

GOPH 5334: Induced Seismicity

Lecture 10: Microseismic and Distributed Acoustic Sensing

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March 4, 2026

Outline

❖ Microseismic data

- Detection and location
- Fracture interpretation
- Bedding plane slip

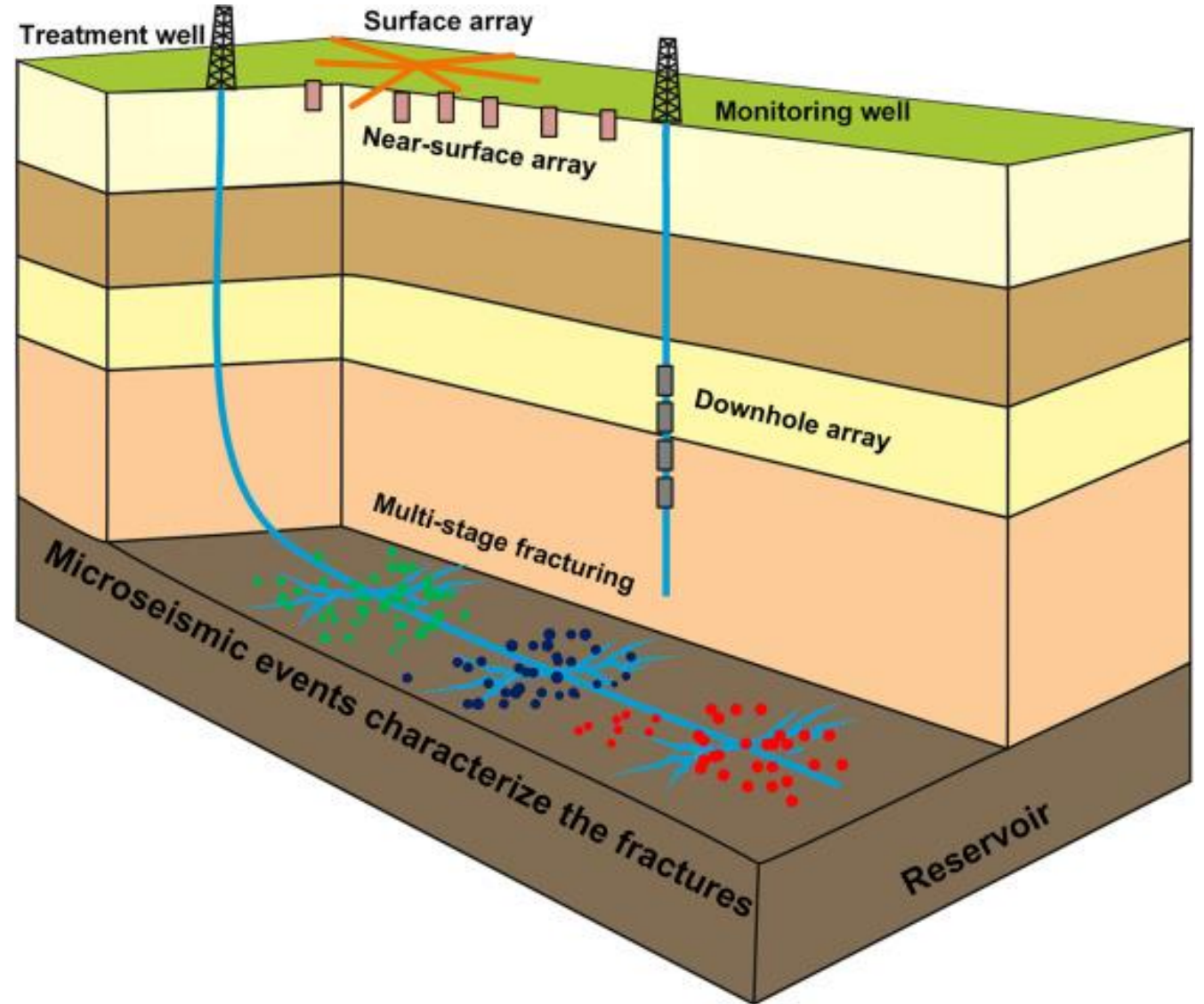
❖ What is distributed acoustic sensing (DAS)?

- Low-frequency vs. high-frequency DAS
- DAS for hydraulic fracturing and microseismic

❖ Looking forward: Texas induced seismicity

Microseismic Data

- ❖ Microseismic data is typically acquired using downhole instrumentation. This is due to signal to noise limitations.
- ❖ The purpose of microseismic monitoring is to **map the extent of hydraulic fractures**.
- ❖ This is usually done for 1-2 wells in a region when a company begins to work there to validate their internal modelling work.
- ❖ Microseismic datasets are rare and worth their weight in gold (\$ millions to acquire and process).

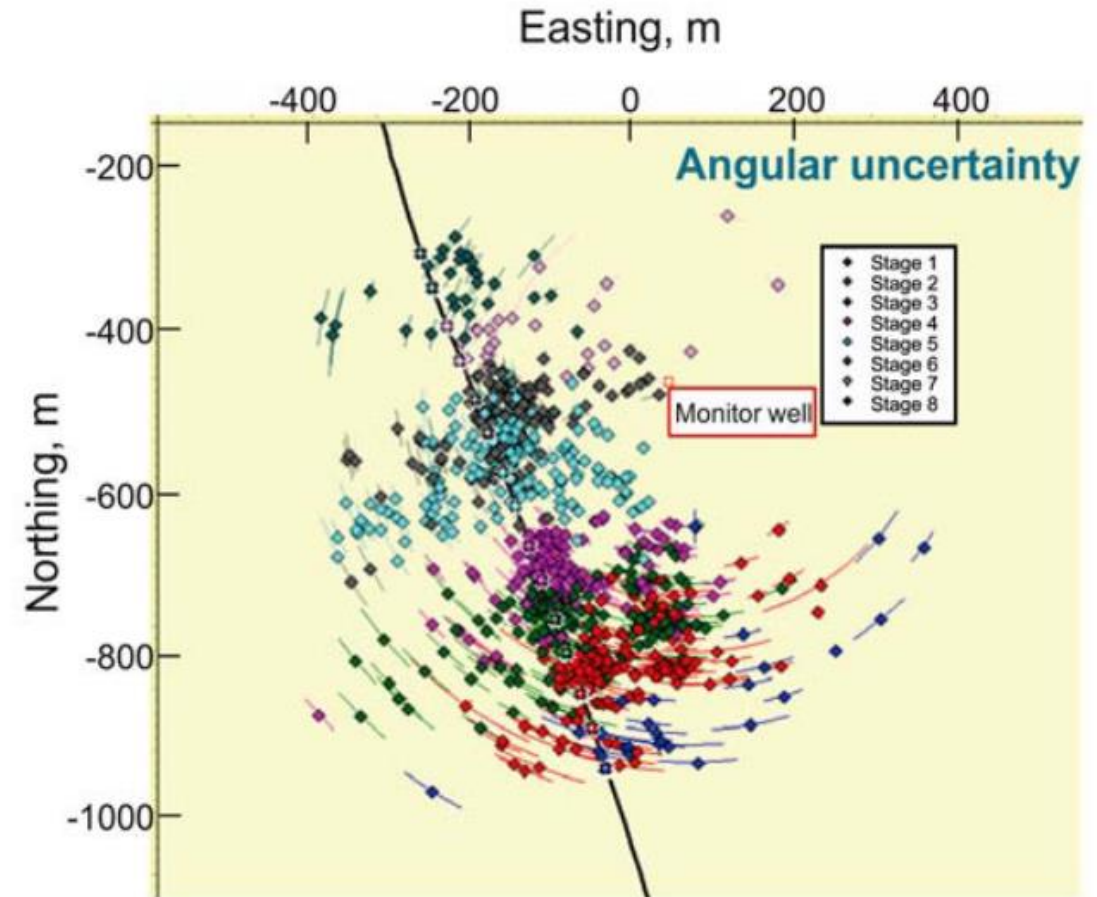
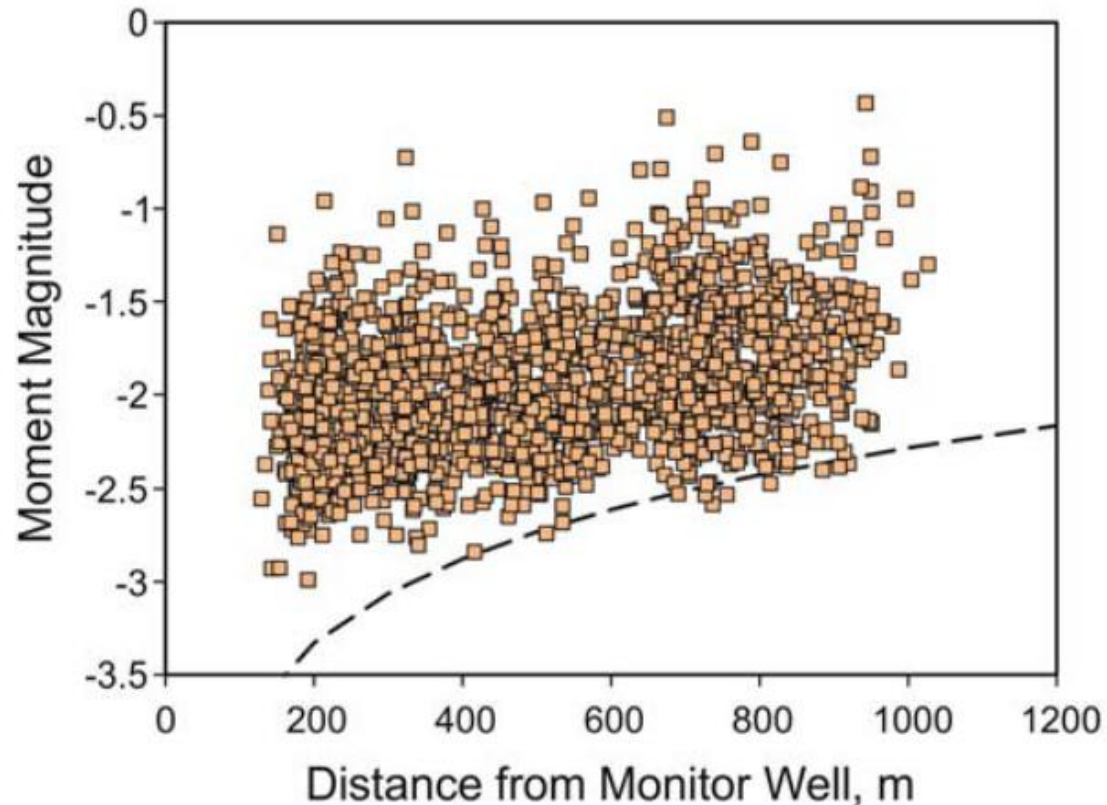


Li et al., 2022

Microseismic Data

- ❖ Detection and location of microseismic events has specific challenges because the events are so small and the monitoring geometry is often unfavorable.

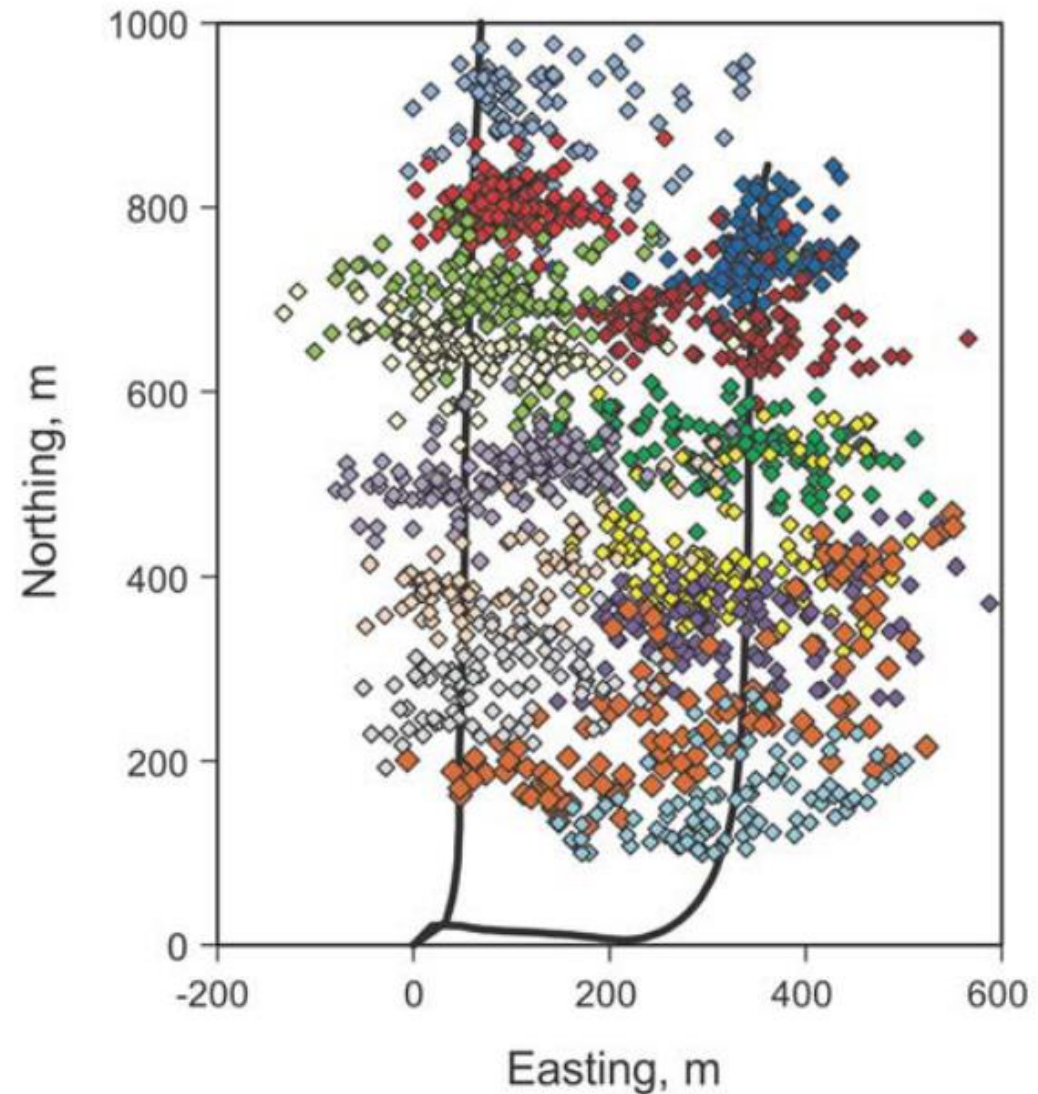
Magnitude distance plot



Warpinski, 2014

Microseismic Data

- ❖ This is an example from a simple well completion. This is what we expect to see when we look at microseismic data.
- ❖ The seismicity is close to the injection wells and each stage is isolated.
- ❖ The **stimulated volume** can be estimated from the microseismic cloud.
- ❖ Stimulated volume is related to the oil yield over the duration of production.



Warpinski, 2014

Microseismic Data

- ❖ **Focal mechanism** determination is especially challenging for microseismic data.

- ❖ This is a comparison between surface and downhole monitoring.

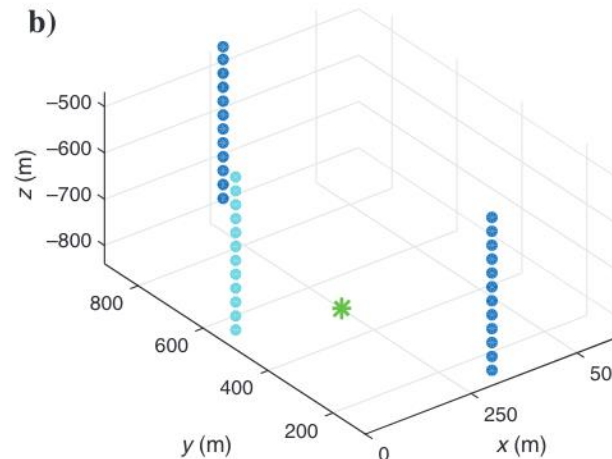
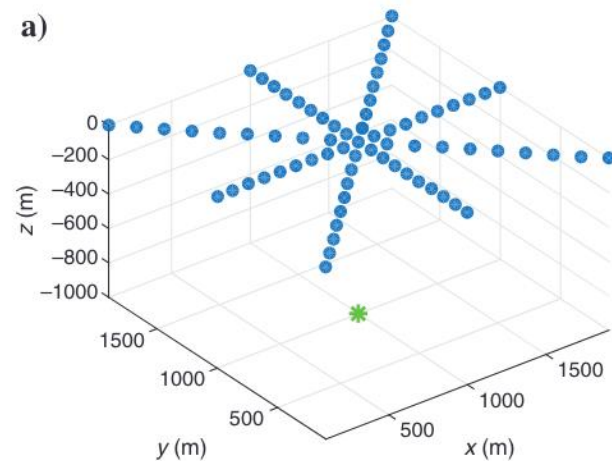
- ❖ The circles are focal spheres and the points are where the stations fall on the focal sphere. For a stable solution, you want good coverage.

- ❖ The sensitivity for the downhole arrays is significantly reduced → consider what would happen if there was only one downhole array?

