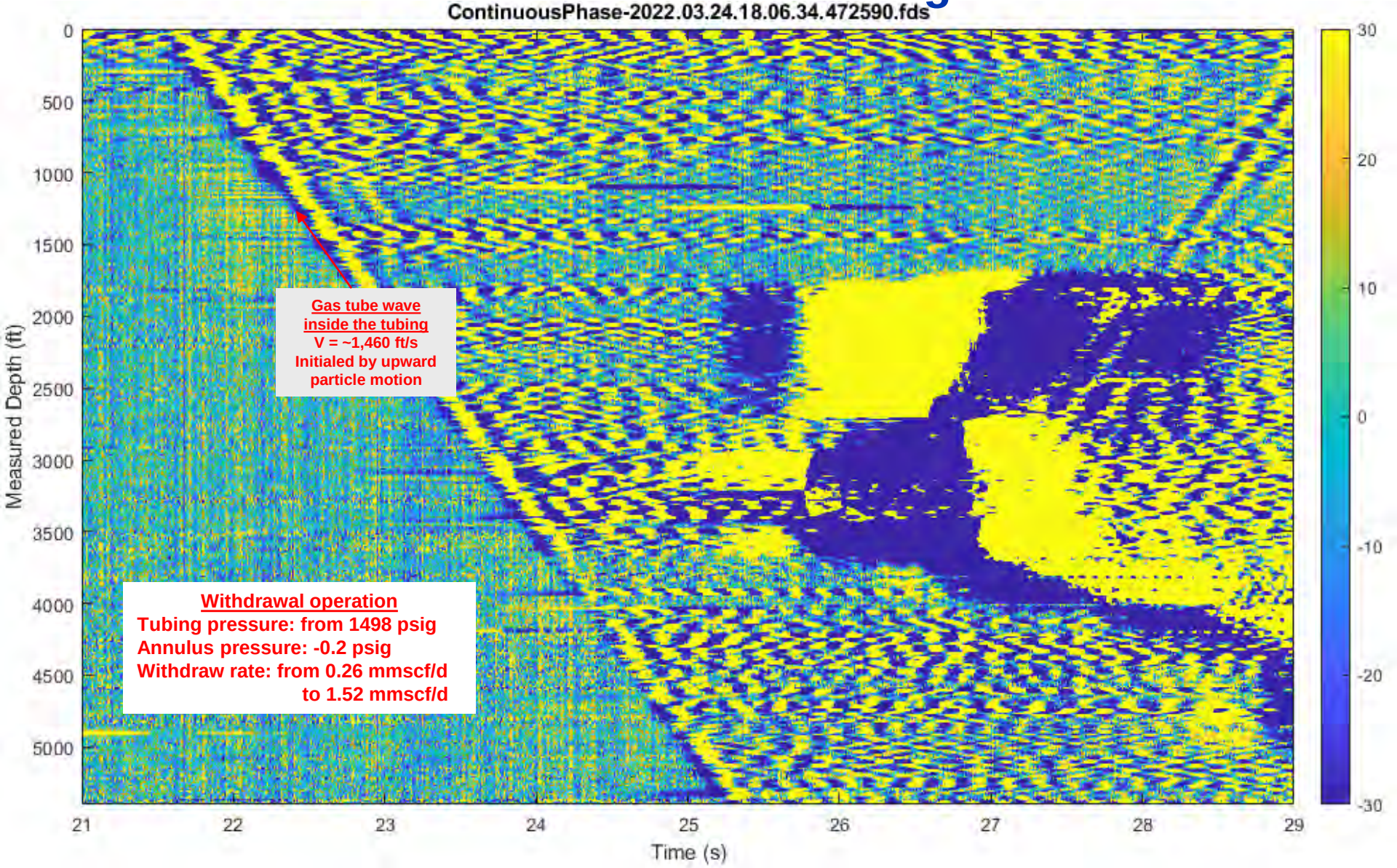
Bubble effect of seismic air gun in underwater photos. Same effect is recorded when Gas is Leaking through tool joints

Bubble effect of seismic air gun in underwater photos. Same effect is recorded when Gas is Leaking through tool joints

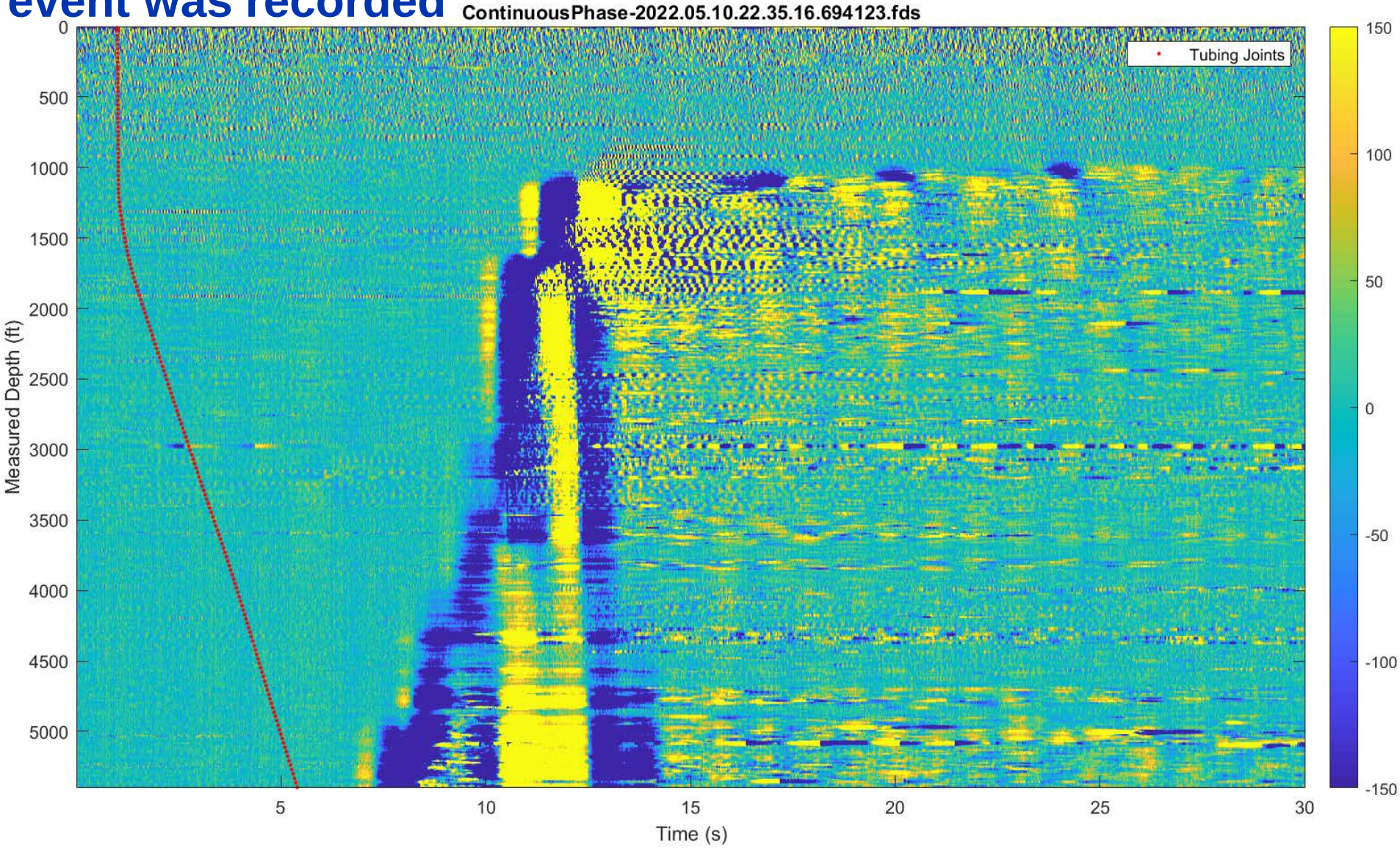
Gas Tube Wave and “Gold Fish” during Gas Withdrawal



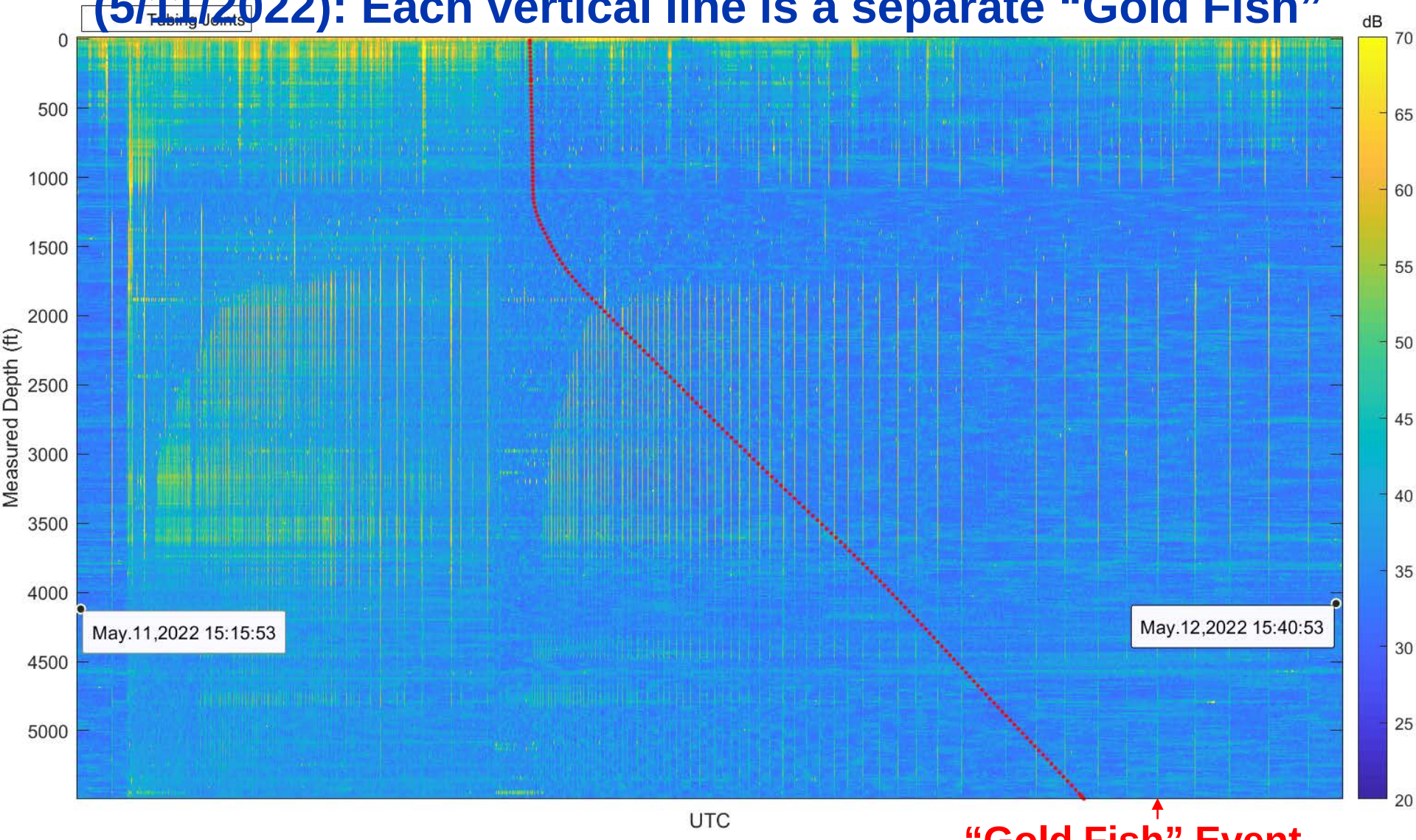
Gas Tube Wave and “Gold Fish” during Gas Withdrawal



EDAS Data during Gas Max Withdrawal. A large “Gold Fish event was recorded

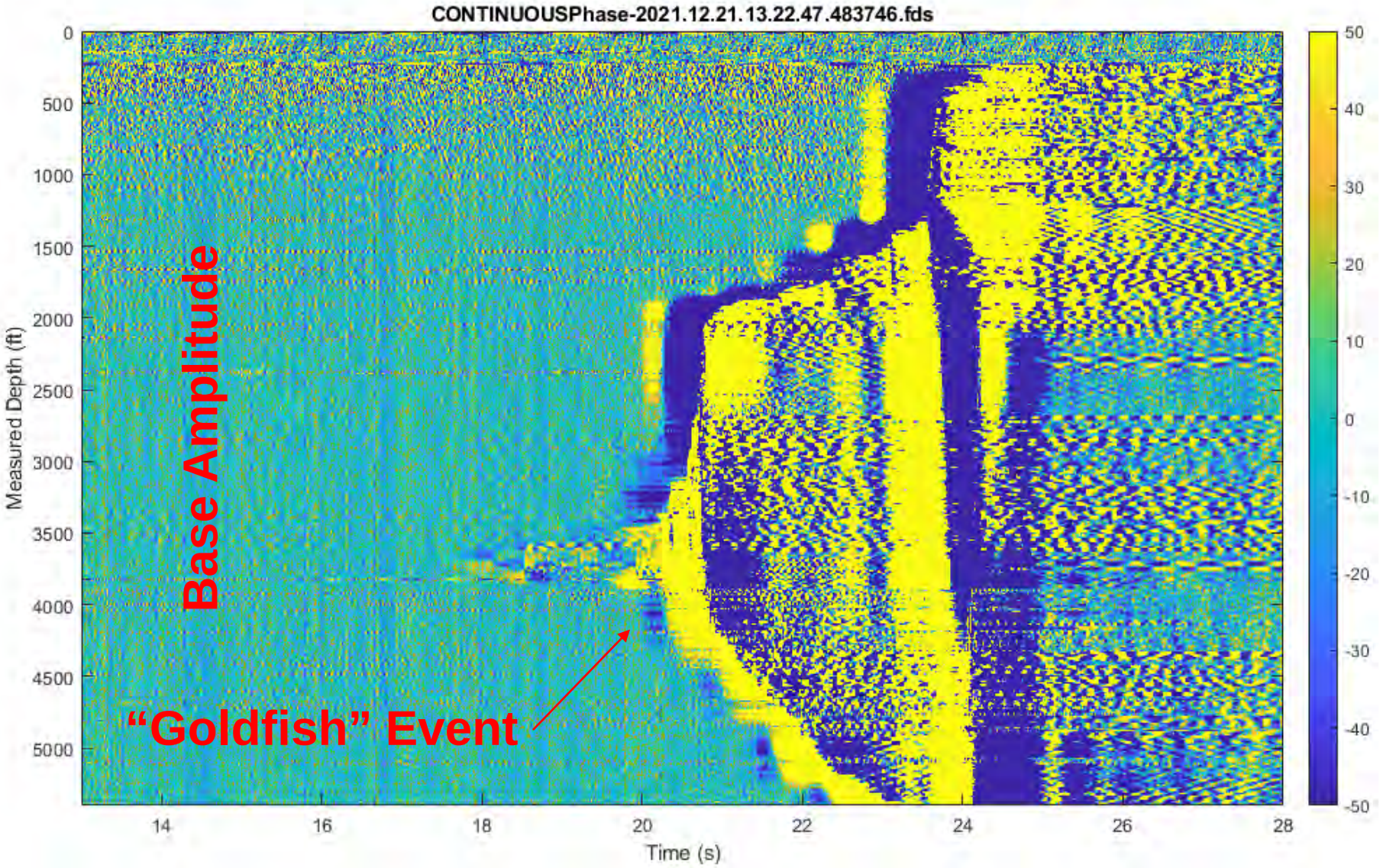


EDAS Overview Data – “Gold Fish” Events over 24 hours (5/11/2022): Each vertical line is a separate “Gold Fish”