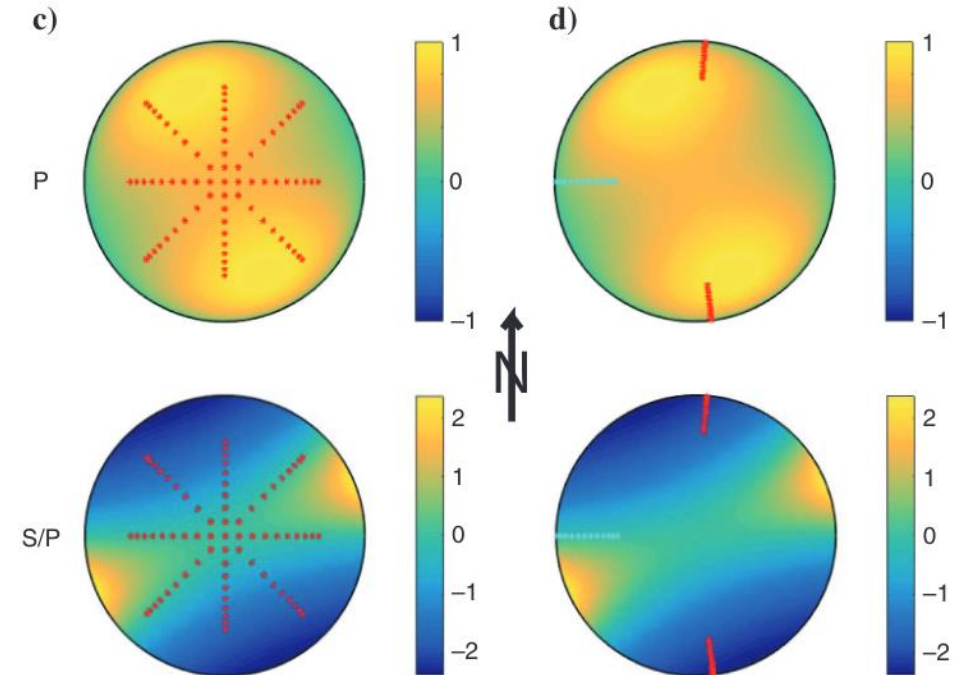
The reliability of microseismic moment-tensor solutions: Surface versus borehole monitoring

2017

Thomas S. Eyre¹ and Mirko van der Baan²



Focal spheres



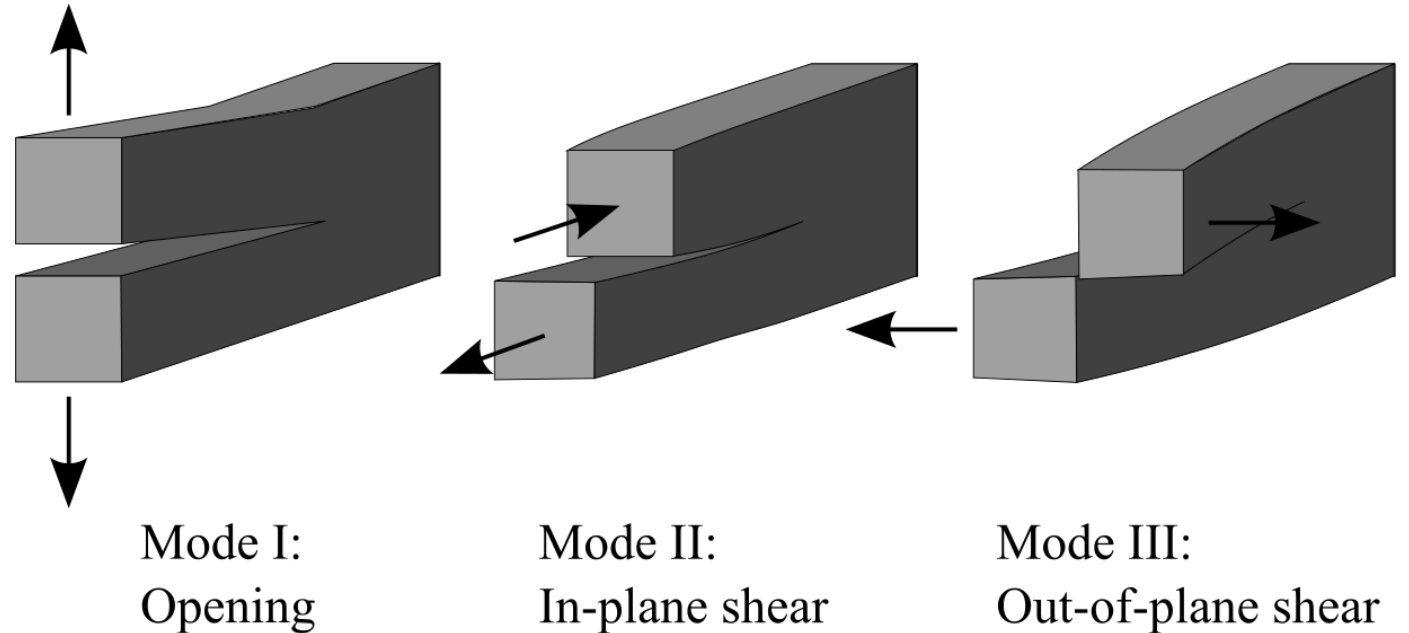
Microseismic Data

❖ Why do we want to calculate focal mechanisms for microseismic data? One reason would be to see if we can identify seismicity related to **opening/closing** of hydraulic fractures. These are called **compensated linear vector dipole (CLVD)** events.

❖ We are referring to Mode I, tensile opening.

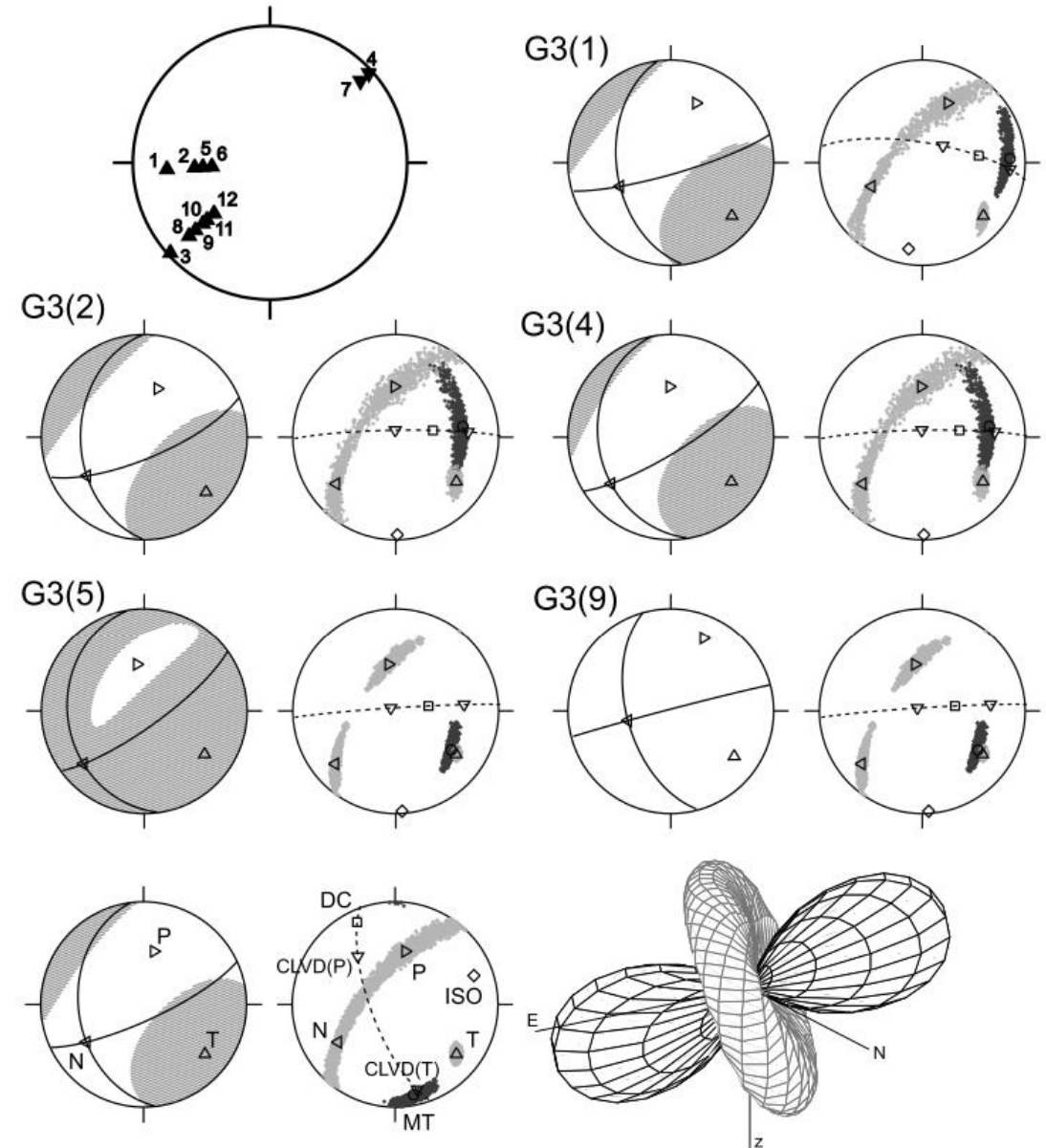
❖ Is it possible to find such events?

$\frac{1}{\sqrt{6}} \begin{pmatrix} 1 & 0 & 0 \\ 0 & -2 & 0 \\ 0 & 0 & 1 \end{pmatrix}$		$\frac{1}{\sqrt{6}} \begin{pmatrix} -2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$	
$\frac{1}{\sqrt{6}} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$		$-\frac{1}{\sqrt{6}} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$	



Microseismic Data

- ❖ Is it possible to find such events?
- ❖ Perhaps. But evidence is limited. Most cases are in regions of high uncertainty and poor station coverage.
- ❖ Let's do a sanity check. When you think of fault slip, the energy release is related to the fault surface and the sides of the fault moving past each other.
- ❖ What kind of “sound” does fracture opening make?



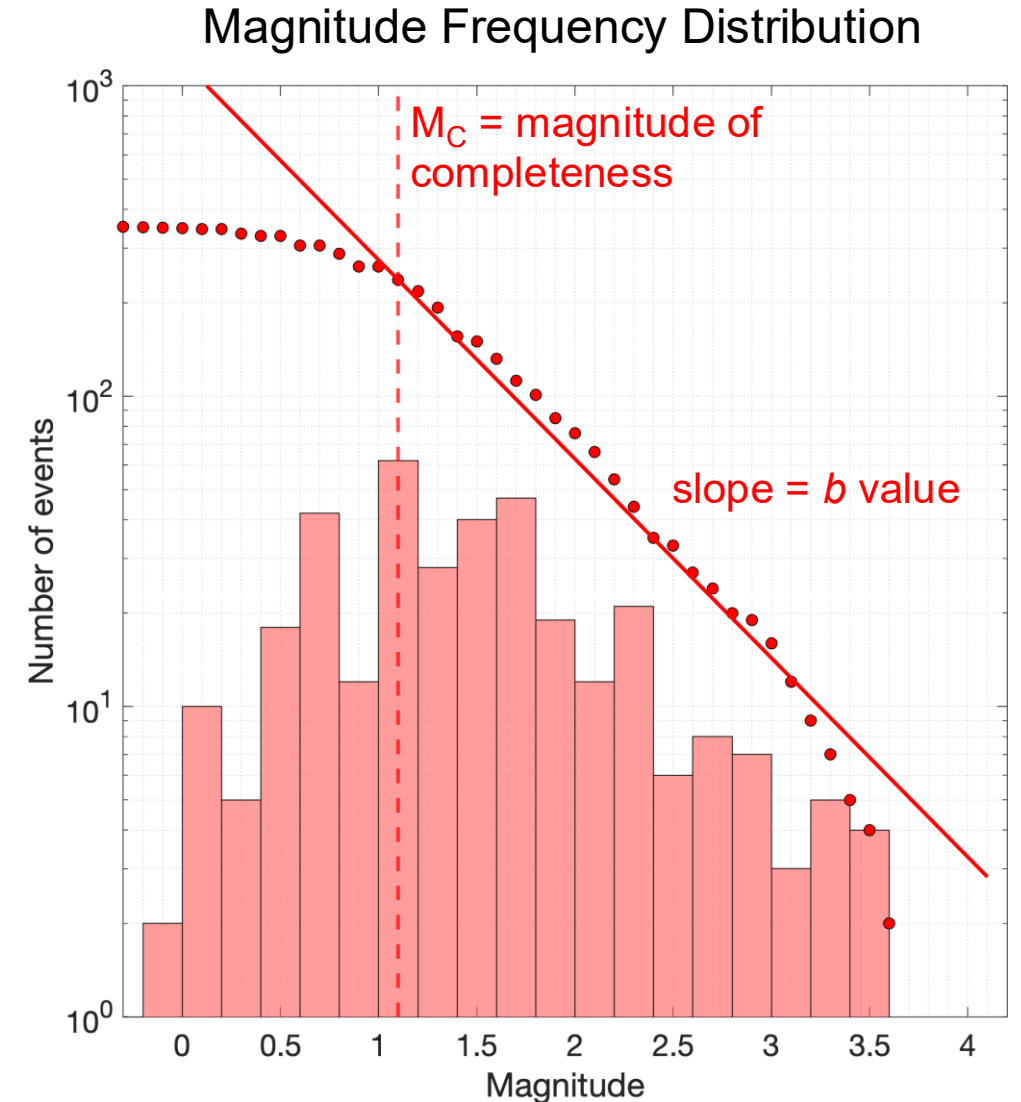
b values

- ❖ Another special aspect of microseismic is the *b*-values.
- ❖ Recall:
- ❖ The Gutenberg-Richter *b value* is the slope of the cumulative distribution of the MFD.

Number of earthquakes Magnitude

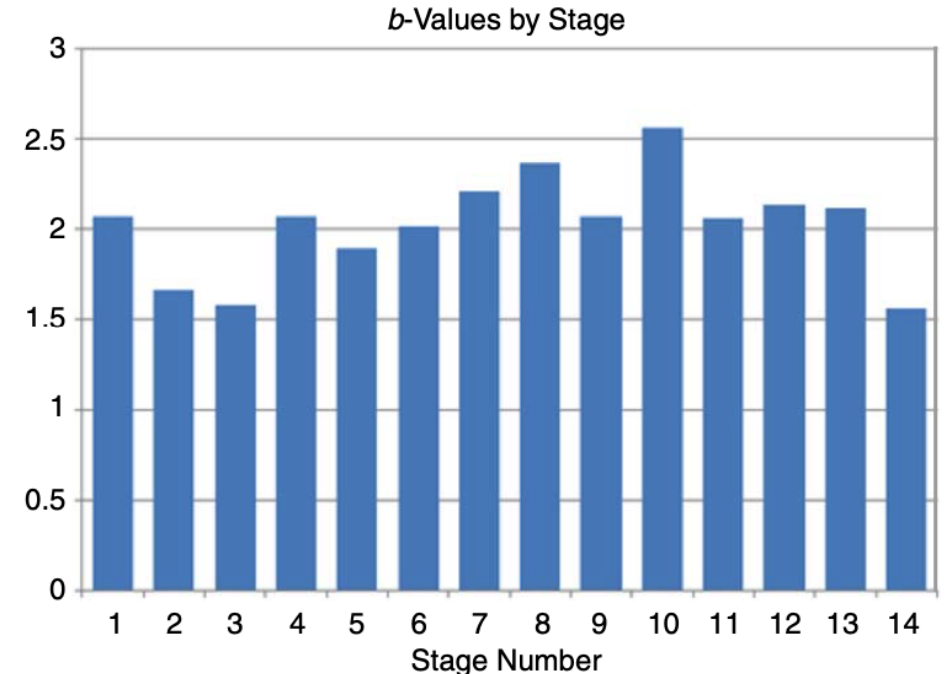
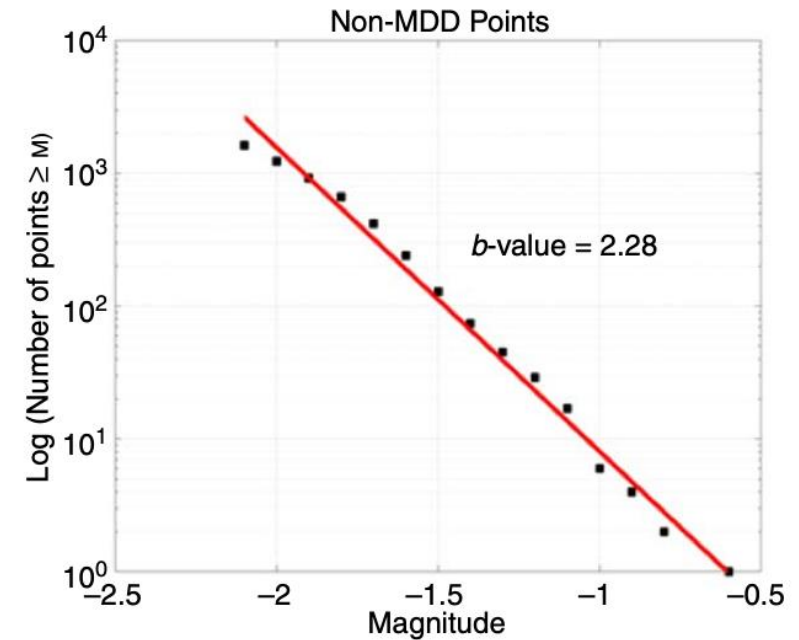
$$\log(N) = a - b(M)$$

a value *b* value



***b* values**

- ❖ In the context of induced seismicity, when we see a ***b* value of ~1**, we know that we have fault activation.
- ❖ We also know that the lower the *b* value, the higher the risk of larger magnitude seismicity.
- ❖ What does a ***b* value of 2** mean?
 1. Strata-bound fractures: repeated energy release through small events.
 2. A decreased likelihood of larger magnitude seismicity.
- ❖ A *b* value close to 2 is a hallmark for fracture activation during hydraulic fracturing.