“Gold Fish” Event

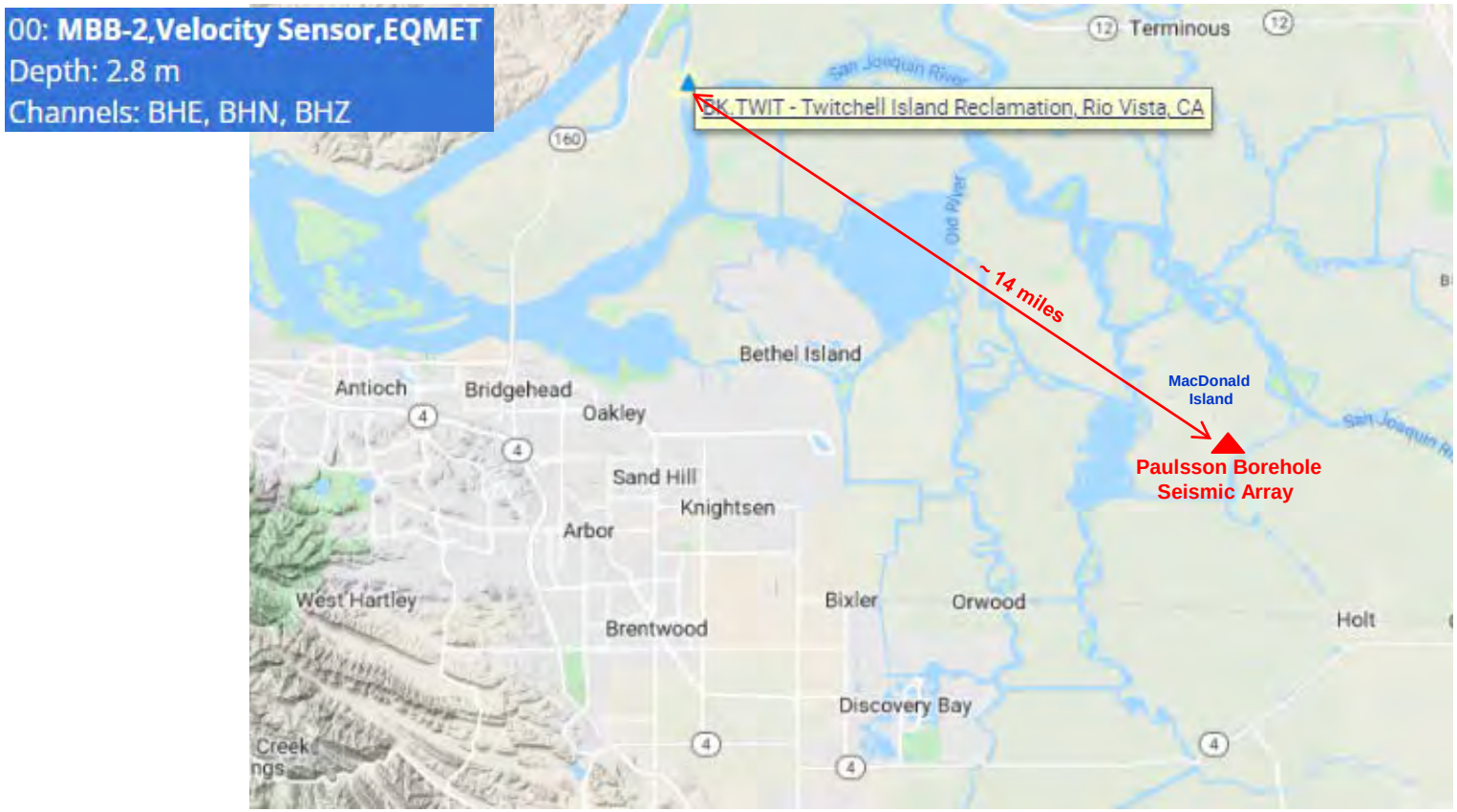
EDAS Data from an Oscillating Gas Bubble Event.



PG&E McDonald Island
EDAS Earthquake Data

USGS Surface Station & Well Site for Paulsson Borehole Seismic Array

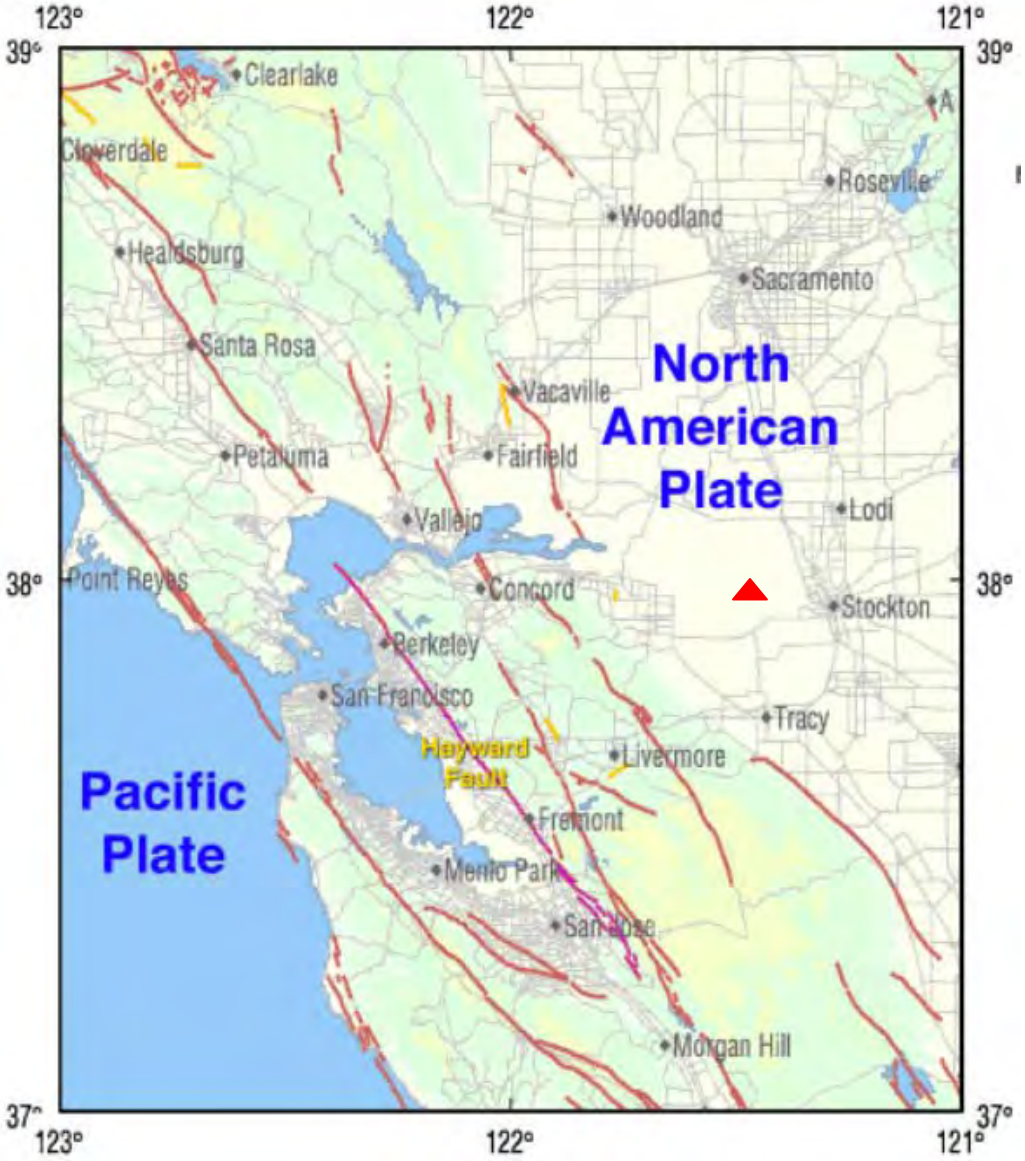
Network	Station Code	Latitude	Longitude	Elevation
BK	TWIT	38.10°	-121.68°	-3 m

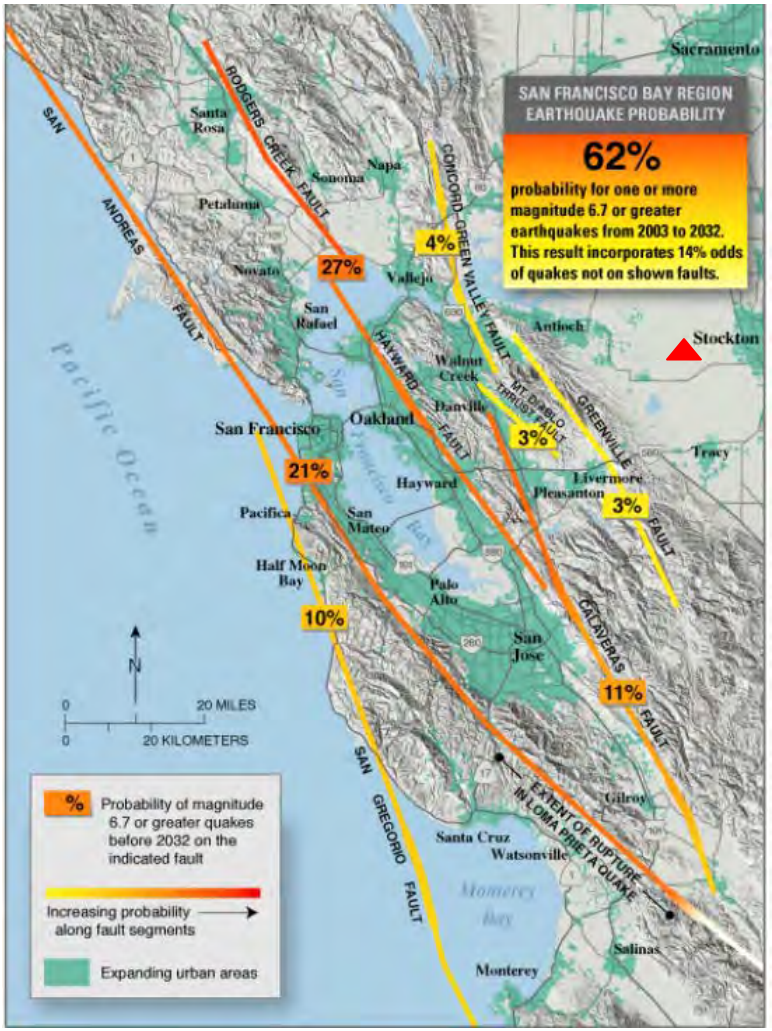


USGS BK-TWIT:
Sampling Rate: 40 Hz
3 Components, 1 pod

Paulsson EDAS
Sampling Rate: 3,000 Hz
Acoustic, 2,500 sensors

Fault Line Maps: We Monitor the Hayward Fault with a DAS Installation

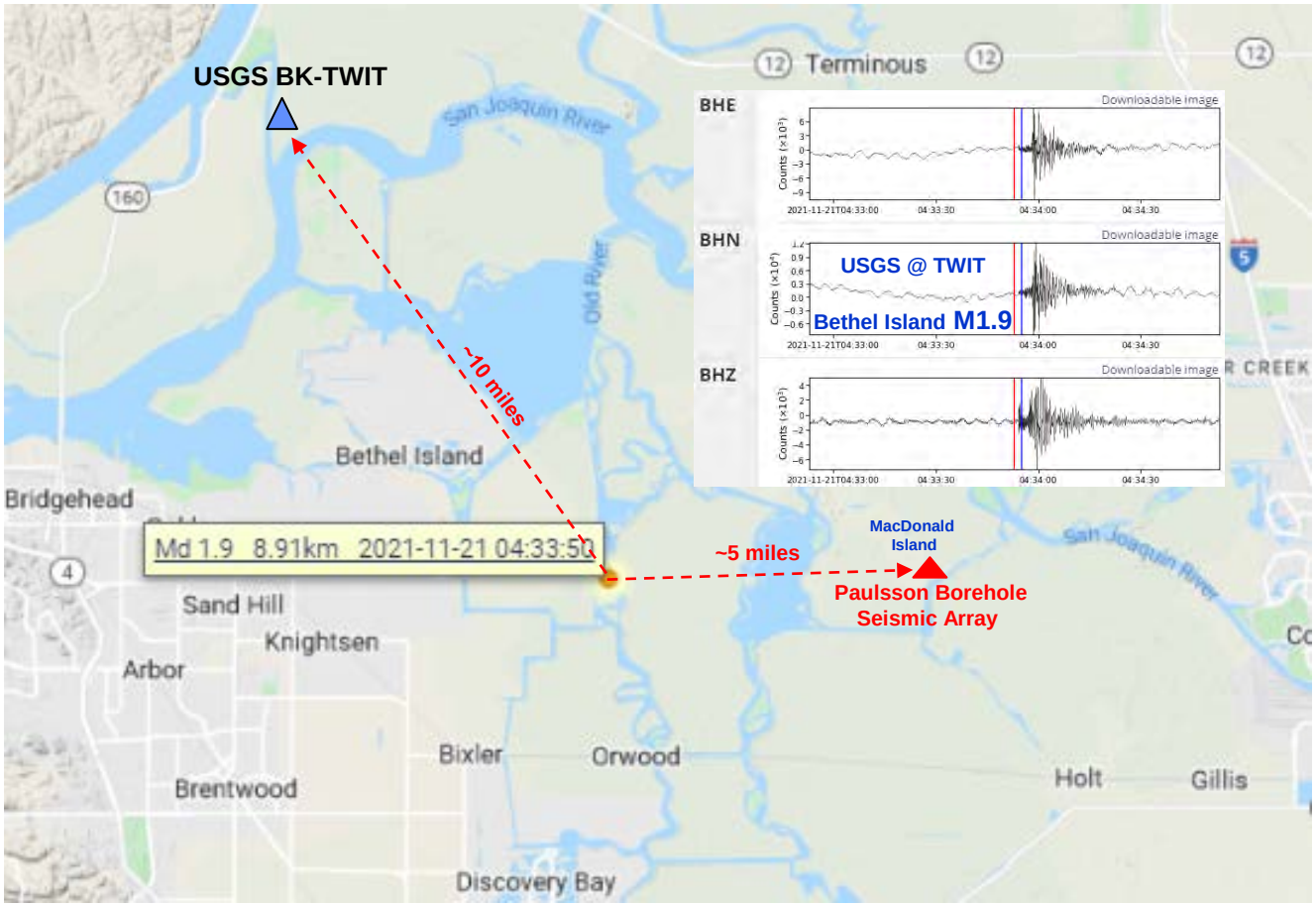




M5 or Larger Observed Earthquakes

M1 – M2 Earthquakes: Bethel Island M1.9 Earthquake (45 MJ)

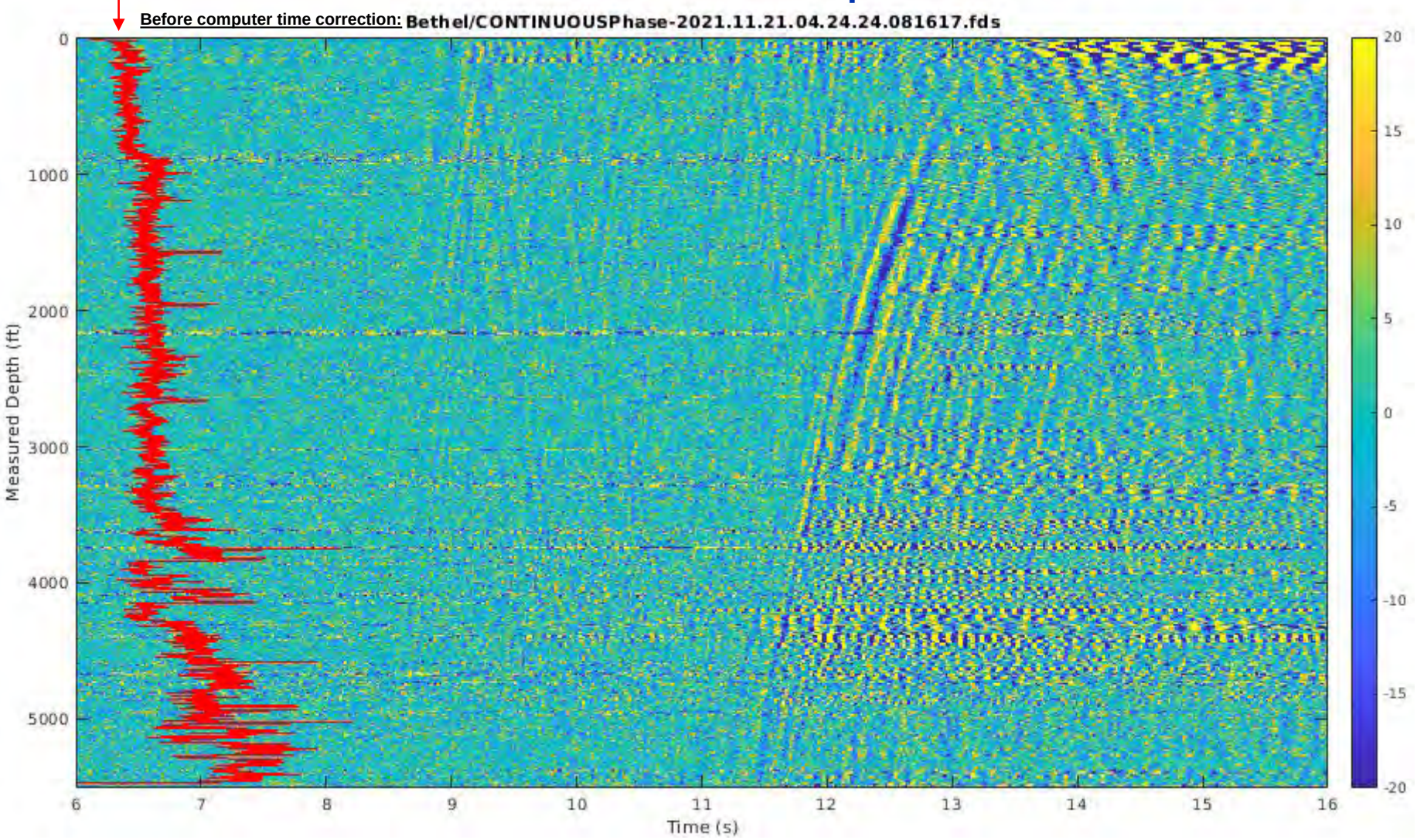
UTC 2021-11-21 04:33:50 Depth 8.91 km



M1 – M2 Earthquakes: Bethel Island M1.9 Earthquake

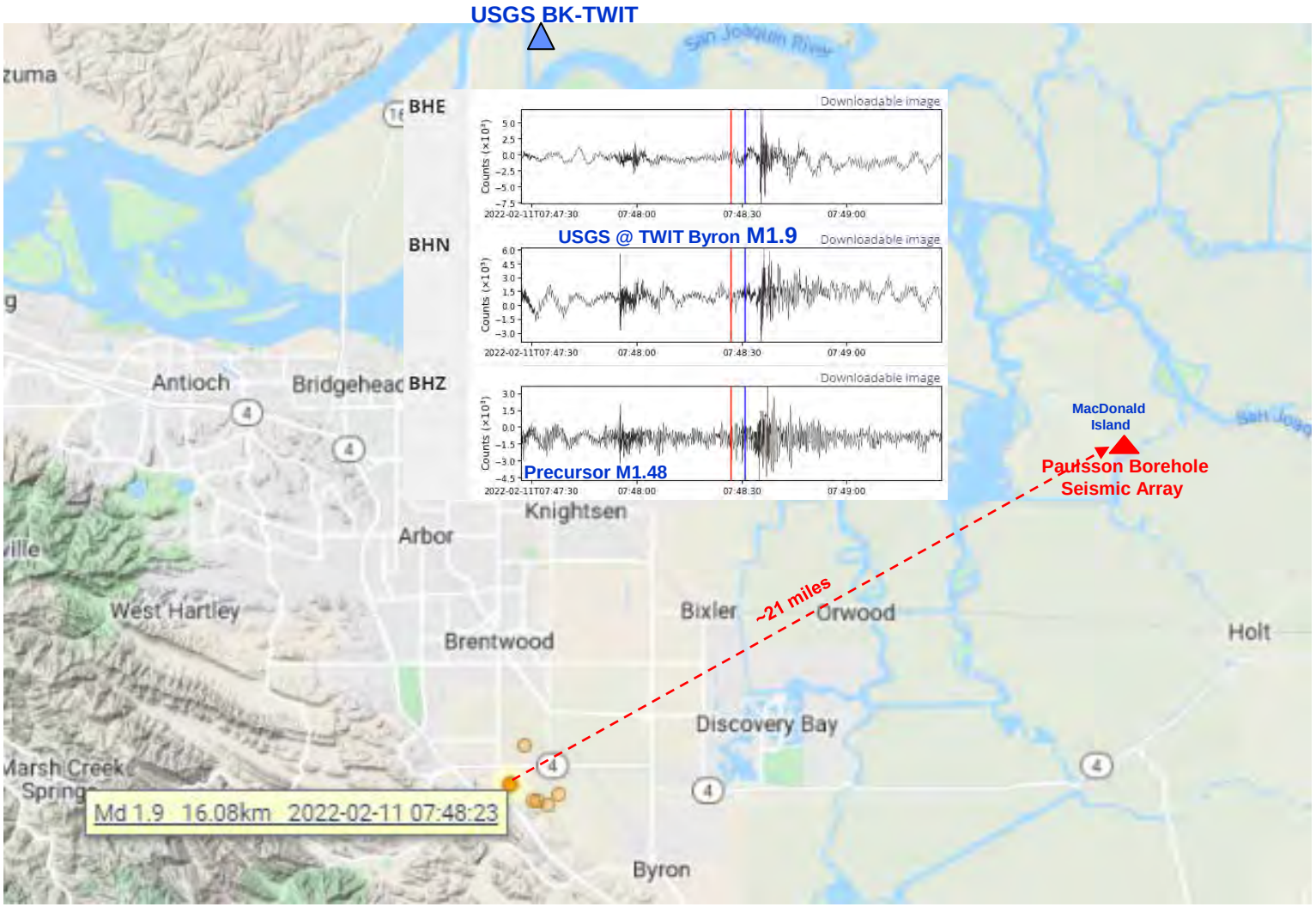
UTC 2021-11-21 04:33:50 Depth 8.91 km

Displacement range: $\pm 3.4\ \mu m$



M1 – M2 Earthquakes: Byron M1.9 Earthquake

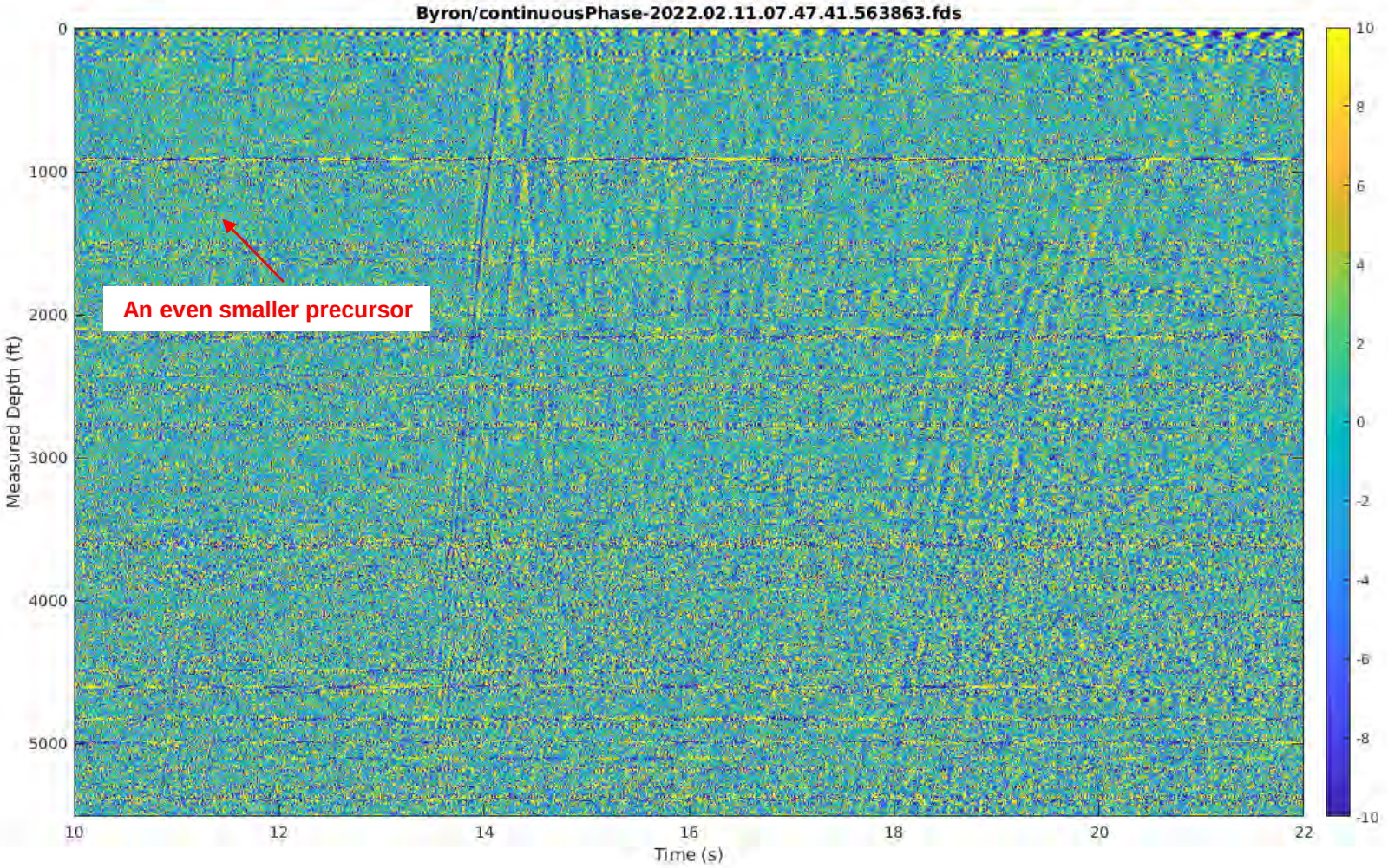
UTC 2022-02-11 07:48:23 Depth 16.08 km



M1 – M2 Earthquakes: Byron Earthquake Precursor M1.48

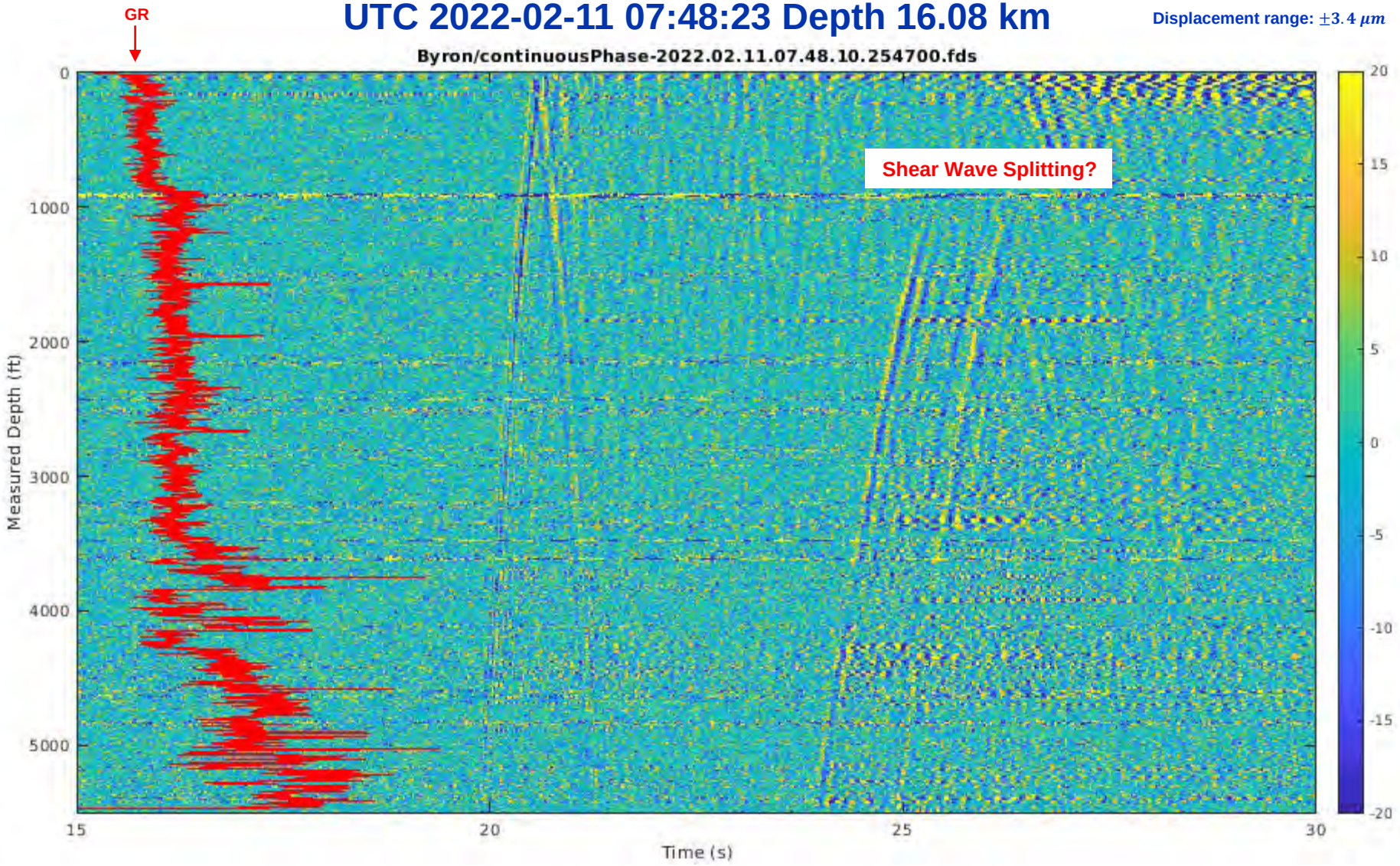
UTC 2022-02-11 07:47:45 Depth 10.12 km