Fracture Interpretation

- ❖ Let's look at a case study from the Midland basin.
- ❖ Hydraulic Fracturing Test Site 1 (HFTS1)
 - Midland Basin, Reagan County
 - 13 wells hydraulically fractured
 - Upper and Middle Wolfcamp
- ❖ Monitored with horizontal and vertical geophone arrays that were moved as the stages were completed.
 - 128,405 events

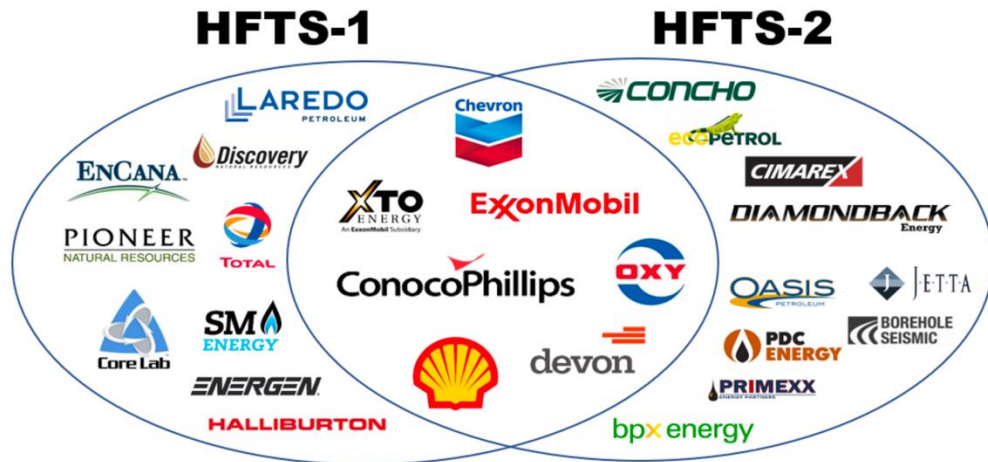
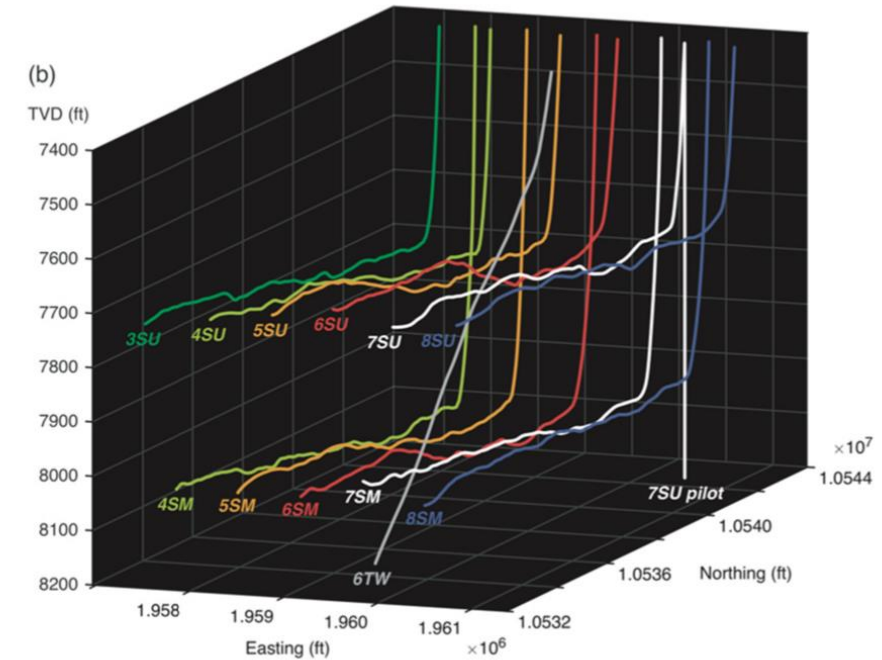
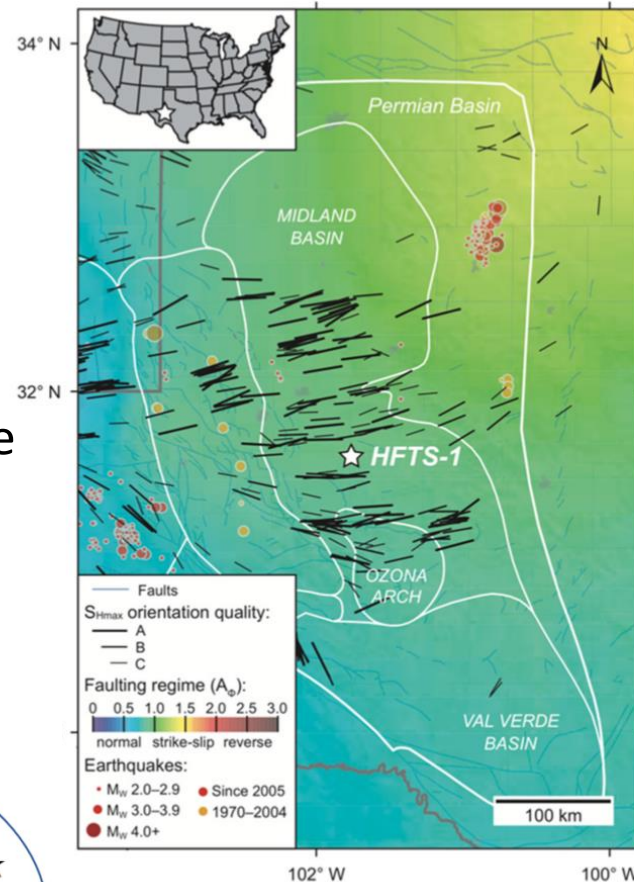


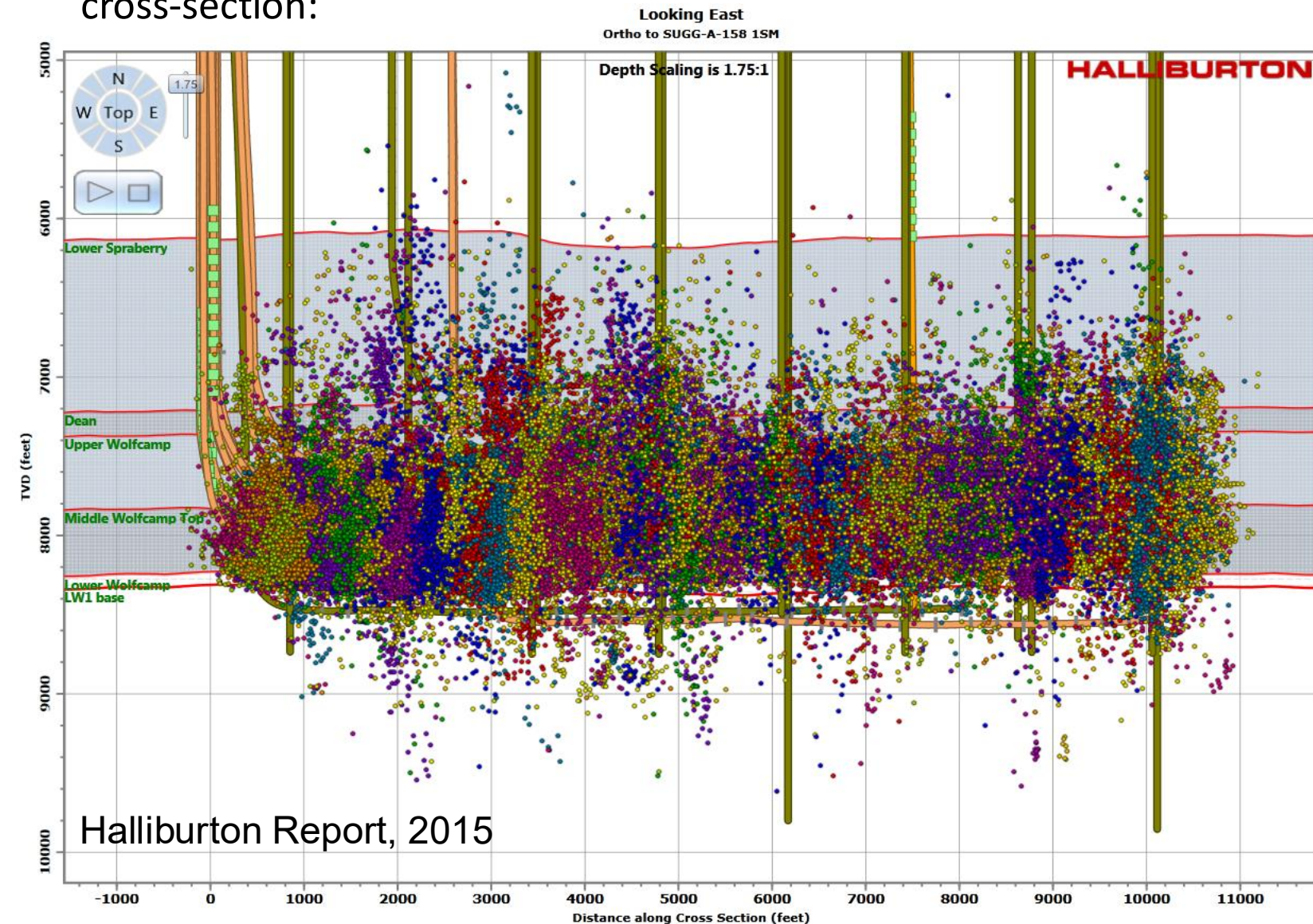
Figure 2: HFTS Industry Sponsors



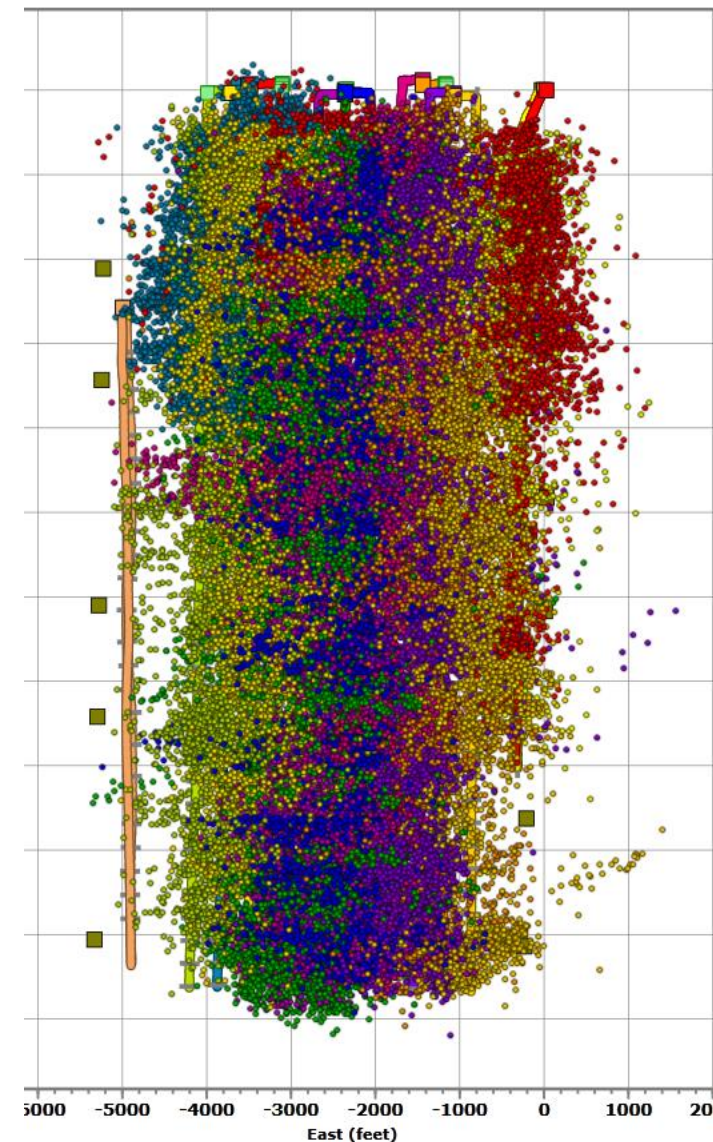
Kohli & Zoback, 2021

Fracture Interpretation

- There were a lot of events detected and located. Below is a cross-section:

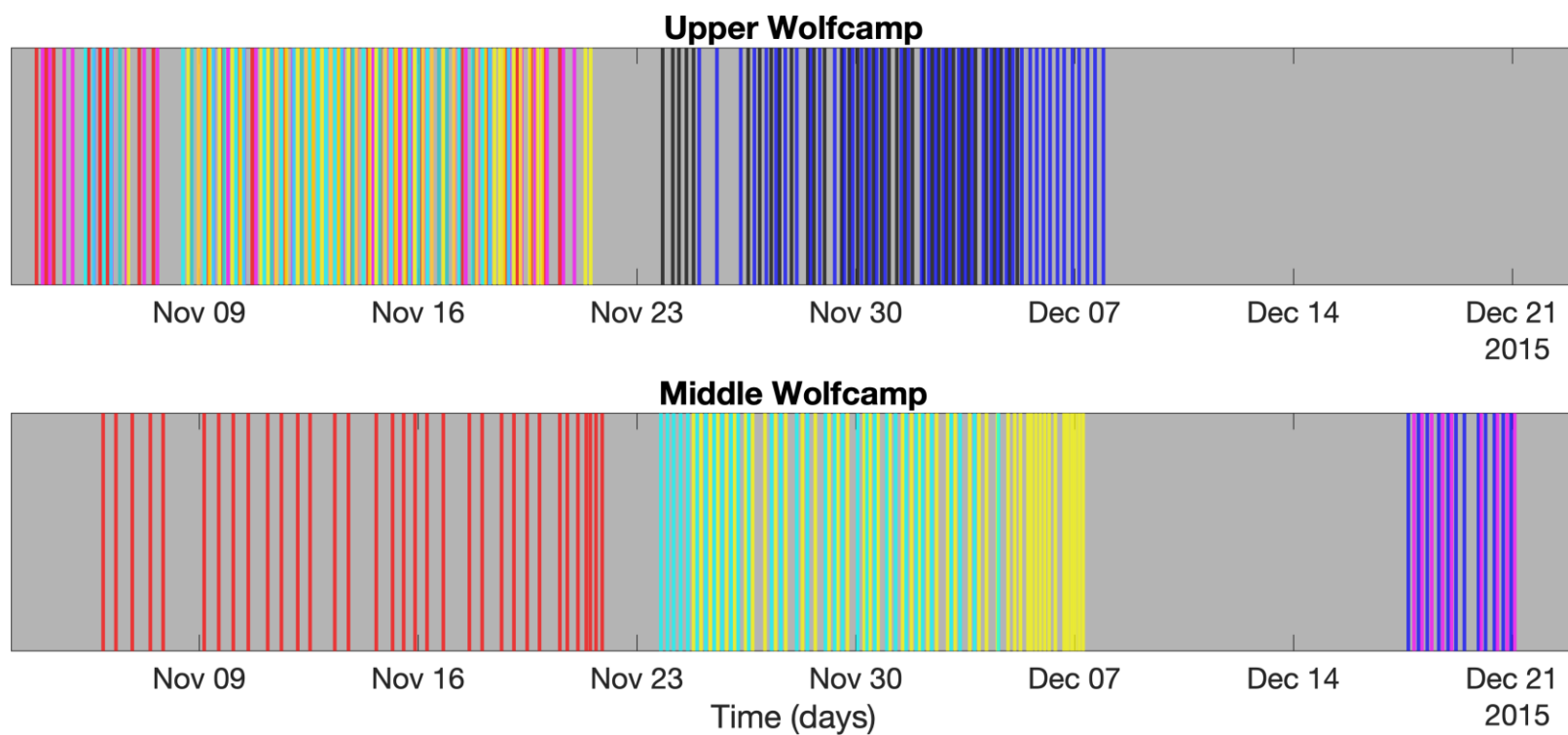


Map view:



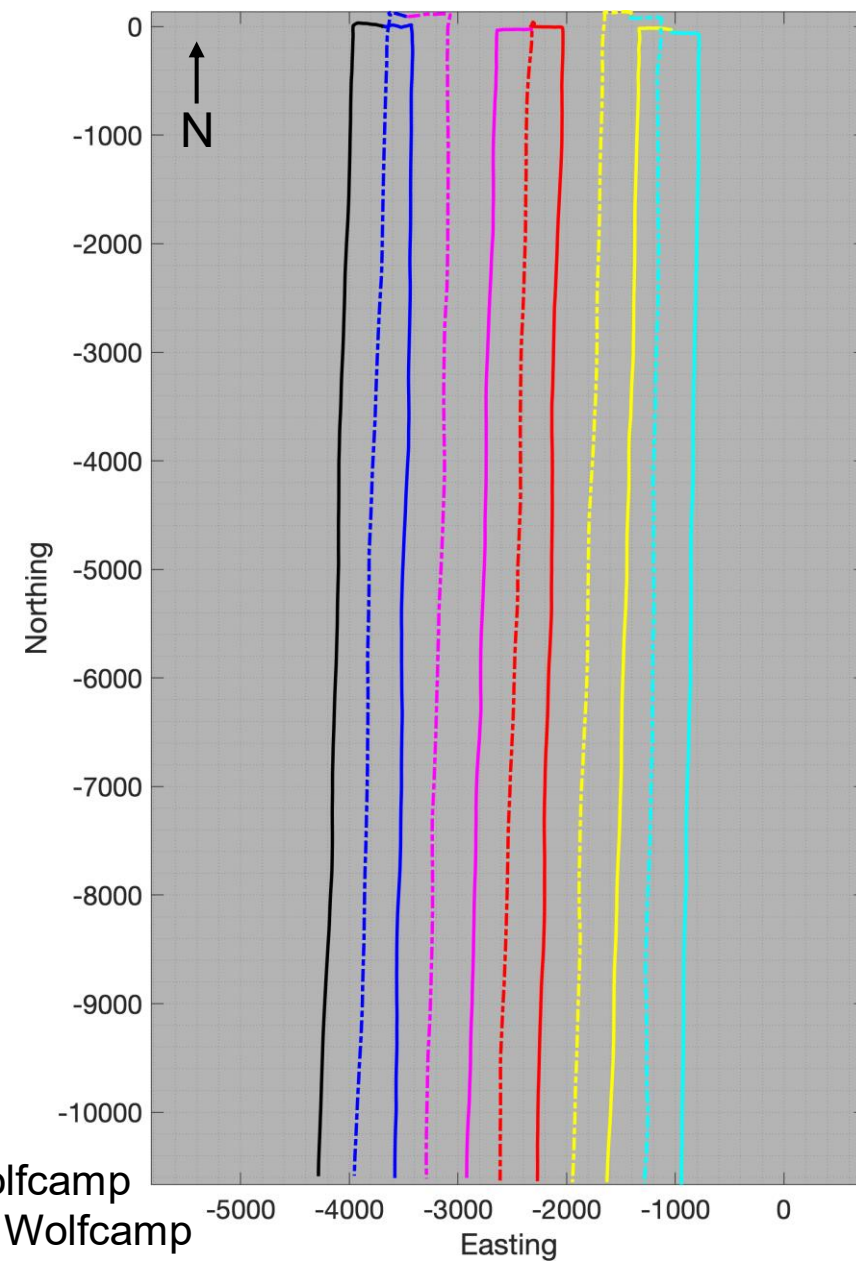
Fracture Interpretation

❖ Timeline of the HF stages:



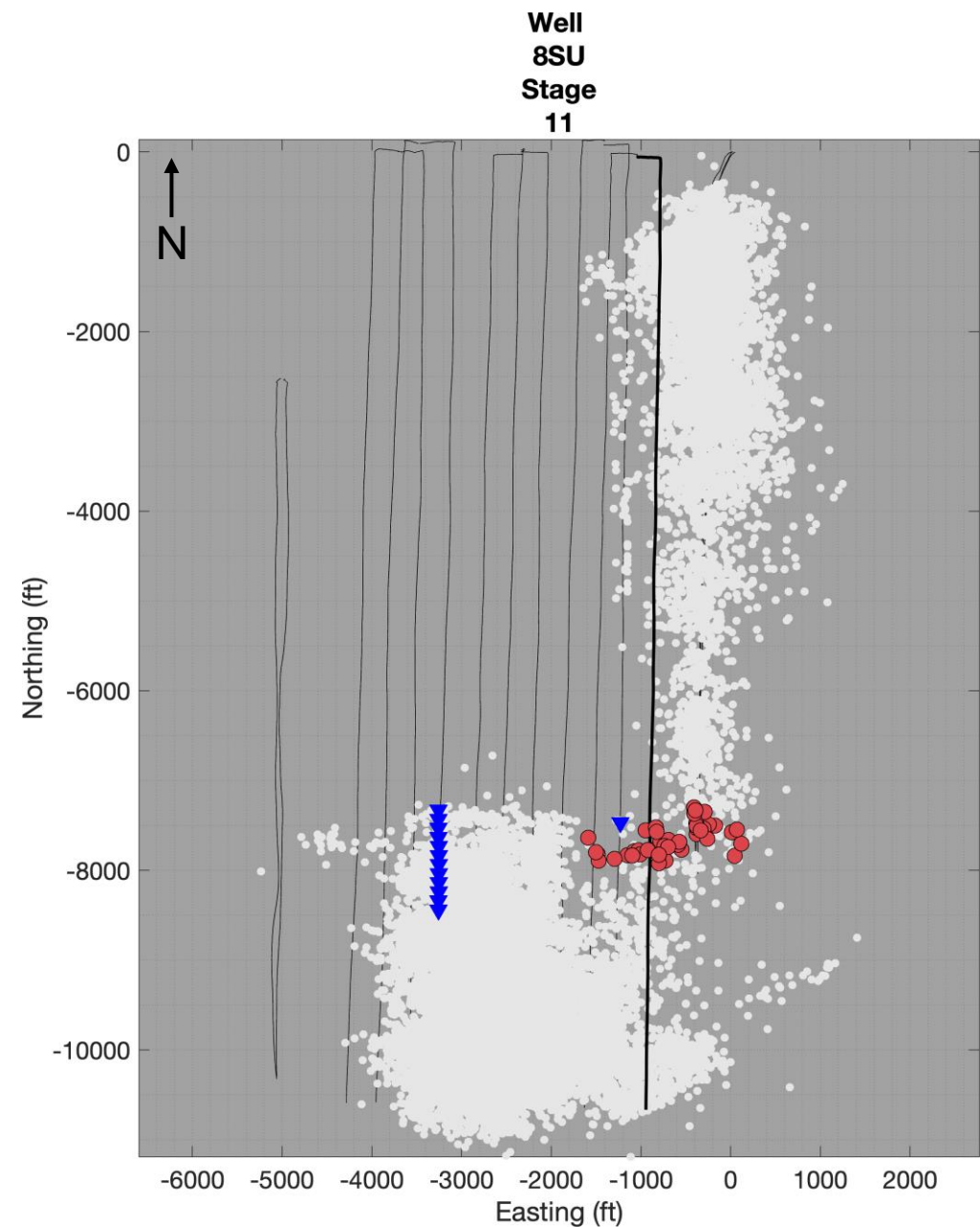
This is a lot of activity!

Solid lines: Upper Wolfcamp
Dashed lines: Middle Wolfcamp



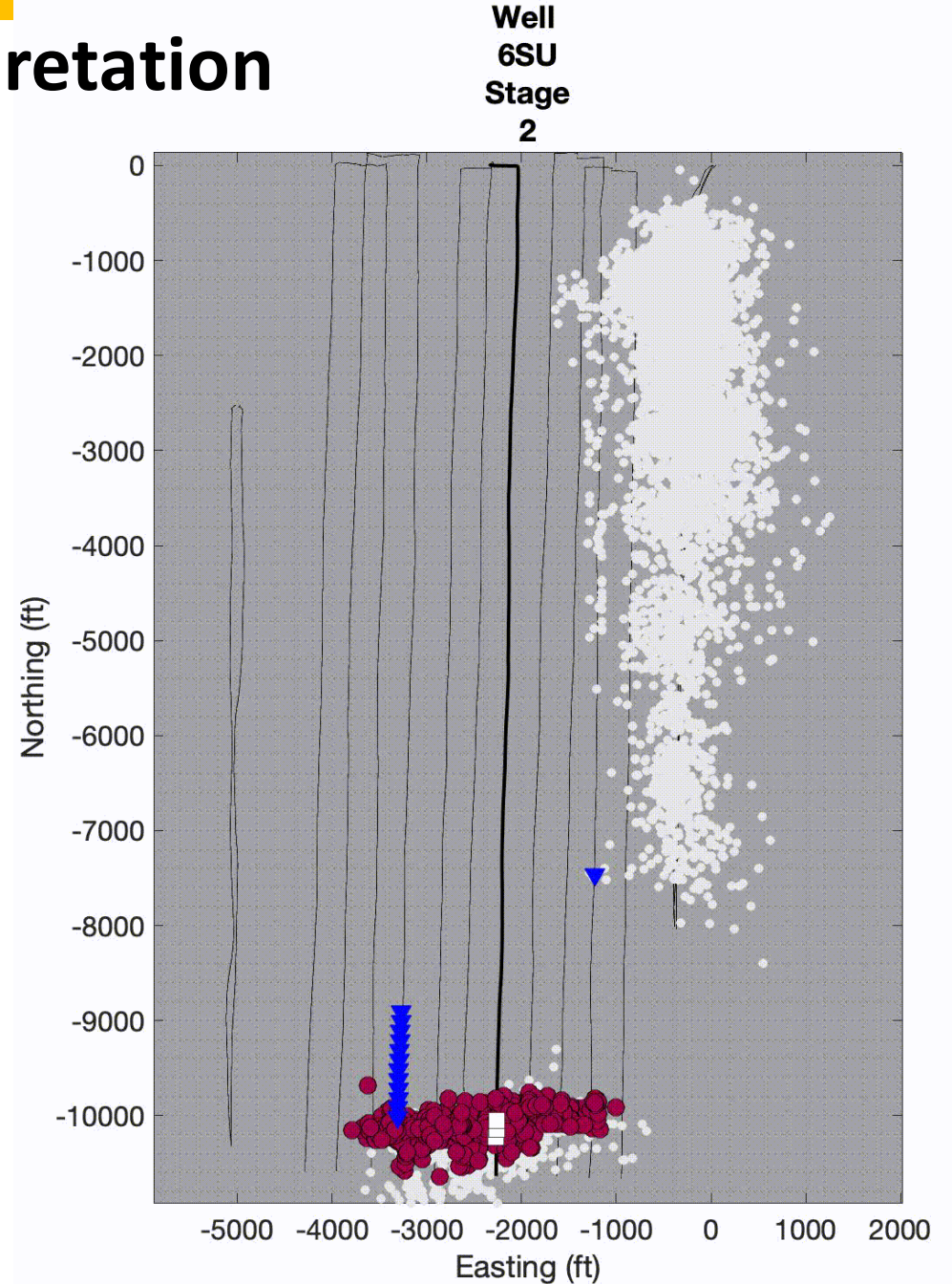
Fracture Interpretation

- ❖ Example stage near the beginning of the program
 - **Blue triangles**: monitoring locations
 - **Grey circles**: previous events
 - **Red circles**: events during the stage
- ❖ The microseismic cloud is small (~ 300 m half-length).



Fracture Interpretation

- ❖ Animation of HF stages:
 - The **horizontal arrays** are moved as the HF stimulation goes from the toe to the heel.
 - One of the **vertical arrays** (-1000,-7500) remains operational for most of the treatment, others come on and off.
 - Twice we have a progression from S to N.
 - Total of 374 stages.

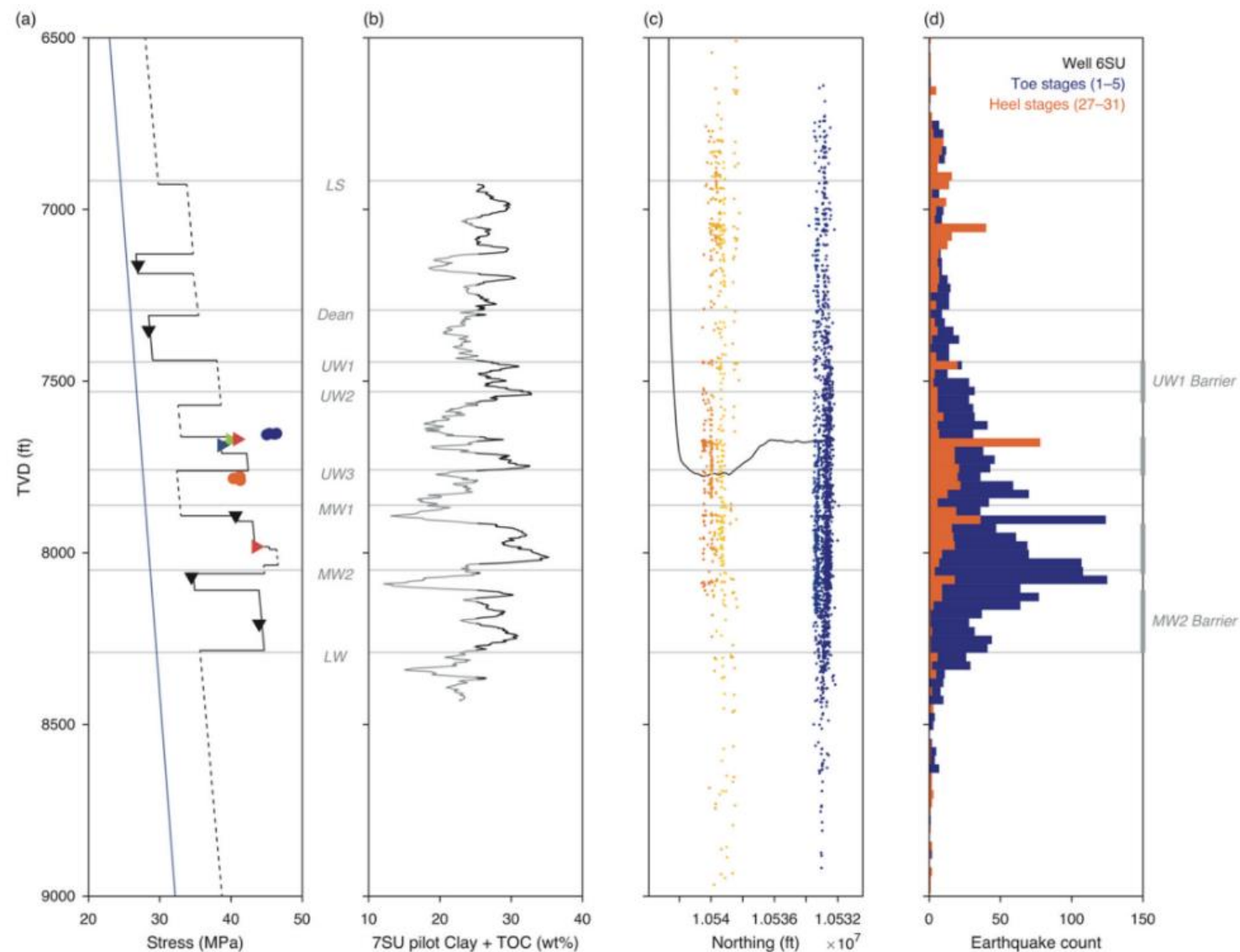


Fracture Interpretation

- ❖ This particular project showed a lot of vertical fracture growth; note the vertical scale.
- ❖ Note the vertical stress heterogeneity and how quickly the stress changes from formation to formation.