Displacement range: $\pm 1.7\ \mu m$



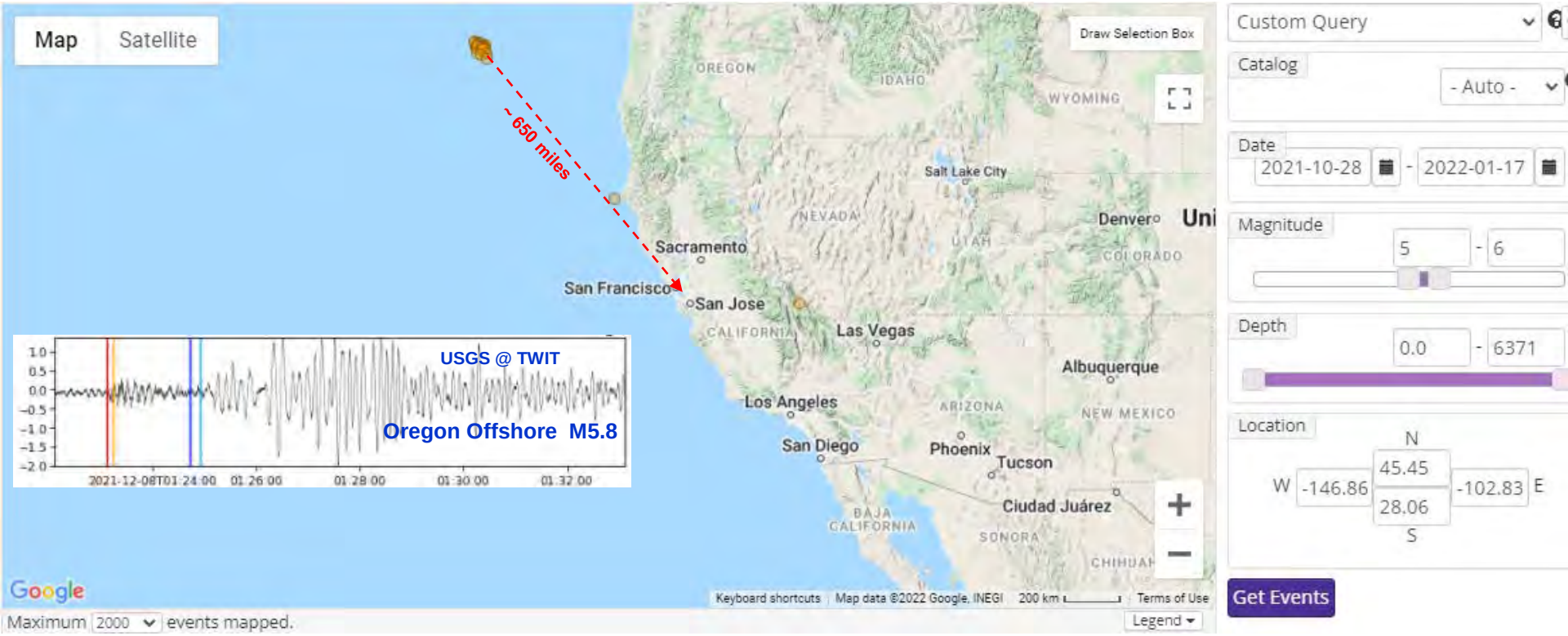
29 Sec later: M1 – M2 Earthquakes: Byron M1.9 Earthquake

UTC 2022-02-11 07:48:23 Depth 16.08 km



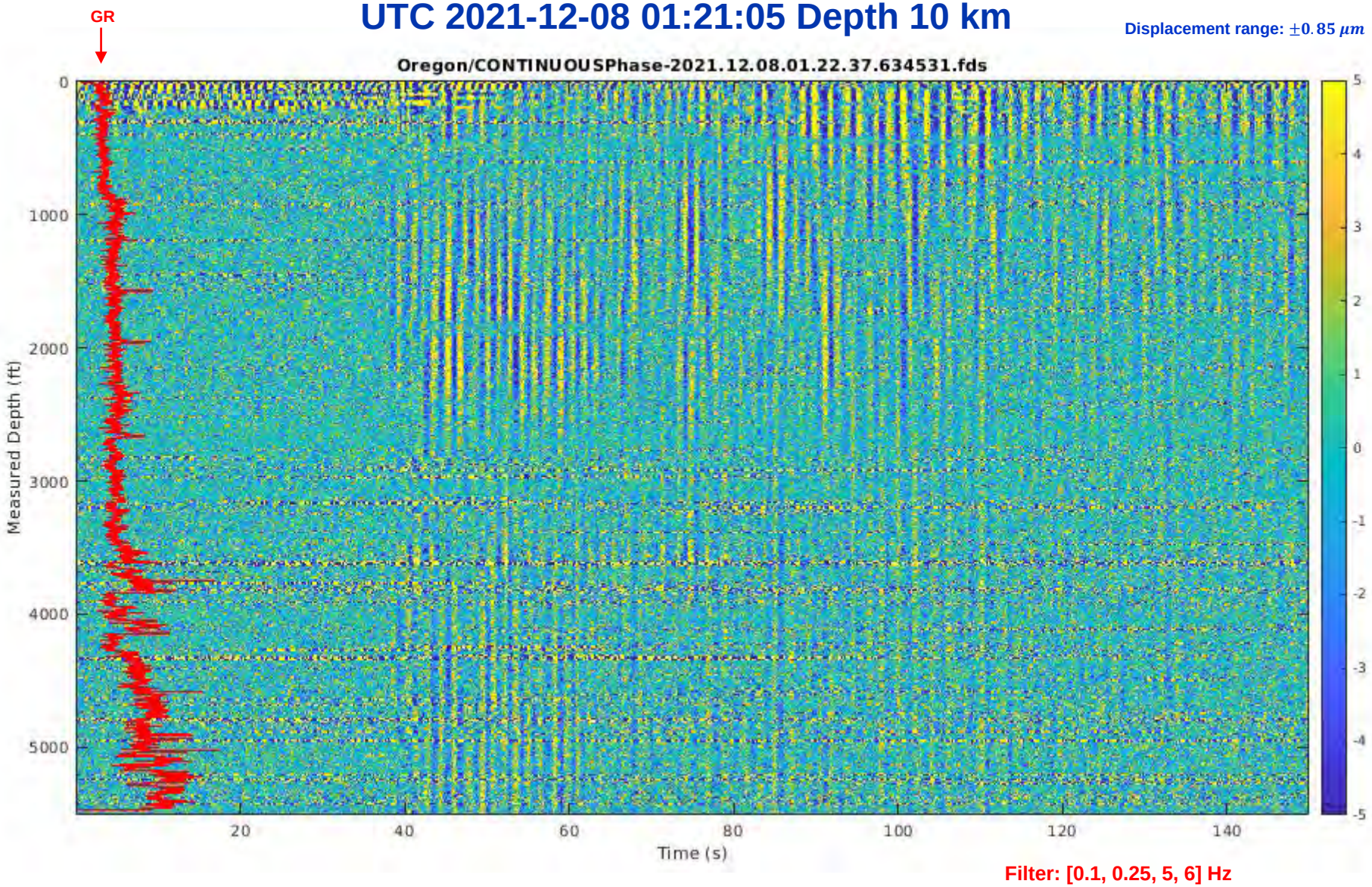
M5 – M6 Earthquakes: Oregon Offshore M5.8 Earthquake

UTC 2021-12-08 01:21:05 Depth 10 km



M5 – M6 Earthquakes: Oregon Offshore M5.8 Earthquake

UTC 2021-12-08 01:21:05 Depth 10 km

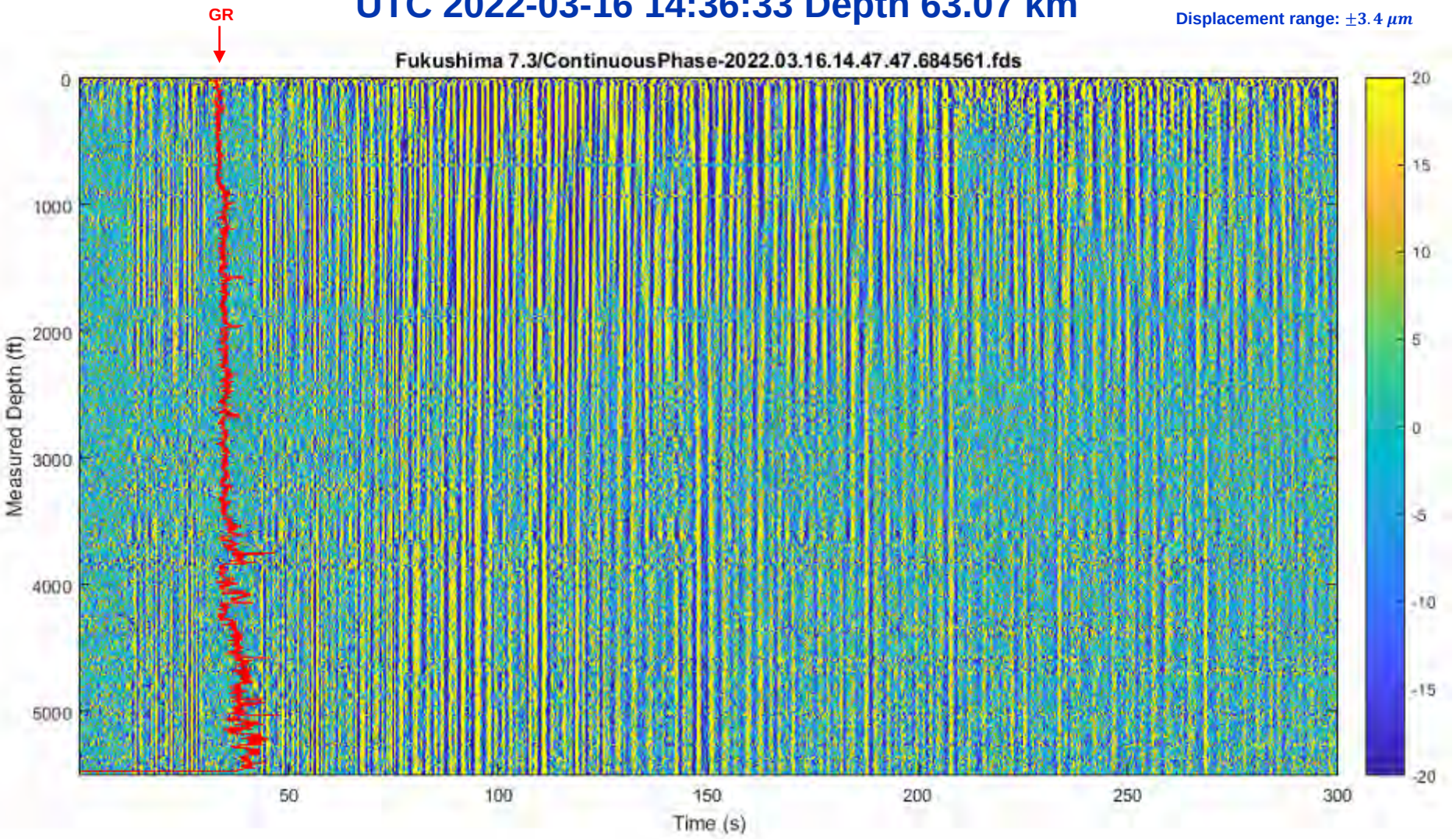


>M7 Earthquakes: Fukushima M7.3 Earthquake (6 PJ (10+15))

UTC 2022-03-16 14:36:33 Depth 63.07 km

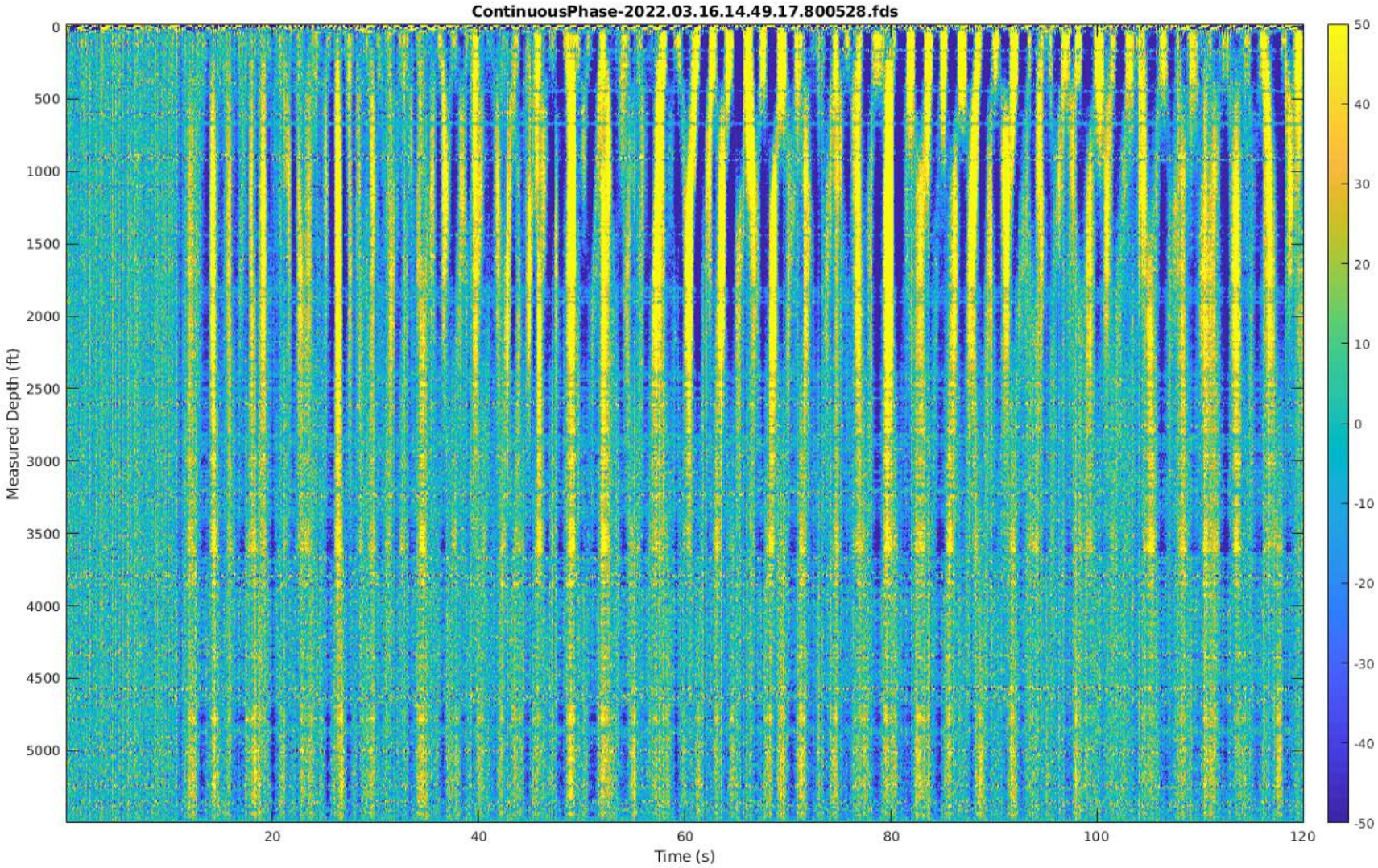
M7 & above Earthquakes: Fukushima M7.3 Earthquake

UTC 2022-03-16 14:36:33 Depth 63.07 km



M7 & above Earthquakes: Fukushima M7.3 Earthquake

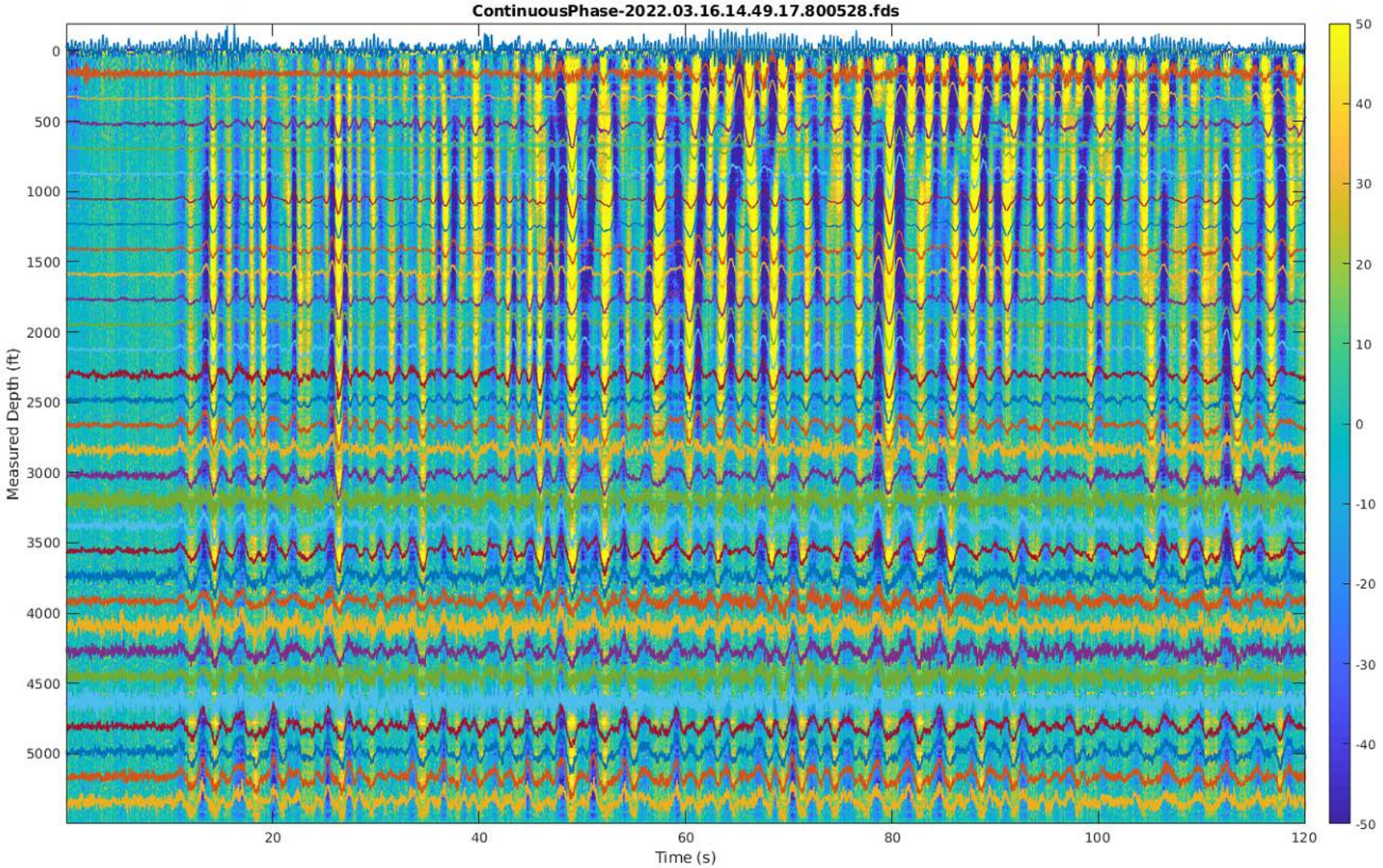
UTC 2022-03-16 14:36:33 Depth 63.07 km



M7 & above Earthquakes: Fukushima M7.3 Earthquake

UTC 2022-03-16 14:36:33 Depth 63.07 km

Filter: 0.1-0.2-18-20 Hz



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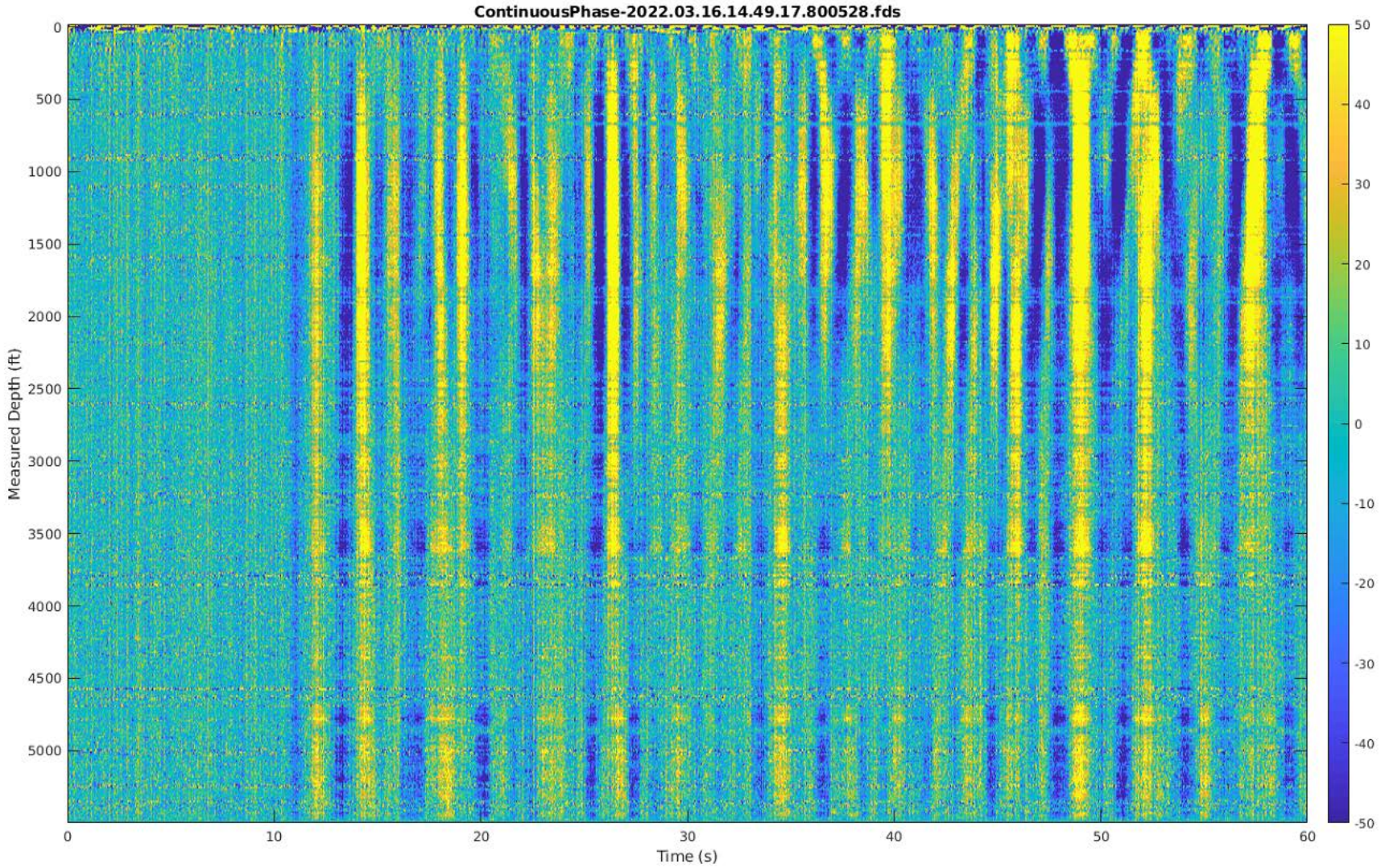