Proppant Lbs/ft	Fluid Bbl/ft	Fracture height		Fracture half length	
		Upwards	Downwards	West	East
1100	33-36	1,228	935	1,659	1,207
1400	38-40	1,070	567	1,242	1,105
1800	55-58	642	586	902	1,109

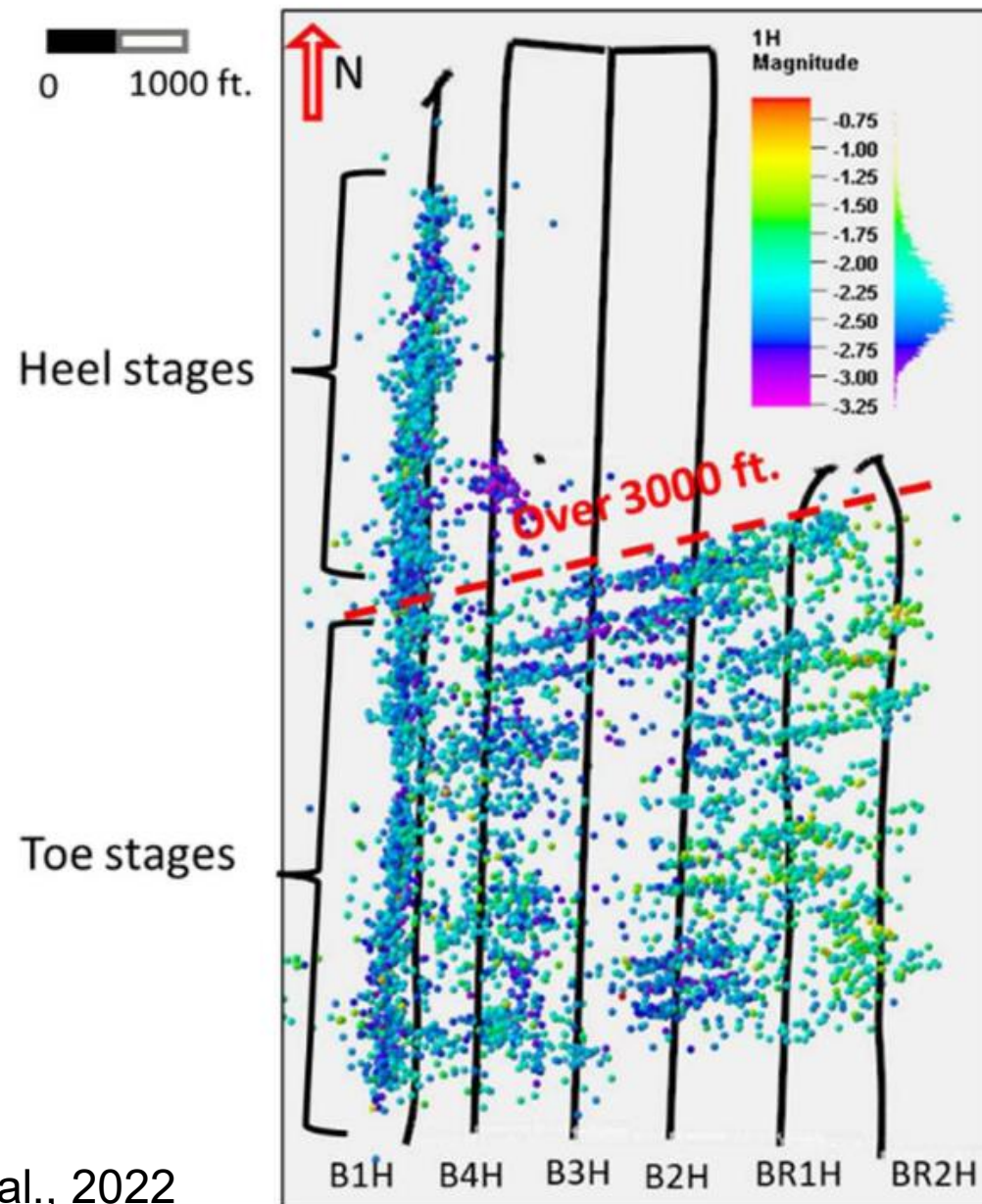
Wang & Stewart, 2022



Fracture Interpretation

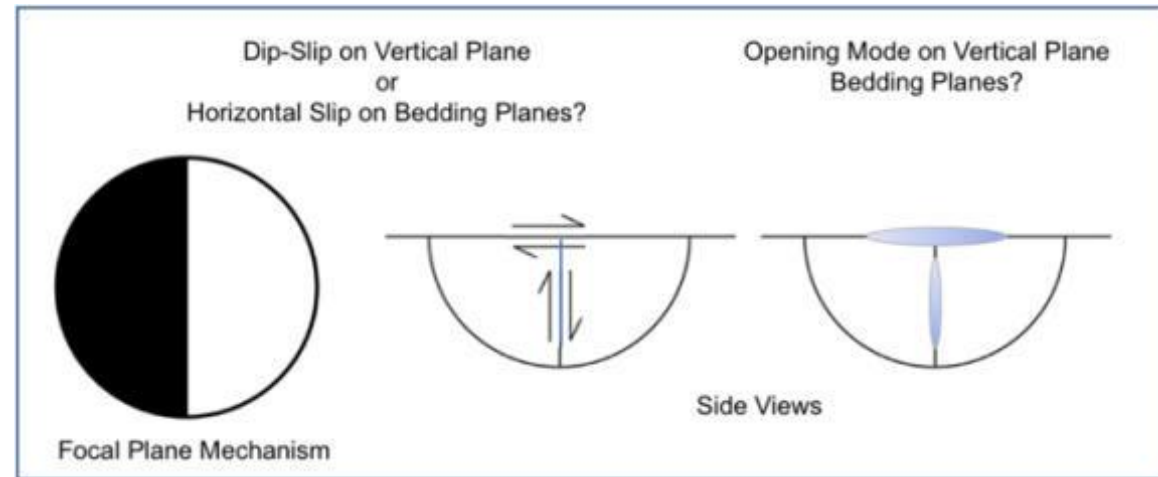
- ❖ Let's consider a different well pad and the associated seismicity.
- ❖ Well B1H is being completed and the circles show the seismicity from only that well.
- ❖ What is happening here?
 - What observations do you have?
 - Discuss together and see if you can come up with a story.

Tan et al., 2022

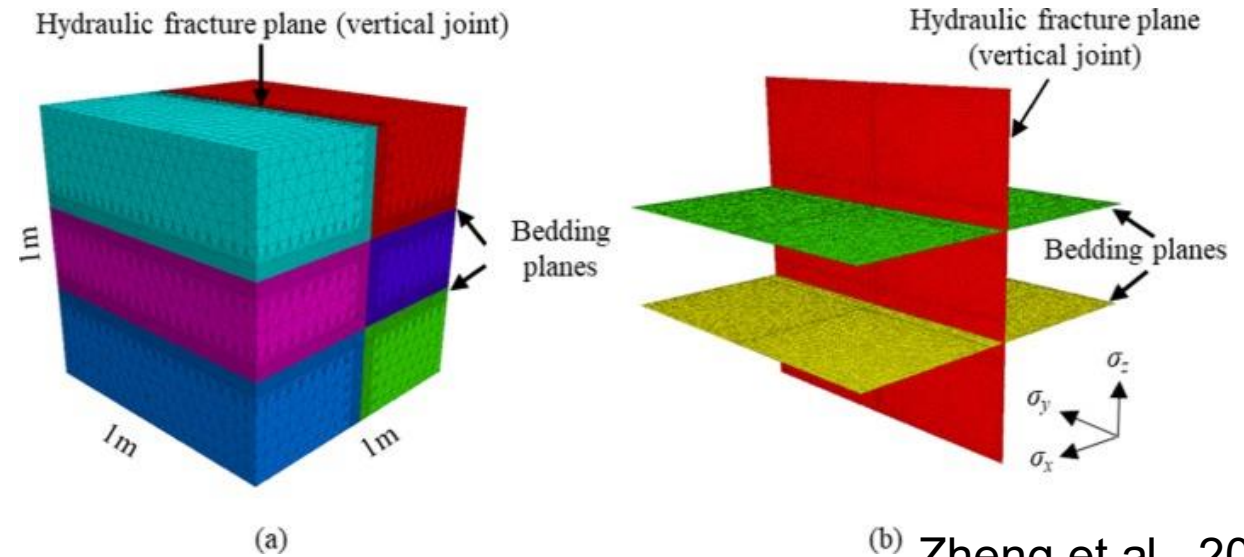


Bedding Plane Slip

- ❖ What is bedding plane slip?
- ❖ Bedding plane slip refers to slip on a horizontal plane.



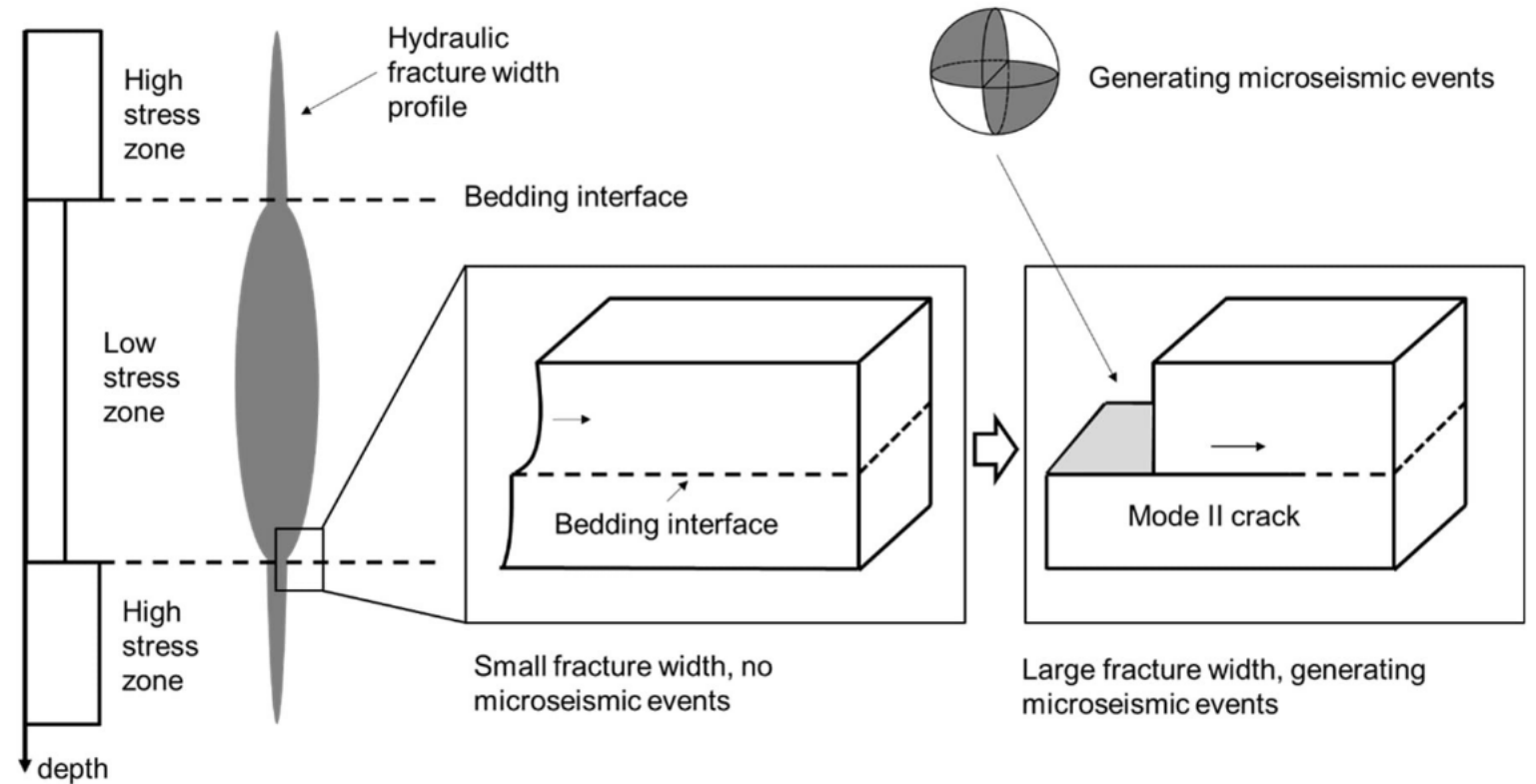
Zoback & Lundstern, 2018



(b) Zheng et al., 2022

Bedding Plane Slip

- ❖ What is bedding plane slip?
- ❖ Bedding plane slip refers to slip on a horizontal plane.
- ❖ Note there needs to be an accompanying lithological change to create an interface along which bedding plane slip can occur.



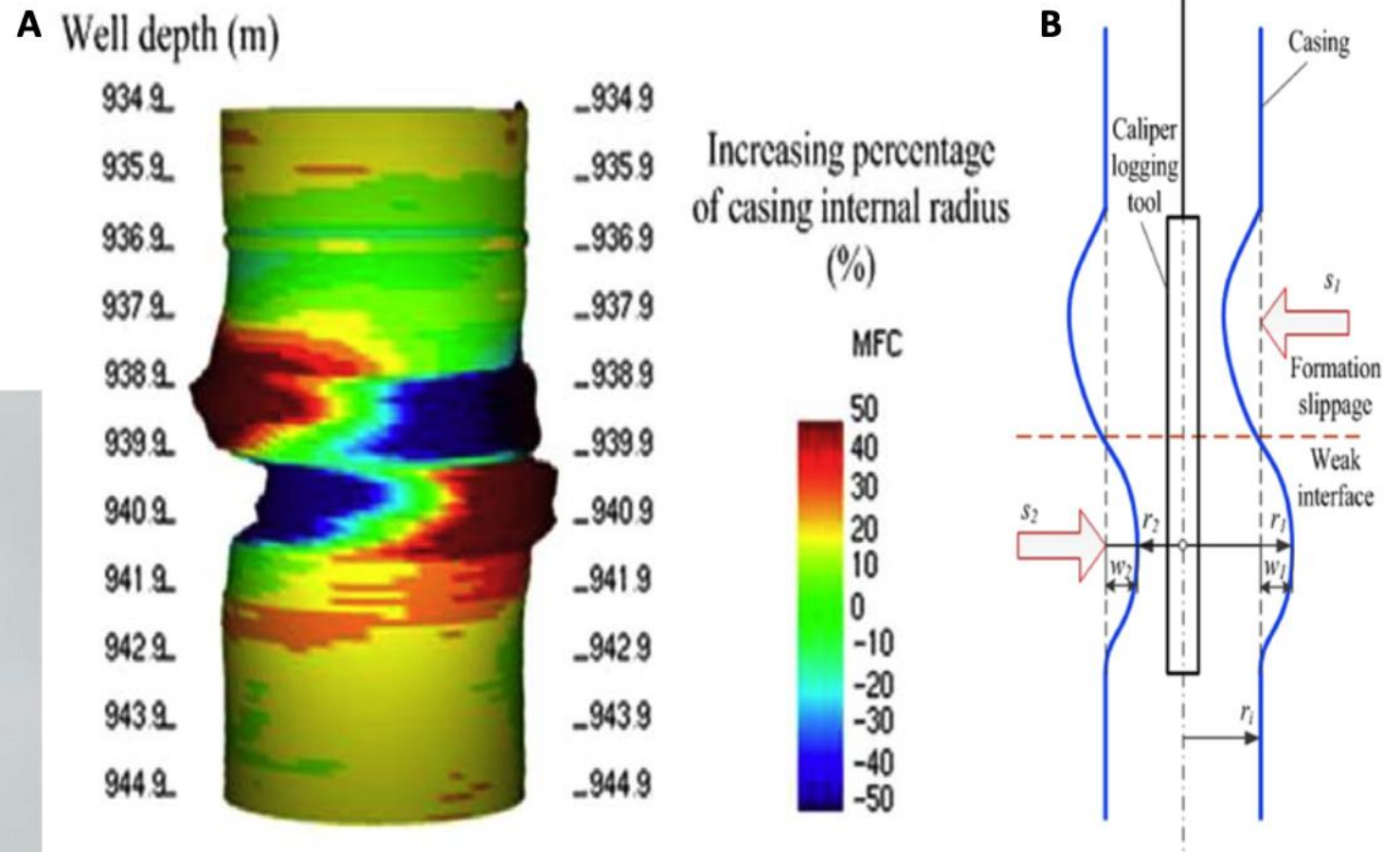
Tan et al., 2022

Bedding Plane Slip

- ❖ **Casing failure** is caused in part due to bedding plane slip.
- ❖ If the casing fails, there may be leaks and the well may even have to be abandoned → \$millions of loss!



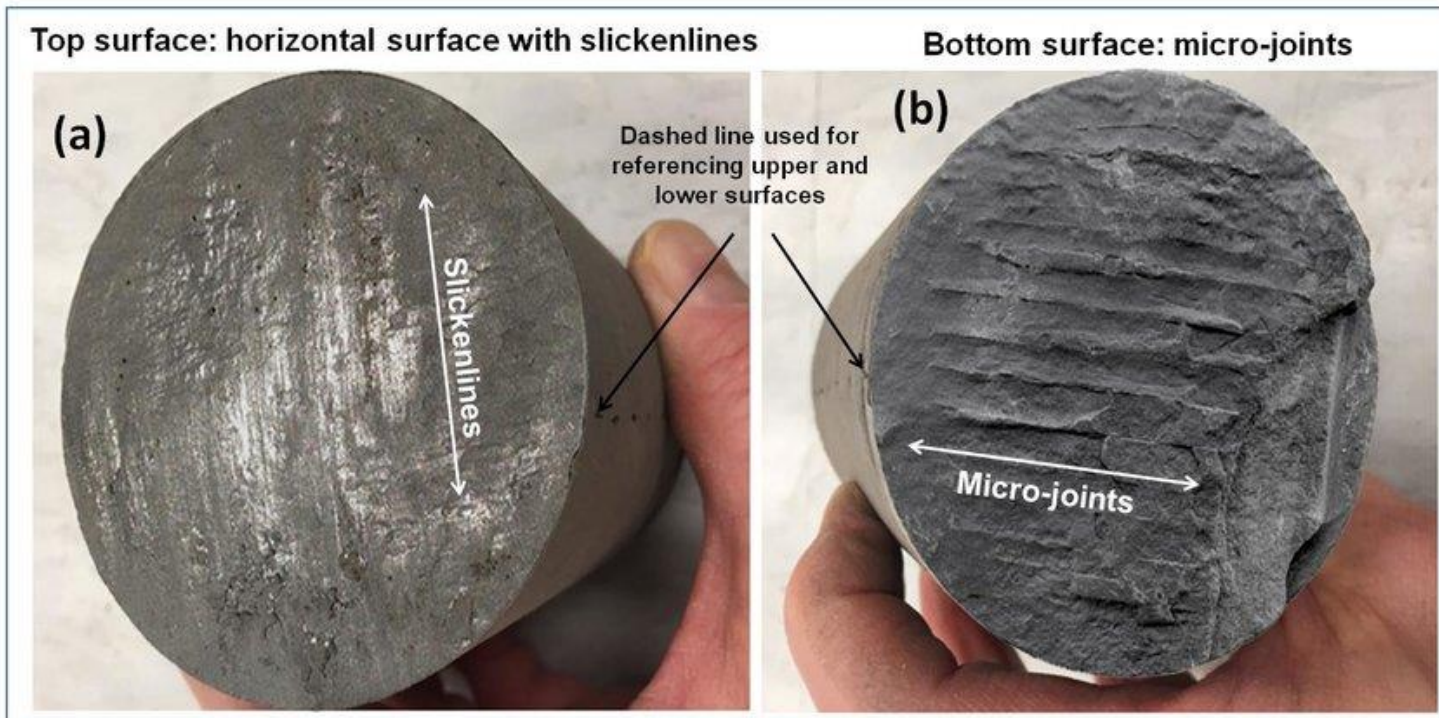
More info [here](#)



Mohammed et al., 2019

Bedding Plane Slip

- ❖ We can see bedding plane slip in core and in outcrops.
- ❖ Slickenlines are smooth, polished features. Common within shales and at boundaries between shales and other formations.