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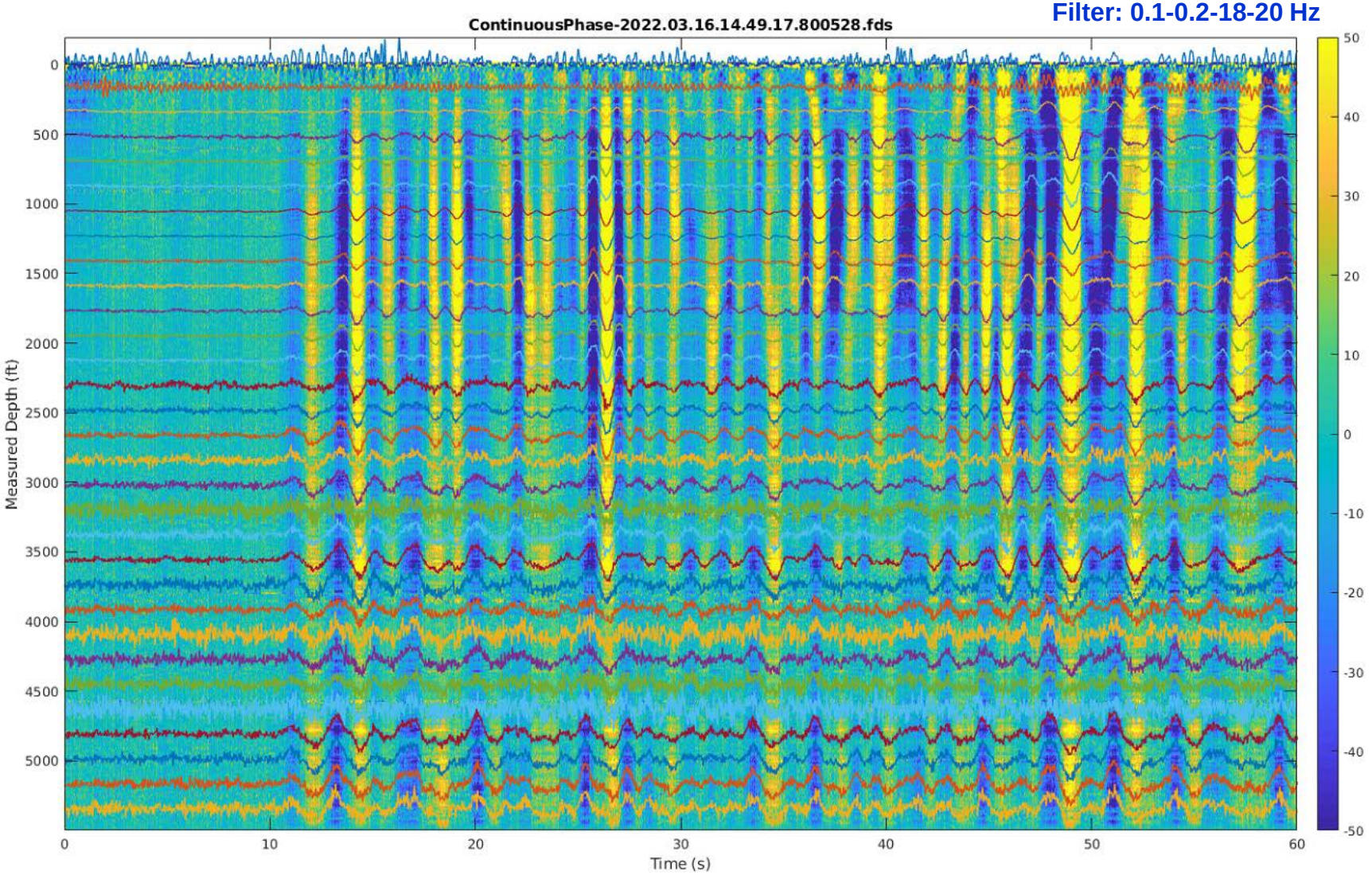

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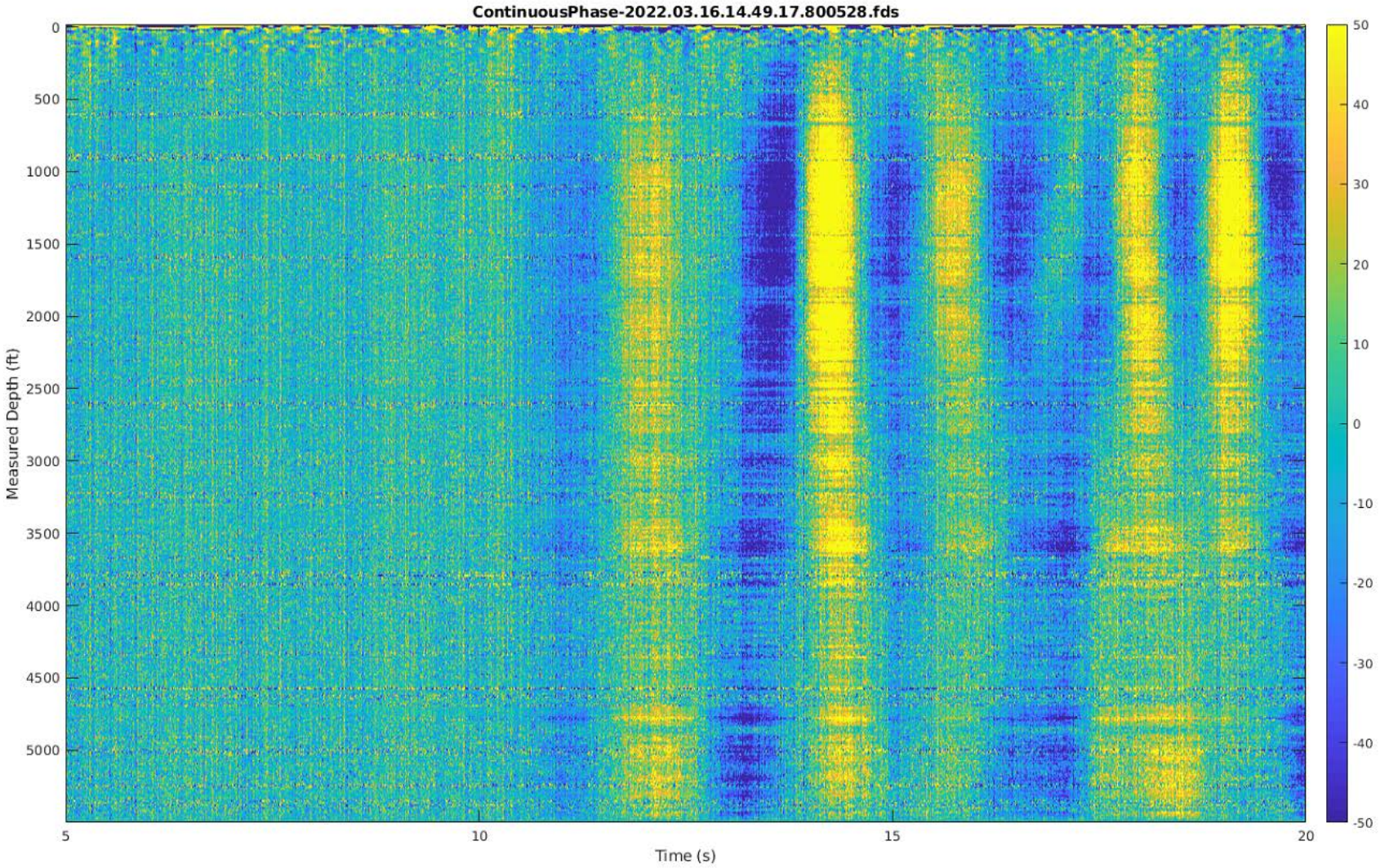

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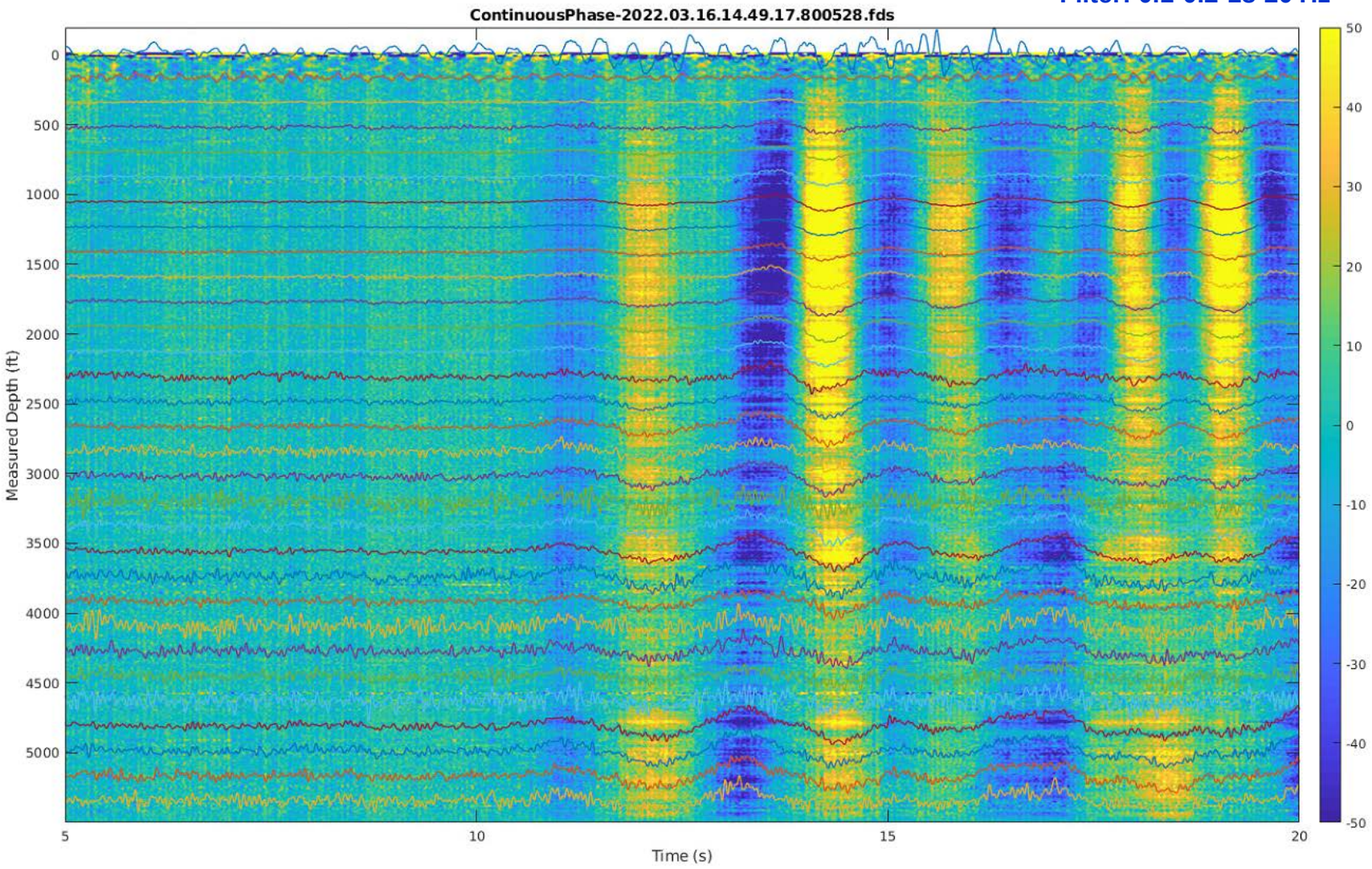
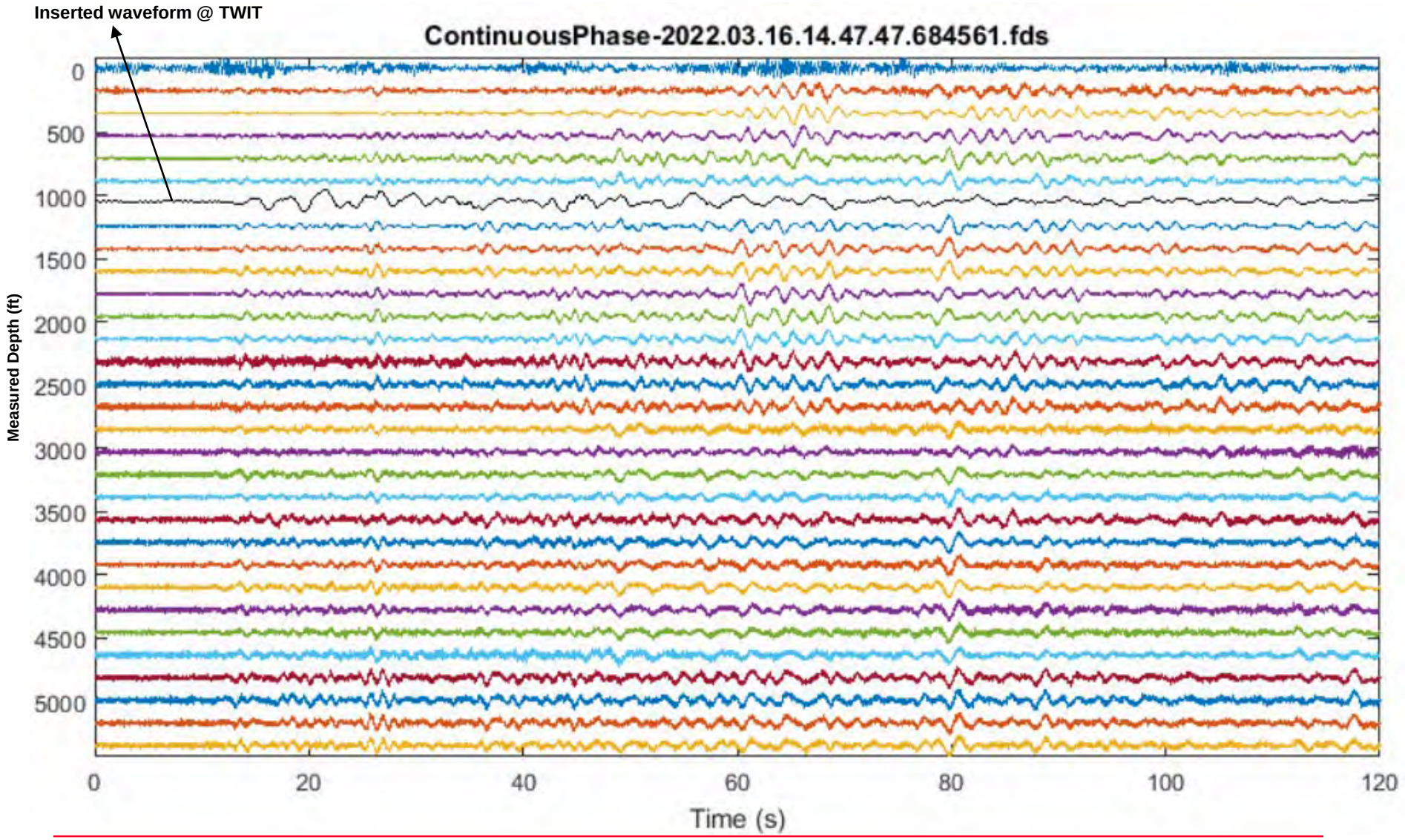


M7 & above Earthquakes: Fukushima M7.3 Earthquake

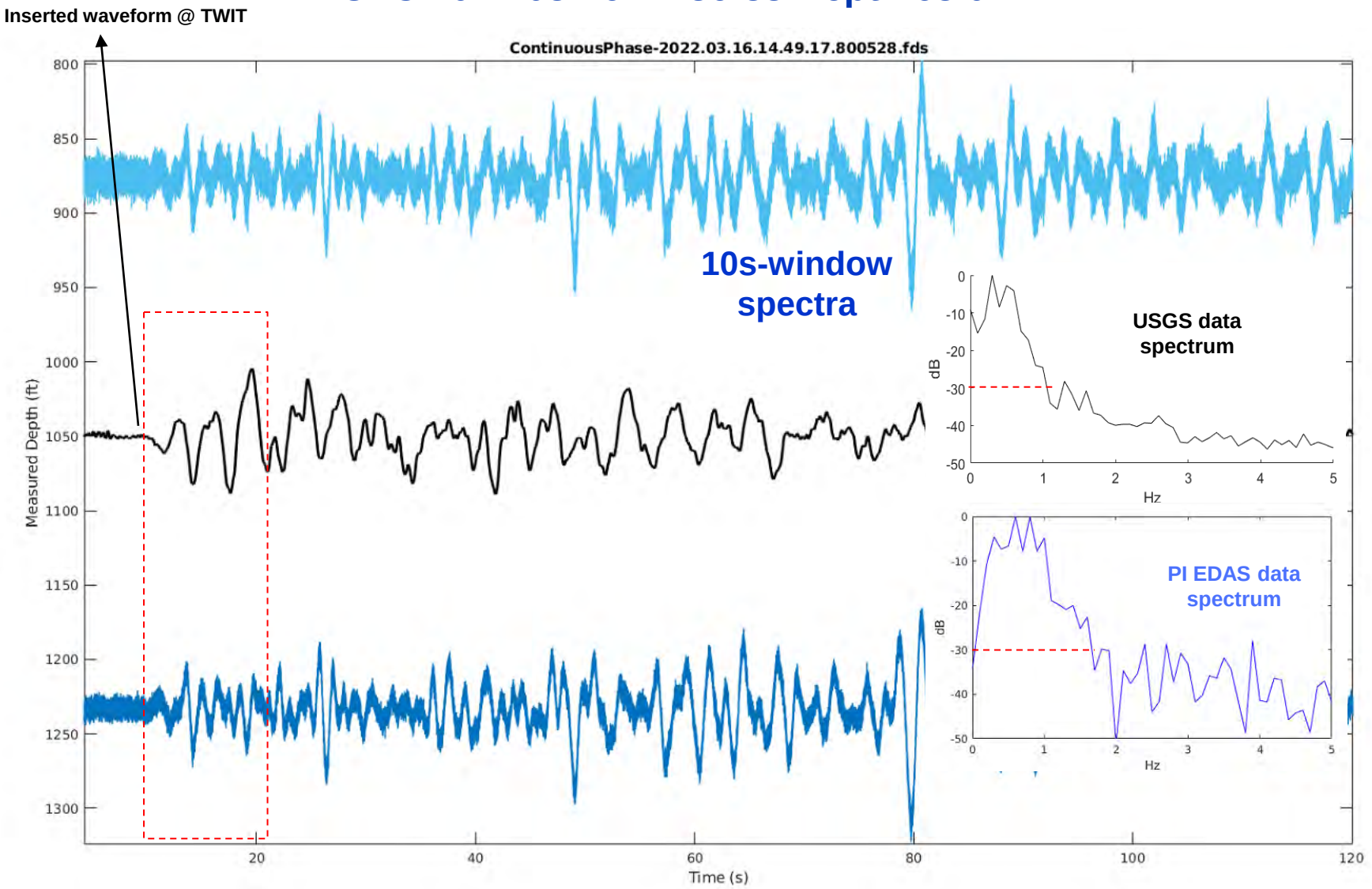
UTC 2022-03-16 14:36:33 Depth 63.07 km

waveforms



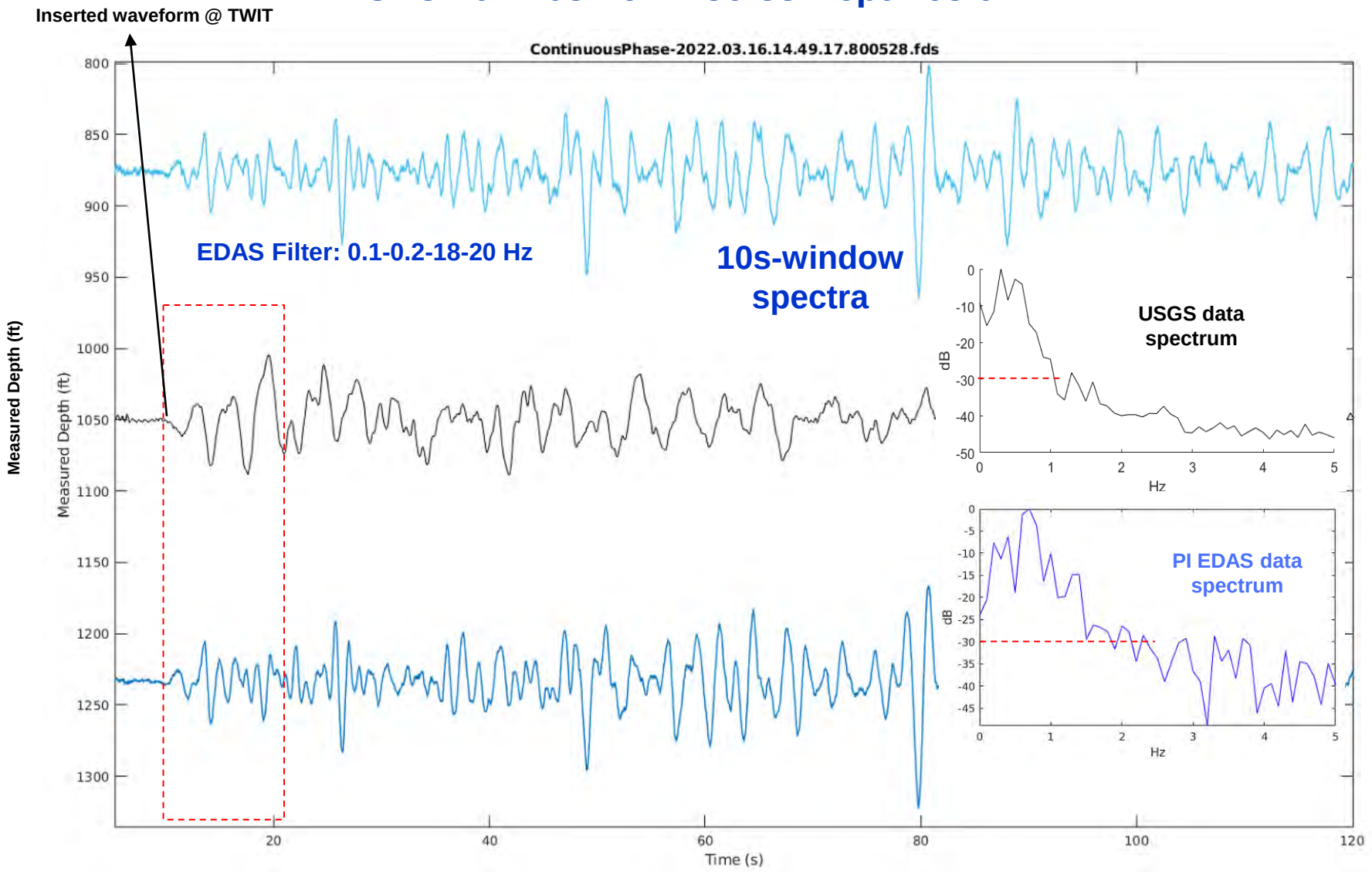
Fukushima M7.3 Earthquake Data Comparison

UTC 2022-03-16 14:36:33 Depth 63.07 km



Fukushima M7.3 Earthquake Data Comparison

UTC 2022-03-16 14:36:33 Depth 63.07 km



Optical Sensors to Secure our Energy
Underground Gas Storage (UGS)+Hydrogen
Carbon Capture Utilization and Storage (CCUS)
Enhanced Geothermal Systems (EGS)
Enhanced Oil & Gas Recovery (EOR)
Pipeline Monitoring on Hayward Fault

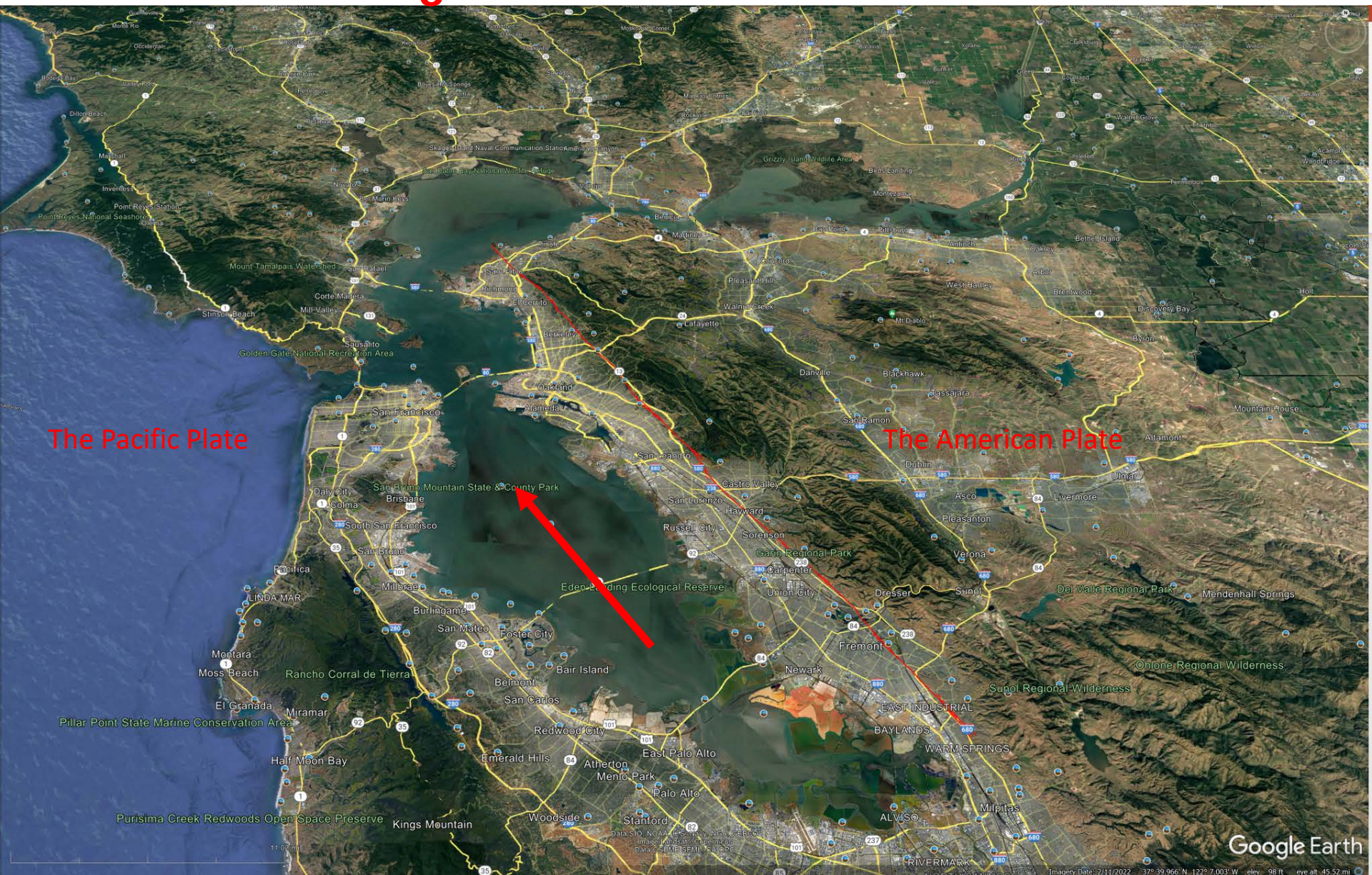
Björn Paulsson*, Mike Wylie & Ruiqing He
Paulsson, Inc.
March 9, 2023

Hayward Fault, California, The Bay Area

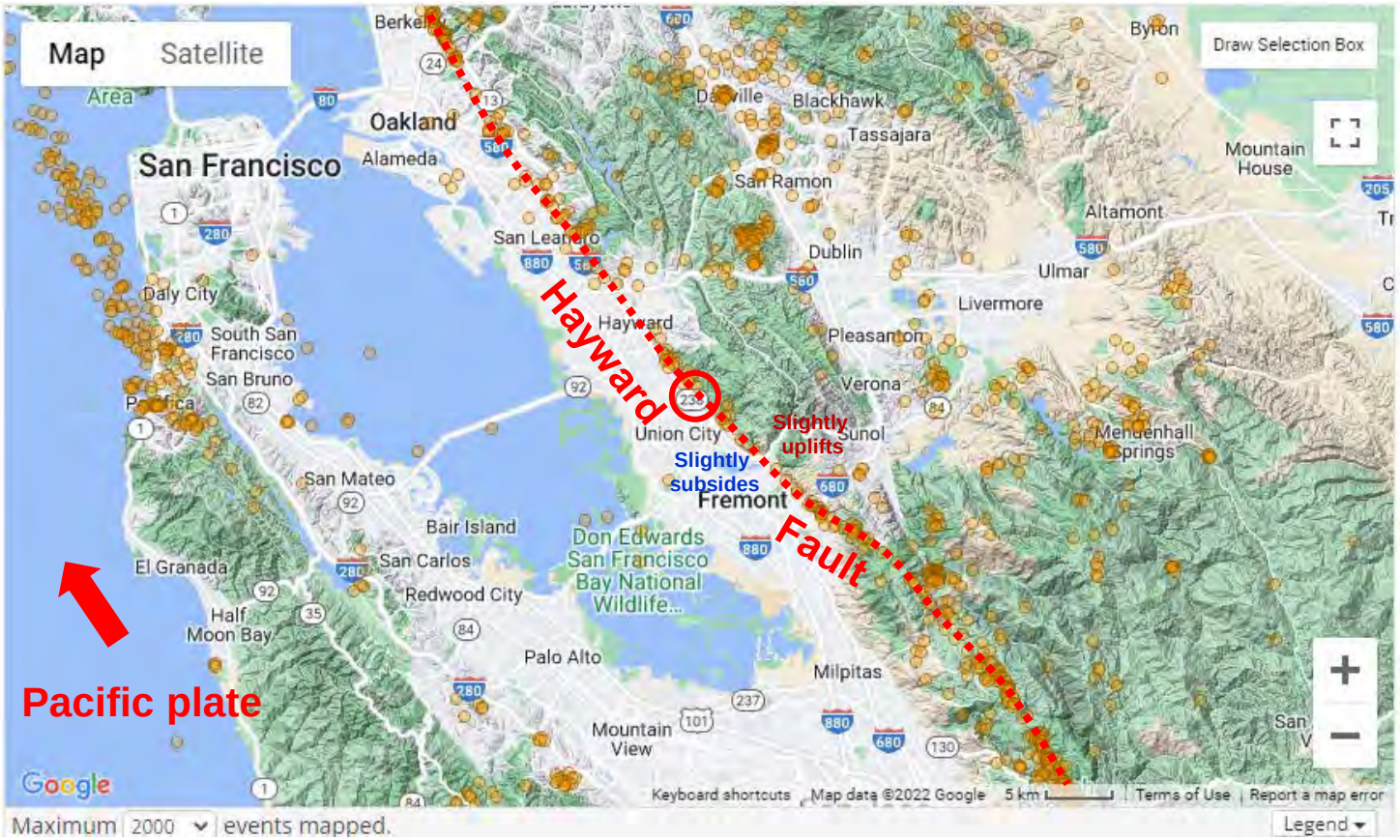
Tracking the Movements of Continents!