Gillen et al., 2019

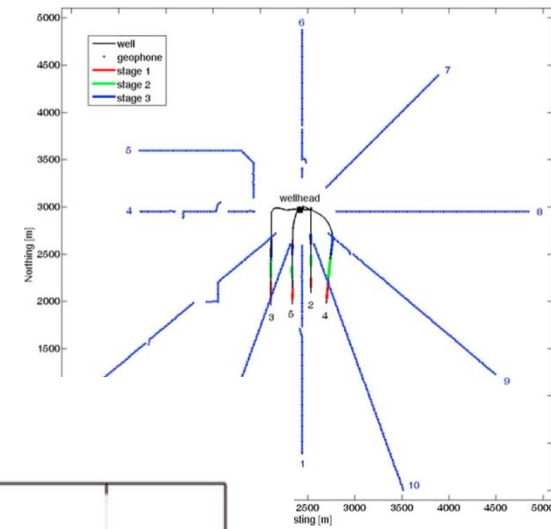
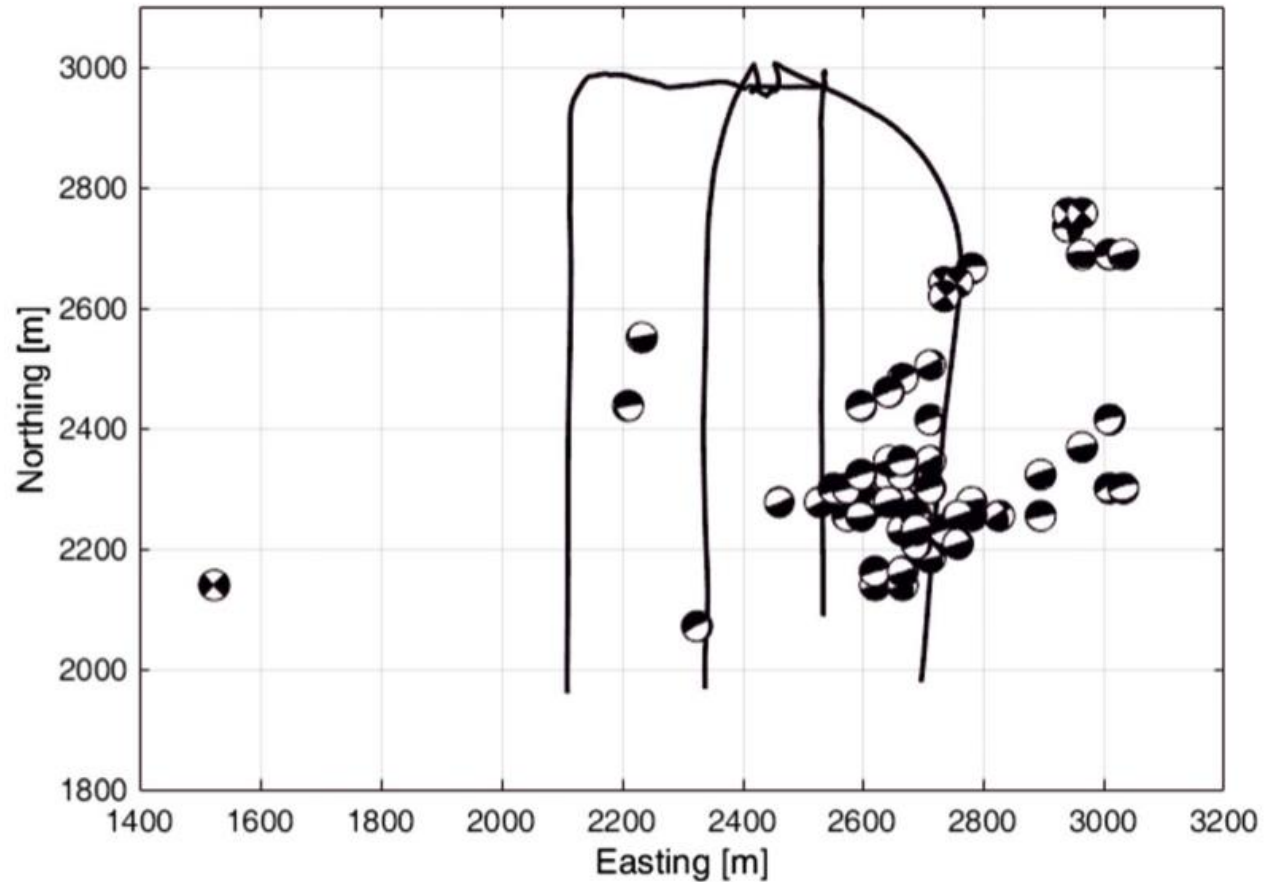
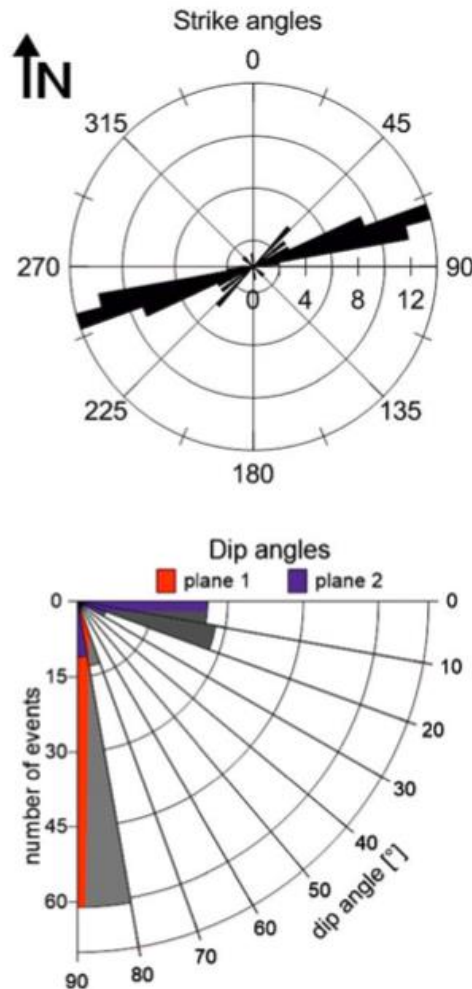
Permian basin example



More info [here](#)

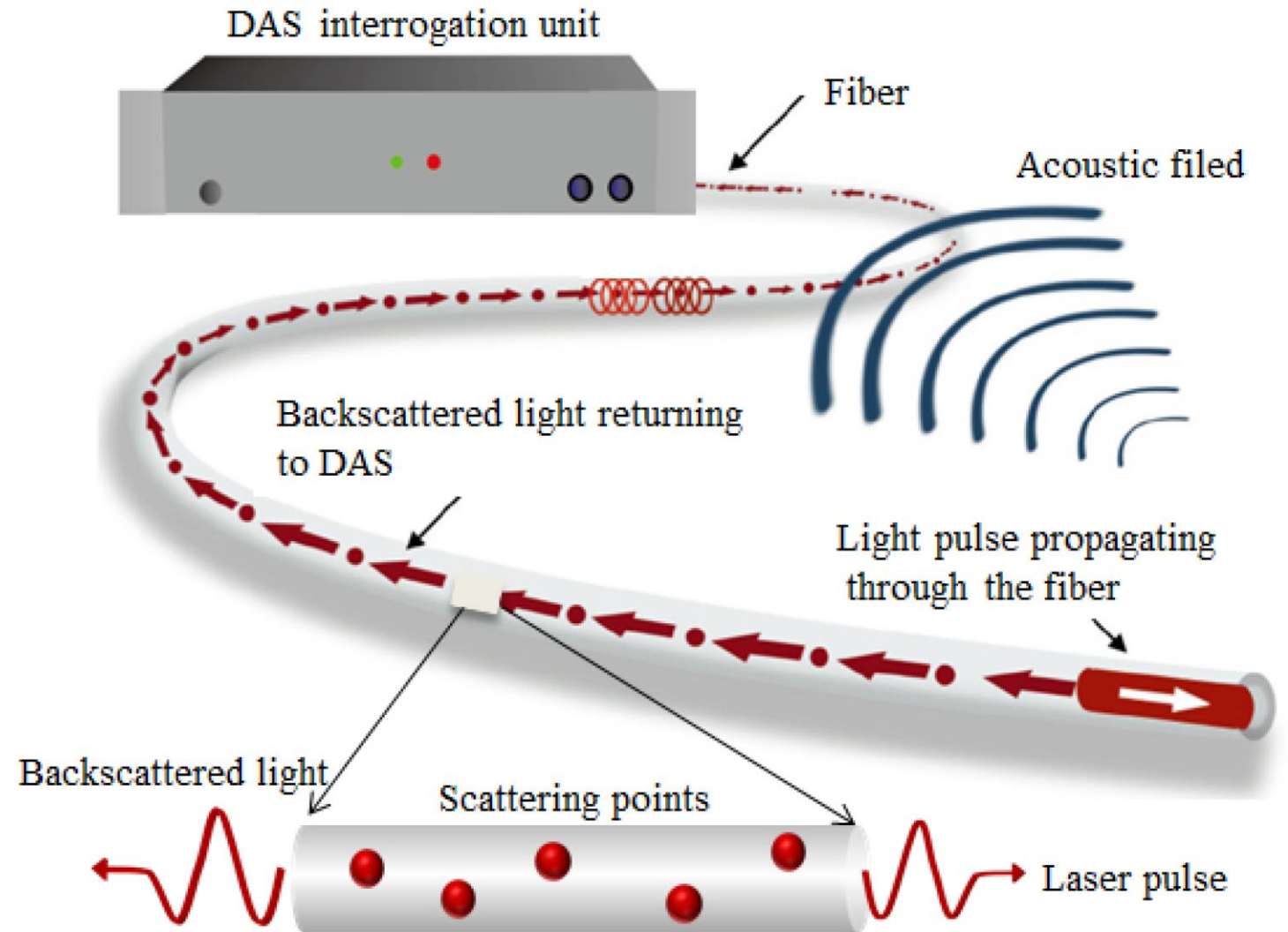
Bedding Plane Slip

- ❖ There is some (limited!) evidence of bedding plane slip from microseismic events. This is an example from a well-monitored well.
- ❖ More work needs to be done → Research!



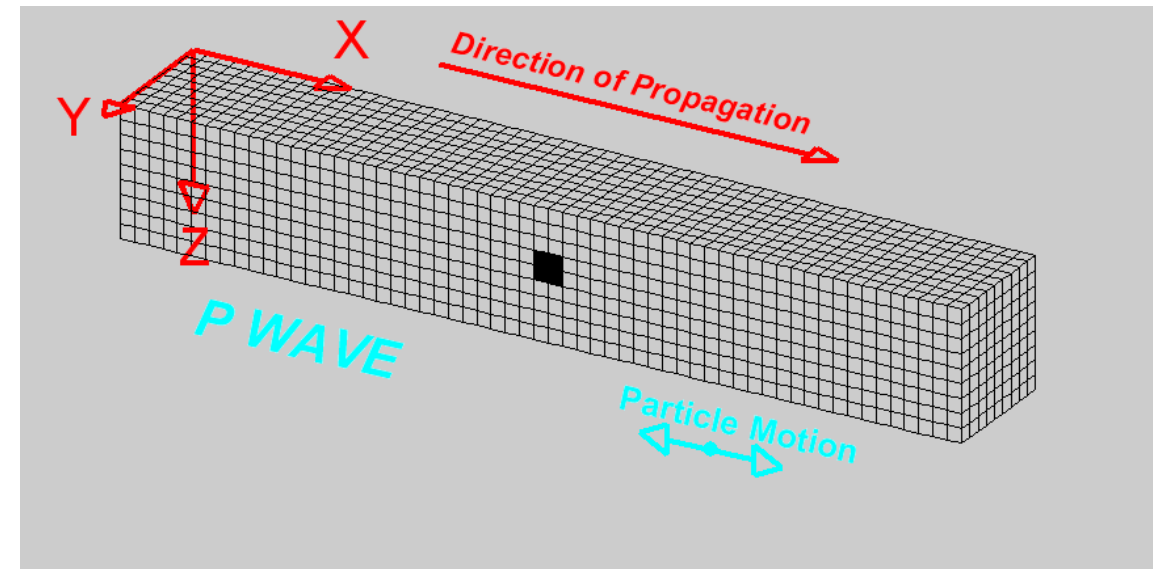
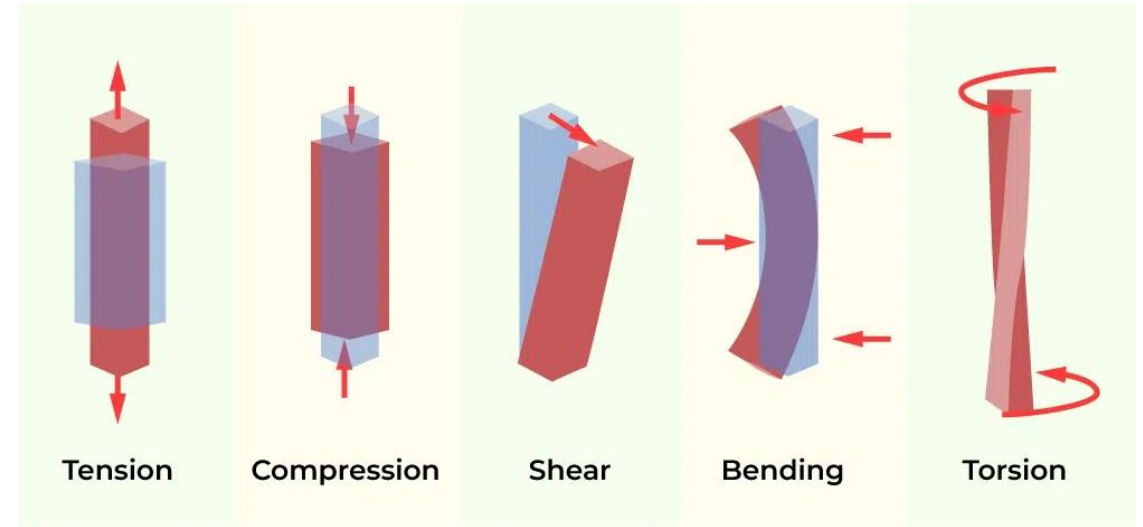
Distributed Acoustic Sensing (DAS)

- ❖ Distributed acoustic sensing is a technology that uses **laser pulses** in **fiber optic cable** to measure **strain** along the fiber.
- ❖ An **interrogator** sends laser pulses along the fiber at specific frequencies.
- ❖ As the laser travels through the fiber, it encounters scattering points and bounces back.
 - In this case scattering is a *good* thing! We need the energy to return back to the interrogator.



Distributed Acoustic Sensing (DAS)

- ❖ The fiber is measuring **strain**. This means it is sensitive to:
 - **Compression**
 - **Dilation (tension)**
- ❖ As earthquake waves propagate, they cause compression and dilation.
- ❖ Therefore, the fiber is able to sense earthquakes as they pass through.



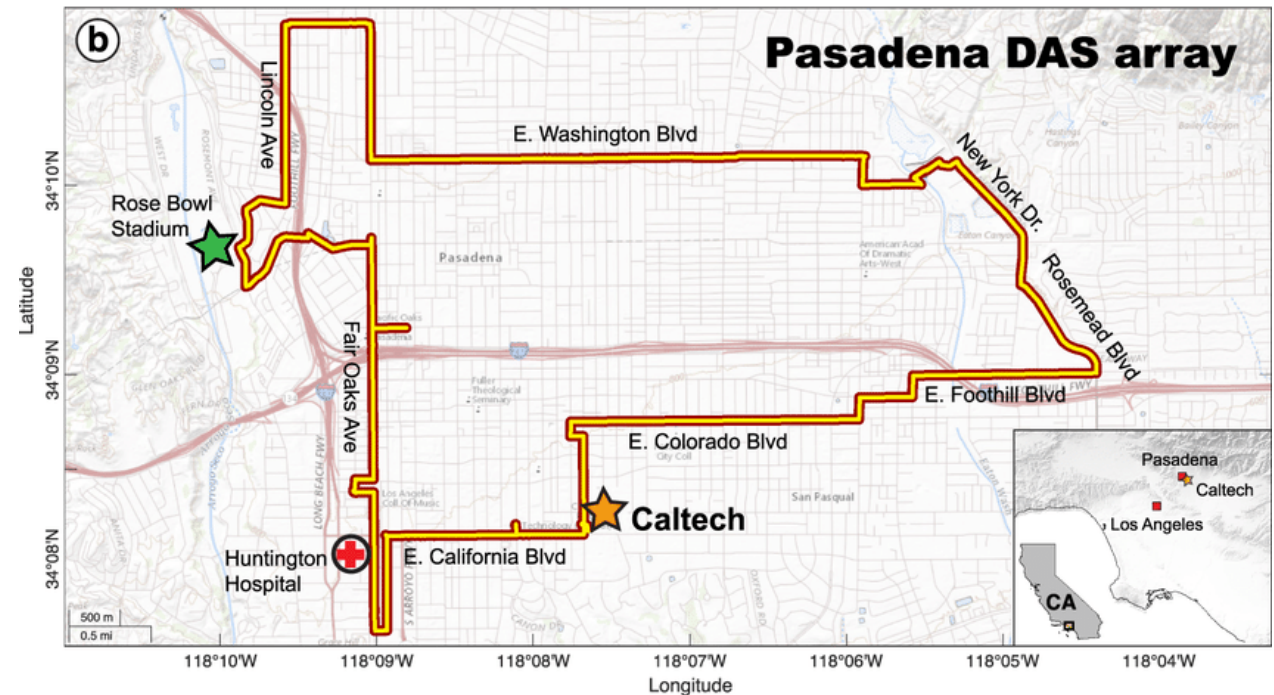
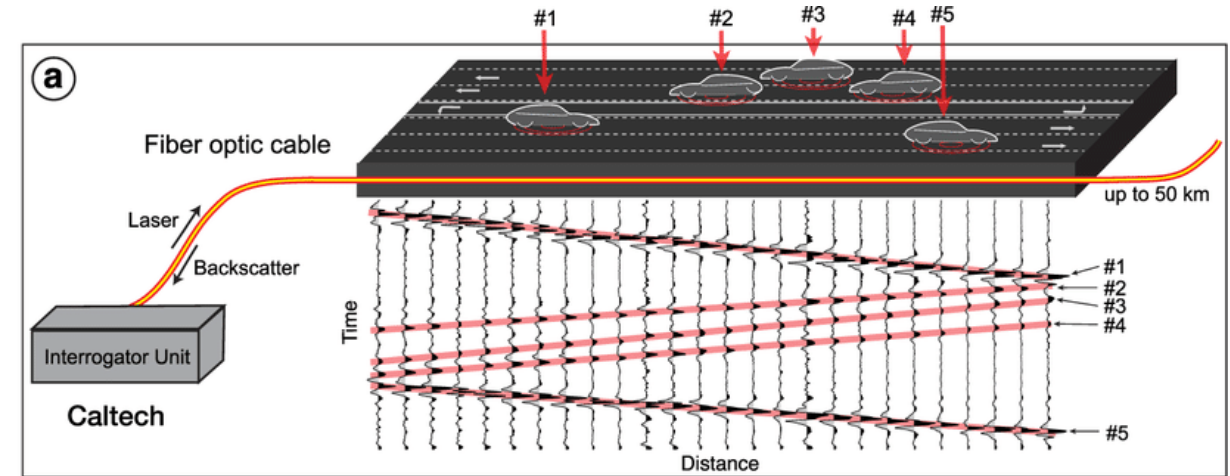
More info [here](#)

Distributed Acoustic Sensing (DAS)

- ❖ DAS is a **continuous** measurement.
- ❖ Geophones and seismometers are deployed in discrete locations, meaning they are point receivers.
- ❖ DAS, however, is measured along a cable which can be tens to thousands of m long.

→ Data analysis quickly becomes challenging since data volumes are enormous; **terabytes** of data.

1 TB = 1000 Gigabytes
1 GB = 1000 Mb



Distributed Acoustic Sensing (DAS)

- ❖ DAS systems record data in a wide range of frequencies.
- ❖ In processing, we split the data into two categories:

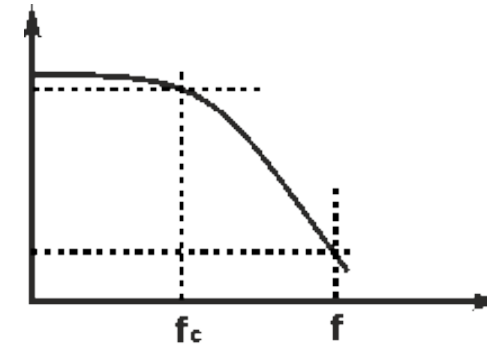
1. High-frequency DAS

- Frequency > 1 Hz
- Used for microseismic monitoring, in a similar range as geophones

2. Low-frequency DAS

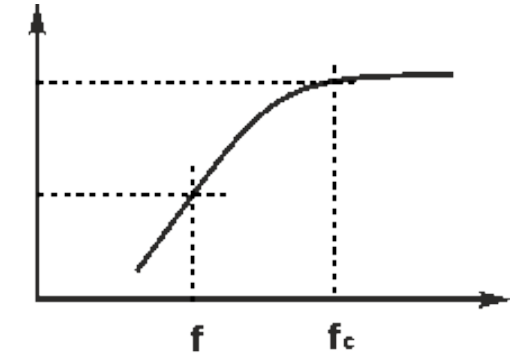
- Frequency < 1 Hz
- Used for monitoring fractures directly – not contaminated with microseismic events

Low pass filter =
keep low frequencies



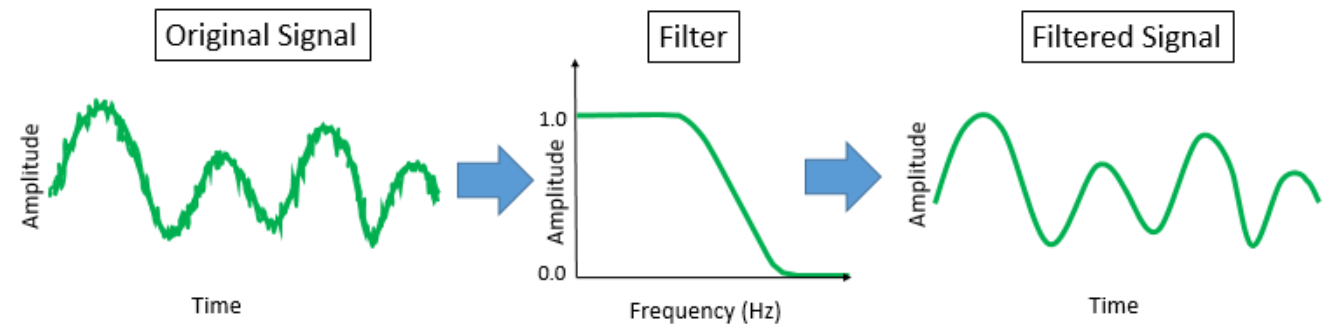
Low Pass

High pass filter =
keep high frequencies



High Pass

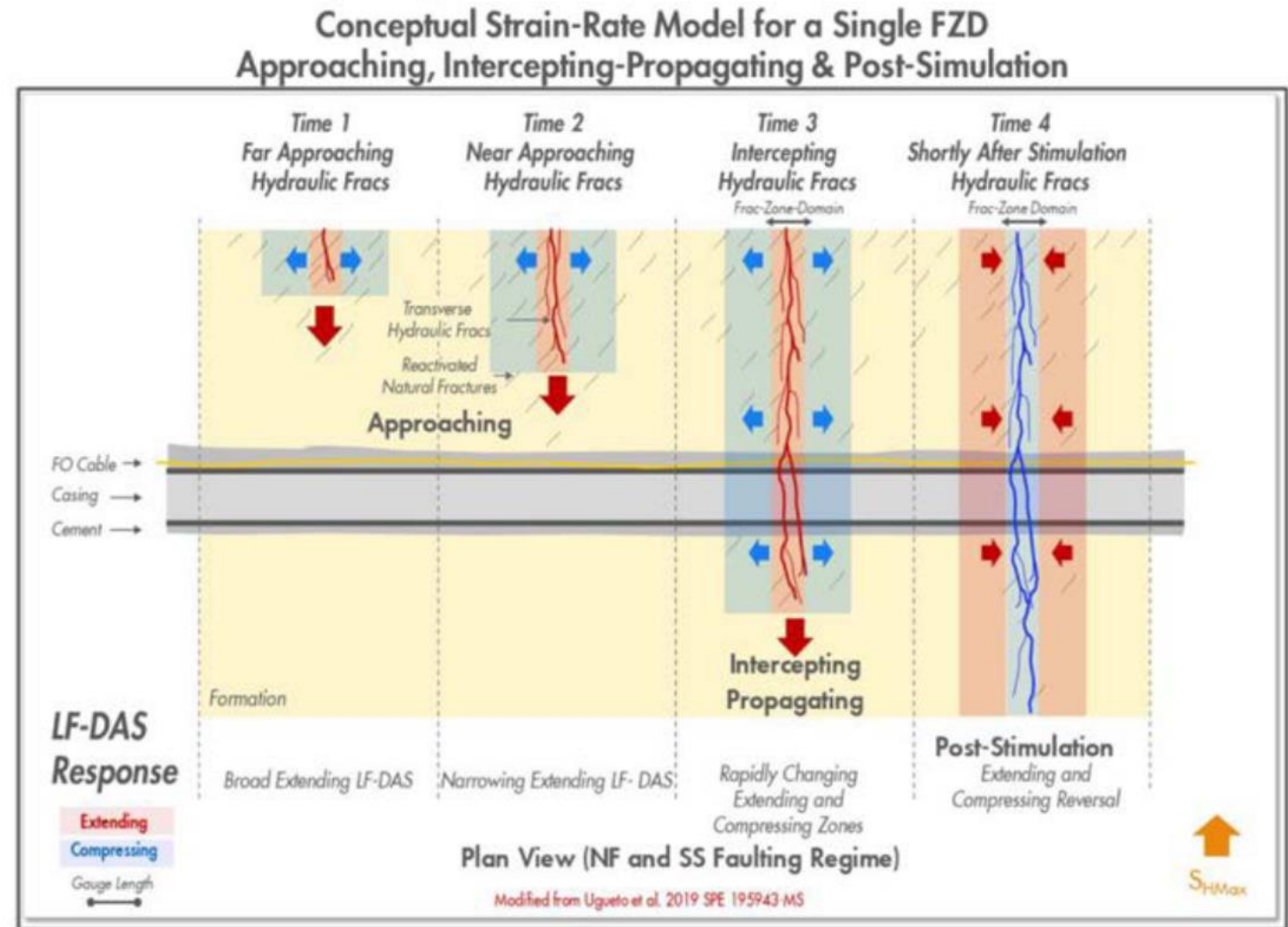
For **low-frequency** DAS, we *remove* the high-frequencies



More on filters [here](#)

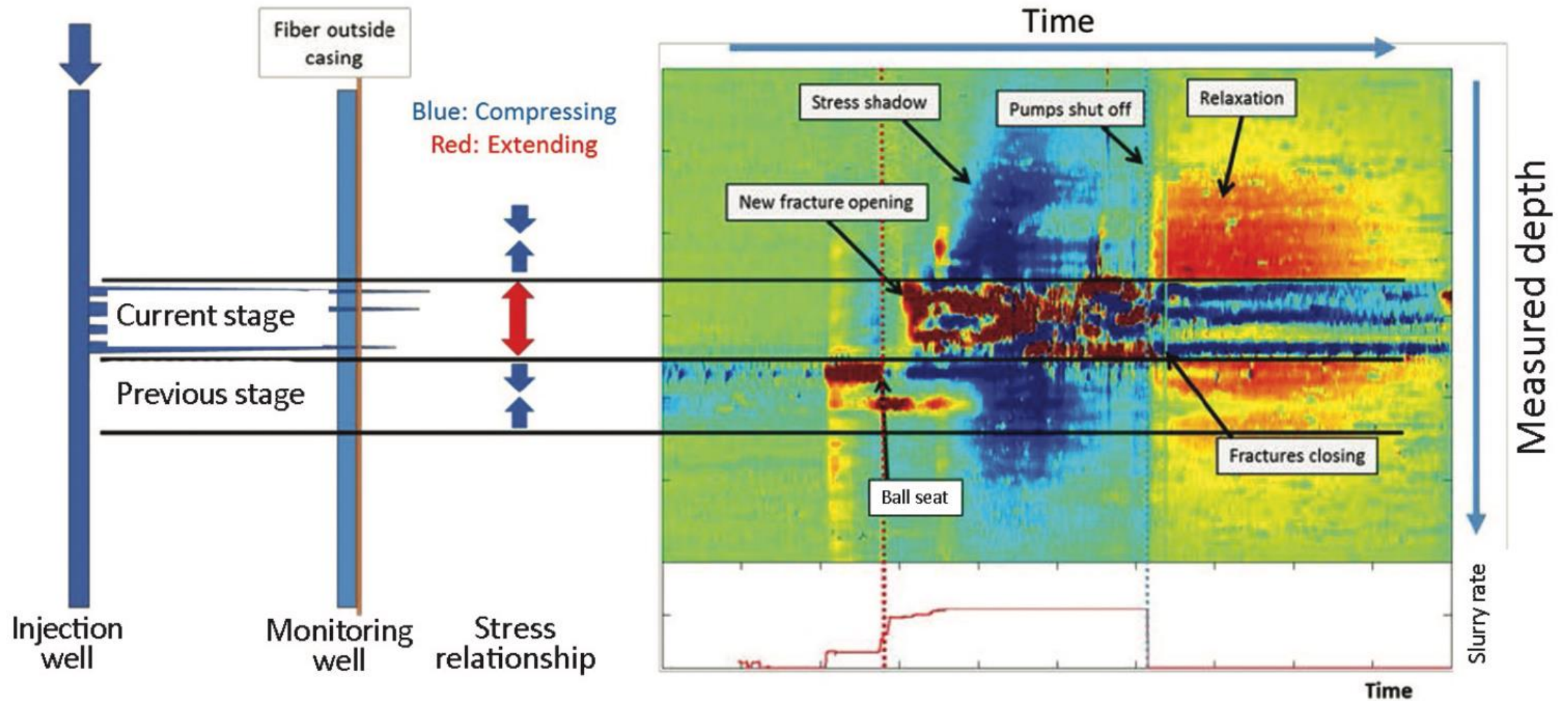
DAS for hydraulic fracturing

- ❖ What does a fracture opening/closing look like? Remember, strain detects **expansion** and **compression**.
- ❖ As the fracture opens, we have expansion and as the fracture closes, we have compression.



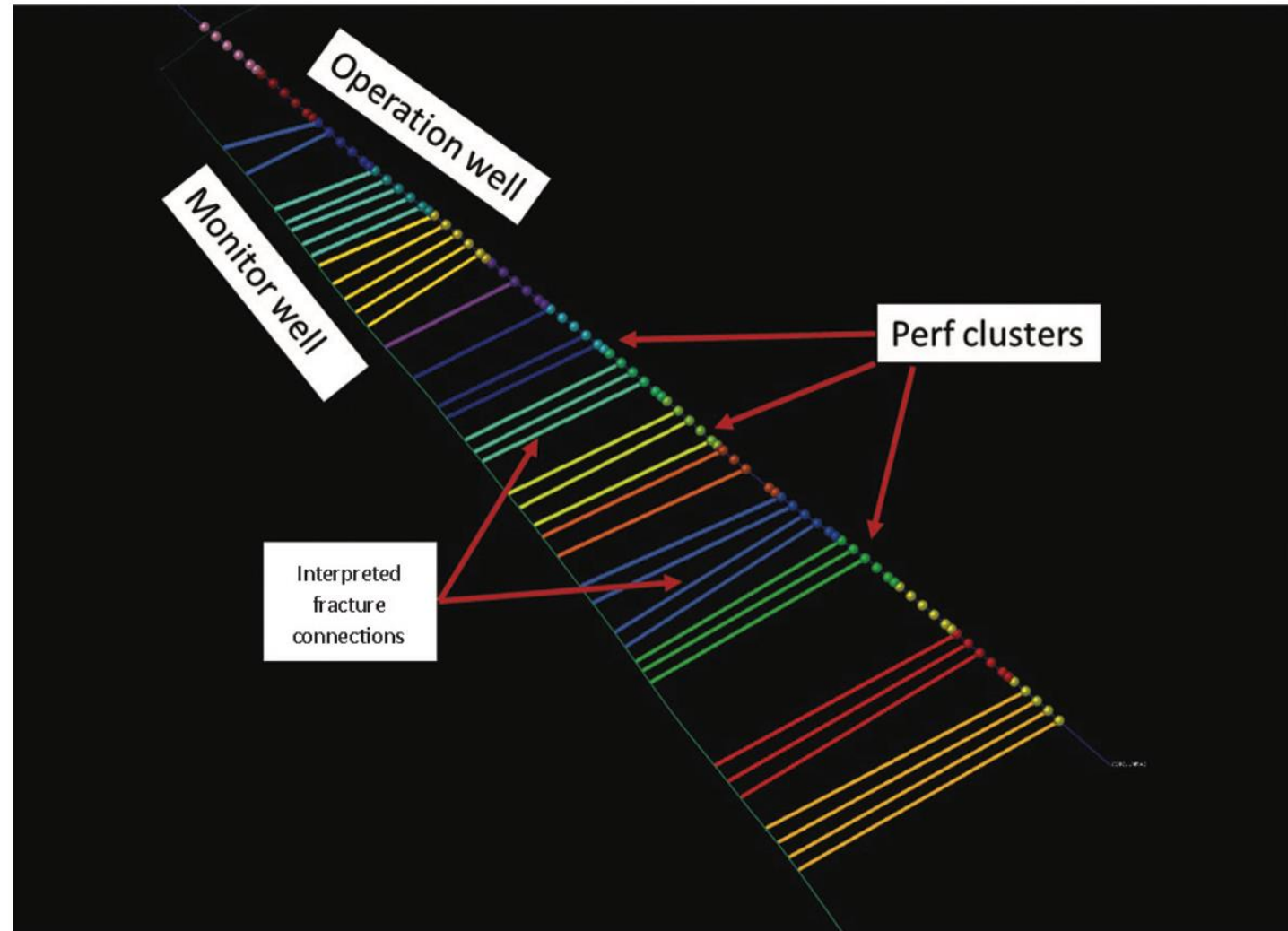
DAS for hydraulic fracturing

- ❖ This works! We can see the fracture approaching, opening and closing:



DAS for hydraulic fracturing

- ❖ Since the location where the fracture opening is known from the position along the DAS fiber, it is possible to pinpoint the locations of where the fractures intersect the neighboring (monitoring) well.
- ❖ What do you notice? Is every perf successful?