Hayward Fault, California, The Bay Area

Tracking the Movements of Continents!



Tectonics:



The Hayward Fault has a strike-slip motion which is when one land mass moves, nearly horizontally in the opposite direction of the other on the surface. This movement causes stress, which results in earthquakes. The Hayward Fault is a strike-slip fault on the surface but changes to a low angle thrust fault as it descends under the Easy Bay Hills. This creates an uplift of the East Bay hills in the Fremont area exposing the rocks of the Briones Formation, which is a fossilerous rock made of marine shells. It is Miocene in age and can be correlated to other similar sediments throughout coastal California. https://www.msnucleus.org/haywardfault/signs/science.html

Hayward Fault, California, The Bay Area

Tracking the Movements of Continents through Neighborhoods

Location:

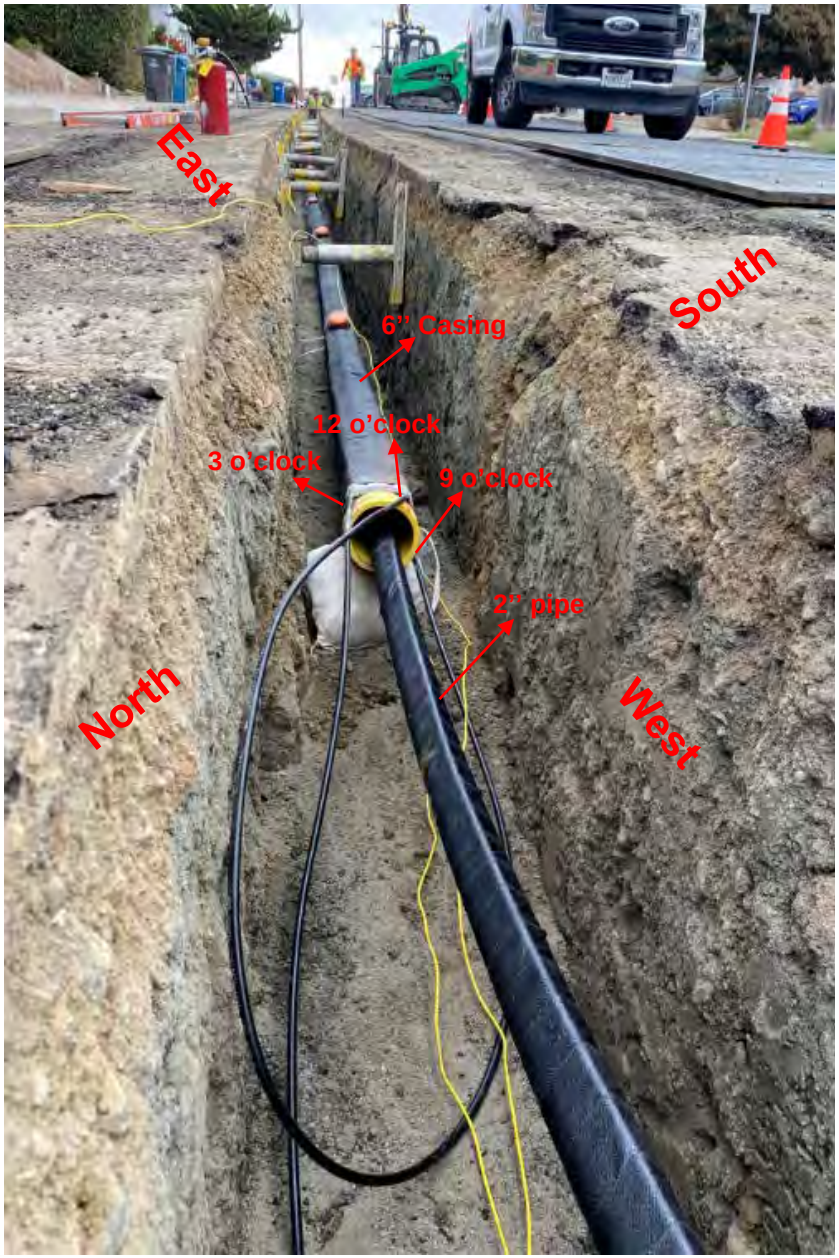
629 Tamarack Dr, Union City, CA

Point	Order Conducted	GPS Coordinates
1	3	37°36.617, -122°01.175
2	4	37°36.621, -122°01.186
3	5	37°36.623, -122°01.195
4	1	37°36.628, -122°01.213
5	2	37°36.631, -122°01.221
6	6	37°36.623, -122°01.193

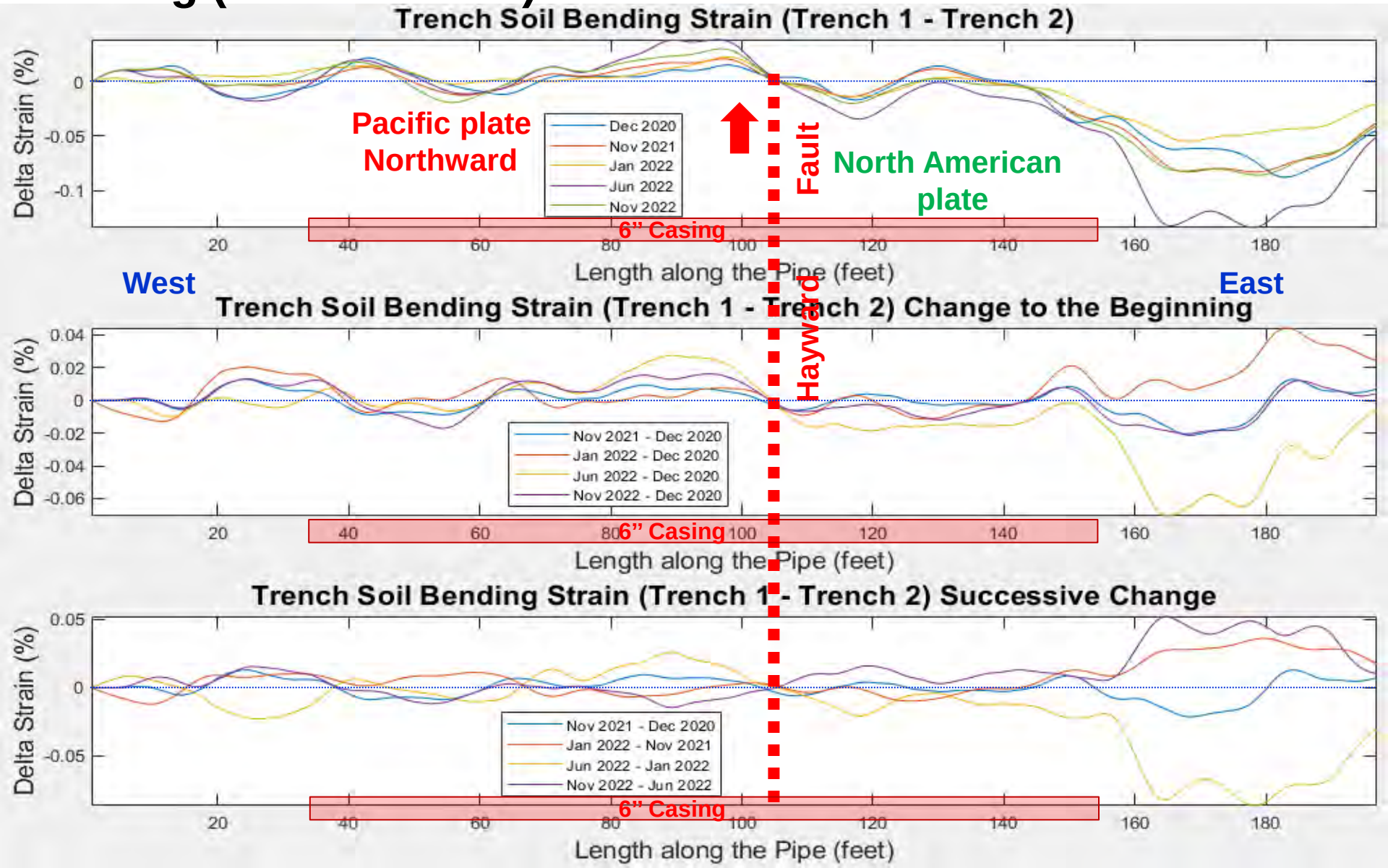
West **East**

Field Photos:

Field Photos:



Bending (North - South) Strain of The Soil in The Trench:

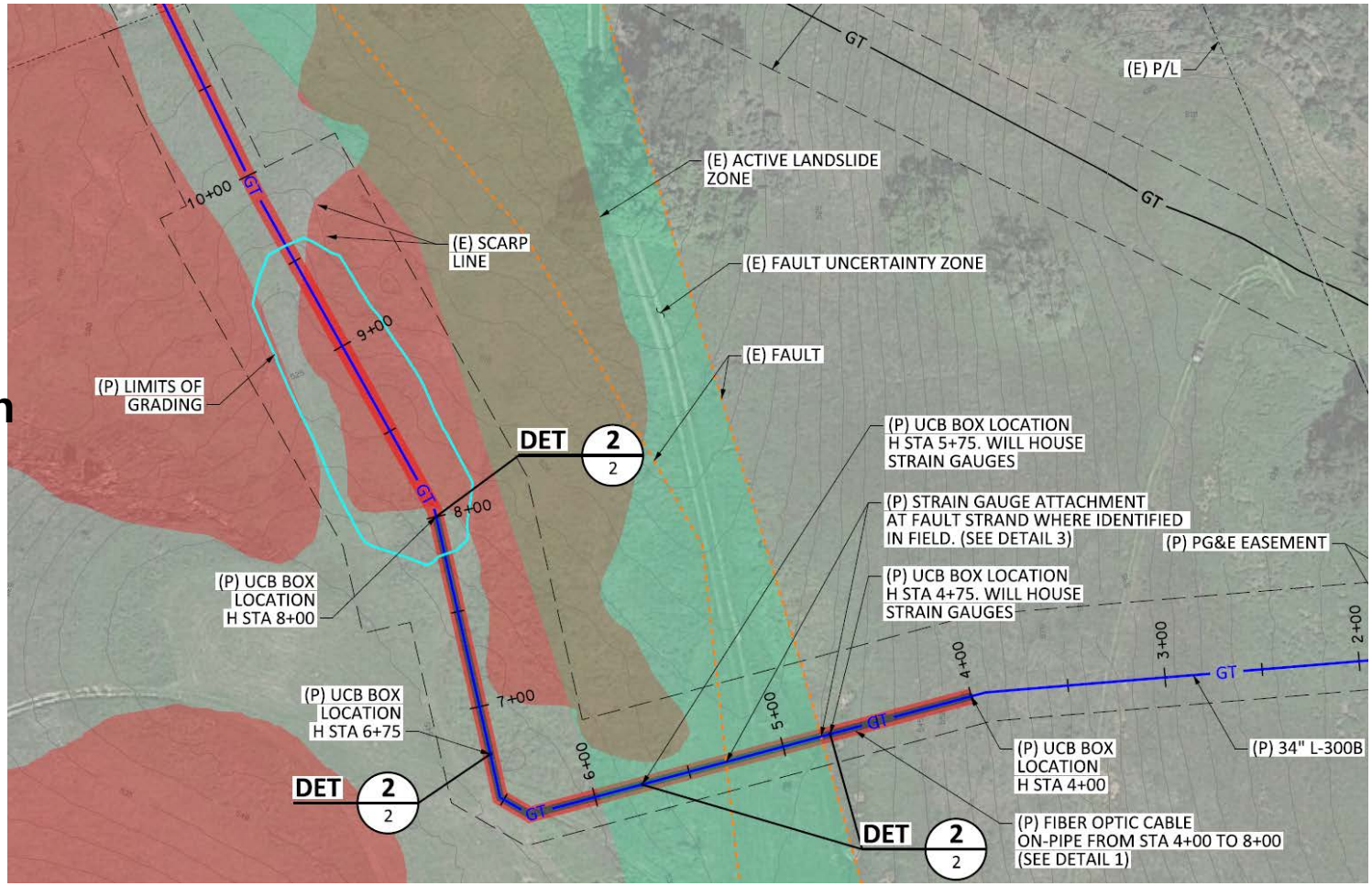


The Pipeline Instrumentation Project

400 ft of pipe is to be instrumented with fiber directly on the pipe.

The location of the ‘boxes’ are every ~80 feet on the heavily inclined portion of the installation.

The last box is at 800 ft.



Crossing the Calaveras Fault Gas Pipeline Monitoring Using Optical Strain, Acoustic, & Temperature Sensors. One Sensor every 3ft. This section is 220ft so 73 optical sensors of each kind.

Installation of Fiber Optic Cable on a Pipeline Crossing the Calaveras Fault

For More Information Contact

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