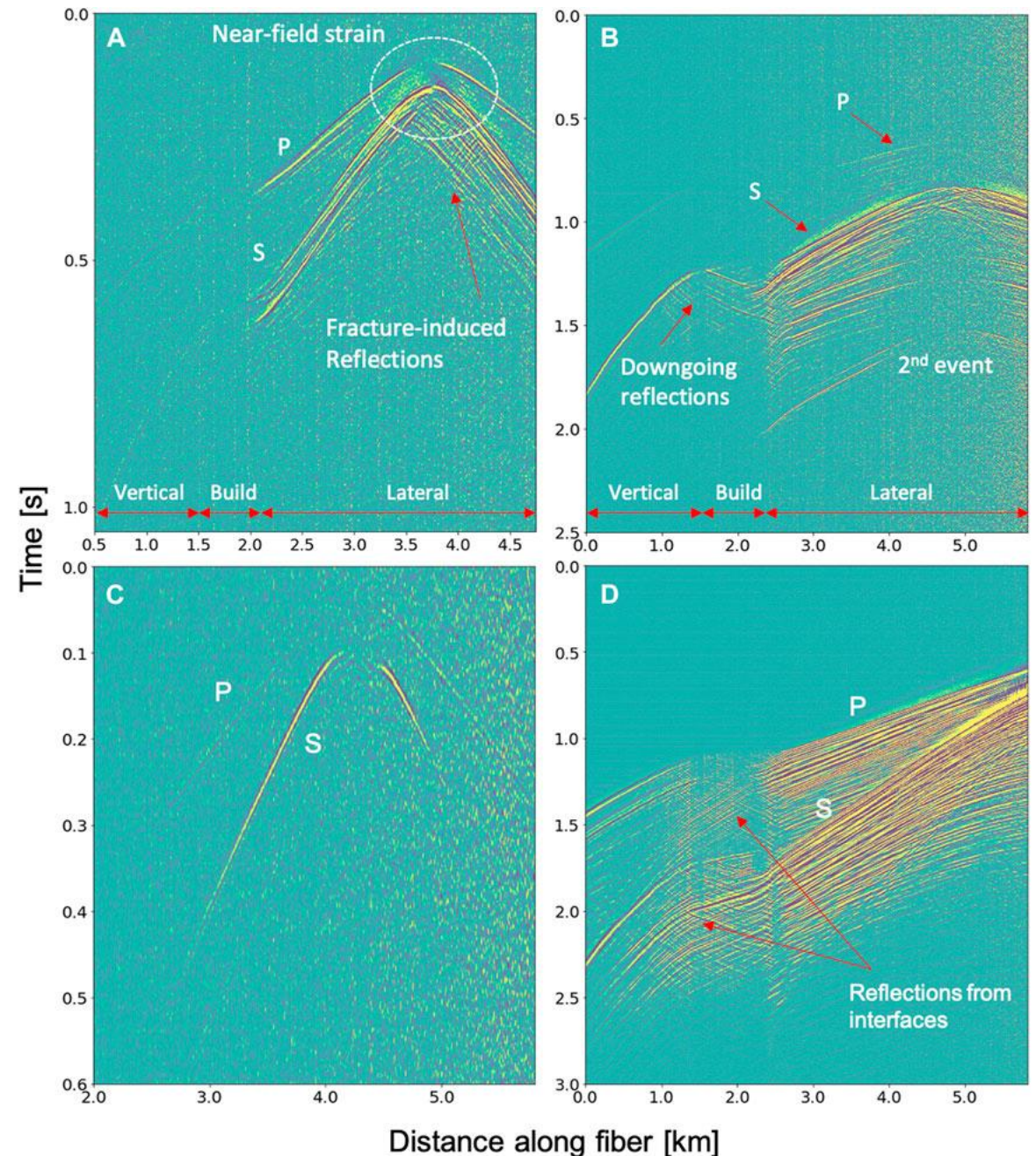


Jin & Roy, 2017

DAS for Microseismic

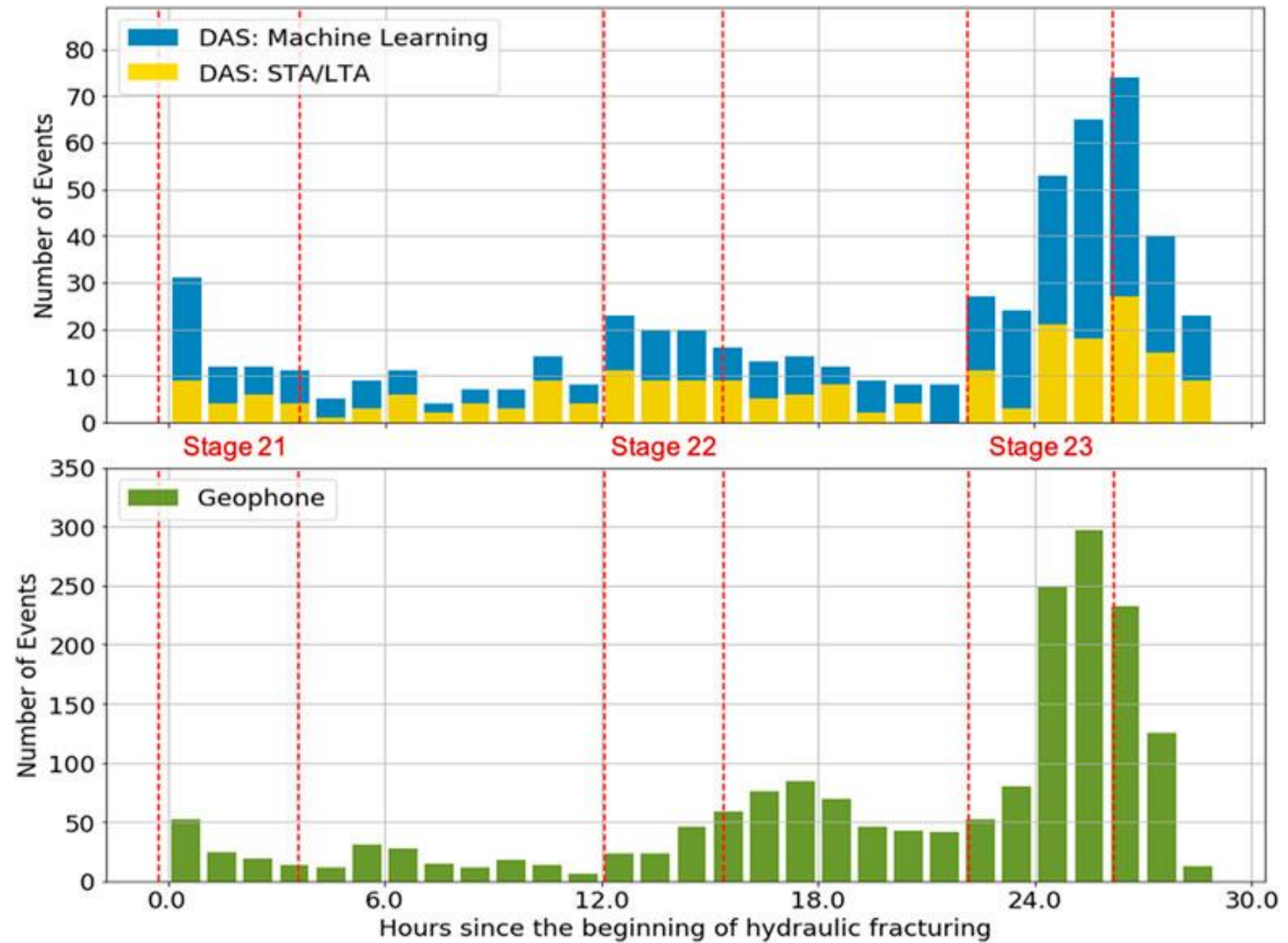
- ❖ Likewise, microseismic events can also be identified on DAS.

FIGURE 2. Examples of microseismic events detected by permanent (cemented) DAS fibers in horizontal wells. Events in **(A,B)** indicate P- and S- arrivals, fracture- and interface-induced reflections, guided wave, shear wave splitting, and near-field strain; event **(C)** is faint but typical of our DAS microseismic data; **(D)** shows a distant event beyond the well toe.



DAS for Microseismic

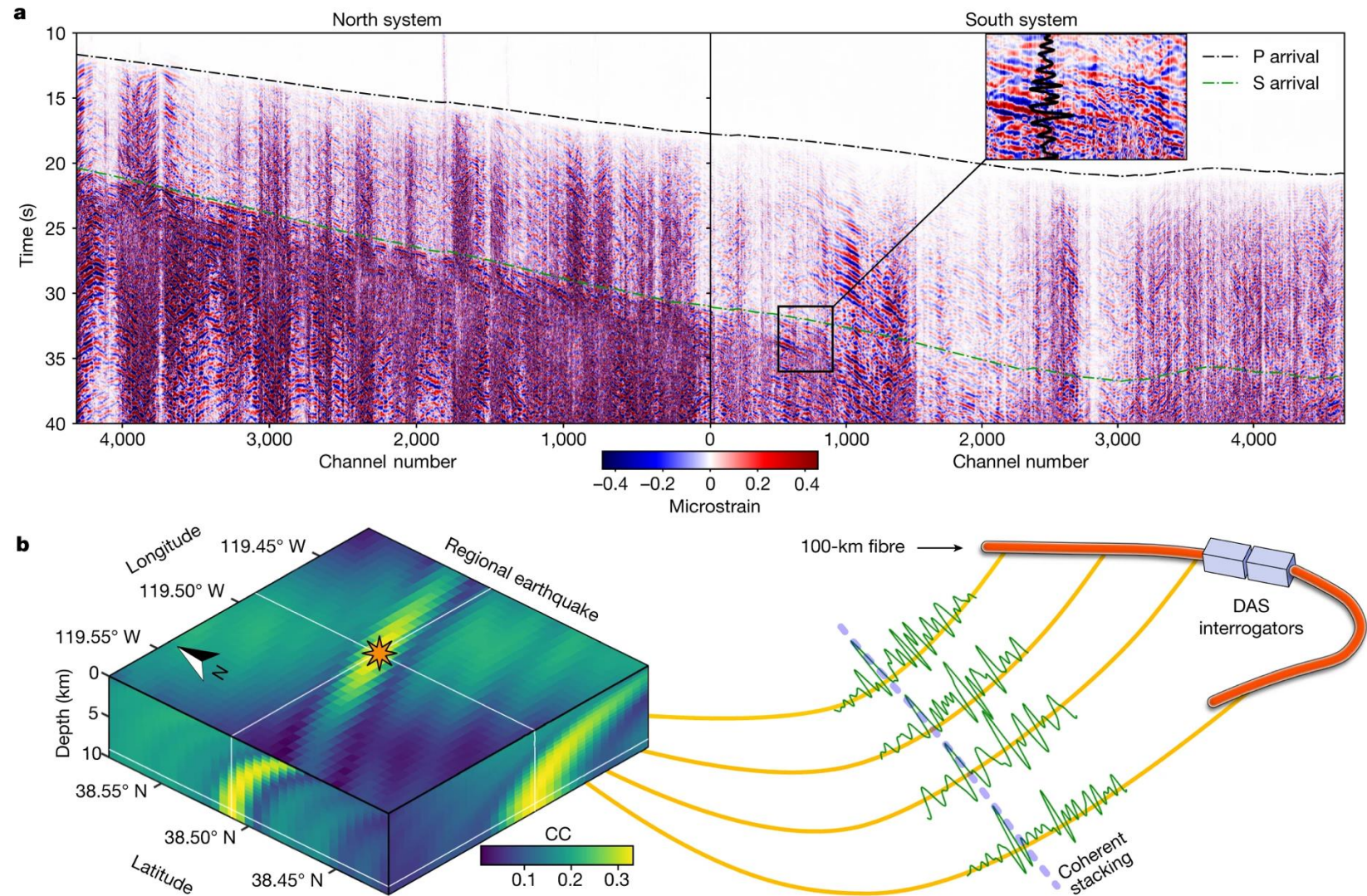
- ❖ One of the challenges with DAS for microseismic is signal to noise ratios.
- ❖ Even with improved fiber quality, there is usually a factor 2-3 reduction in the signal to noise ratio on DAS.
- ❖ Therefore, the smallest events are missed.
- ❖ Sanity check: is this a serious problem?



Ma et al., 2023

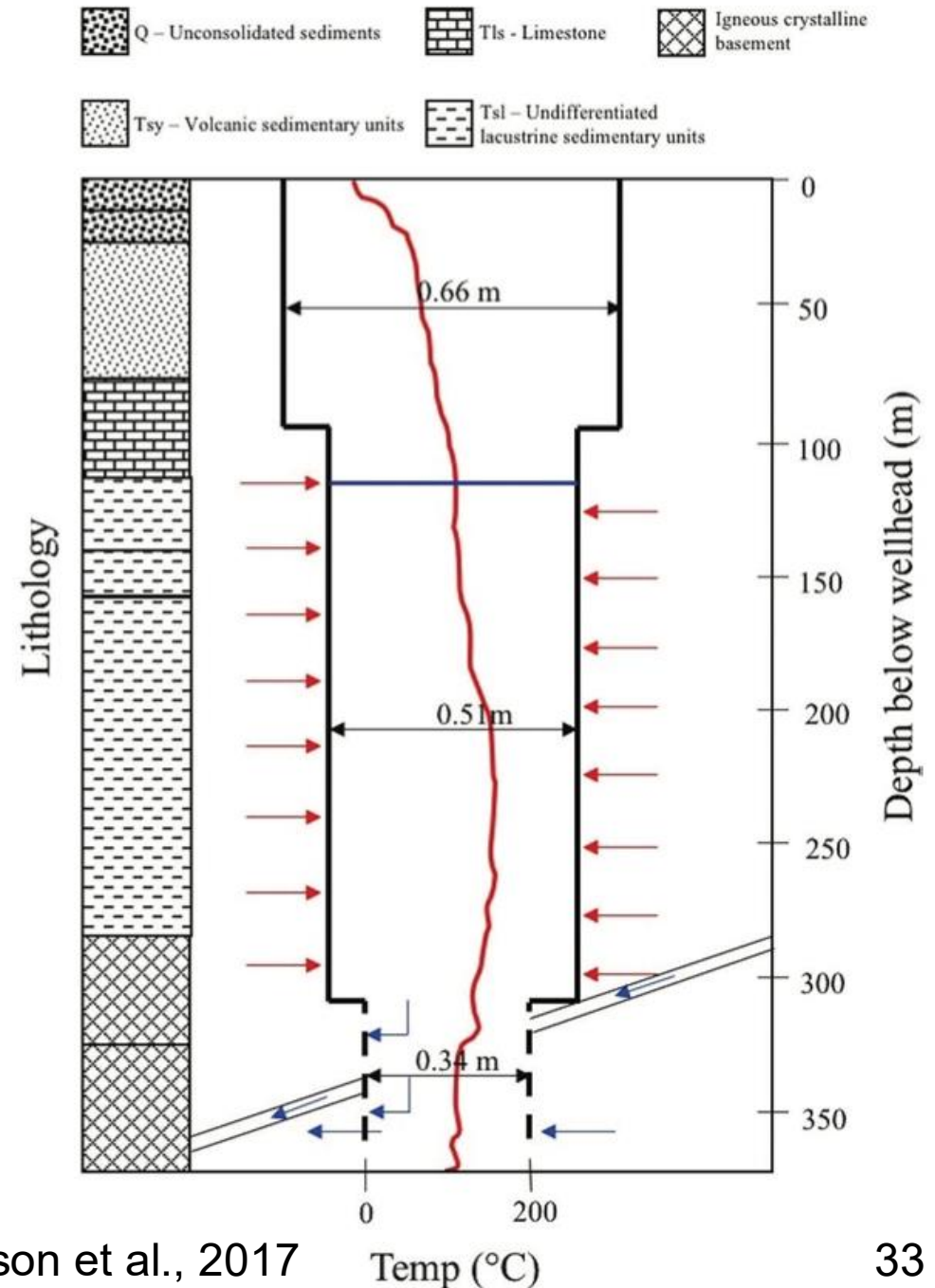
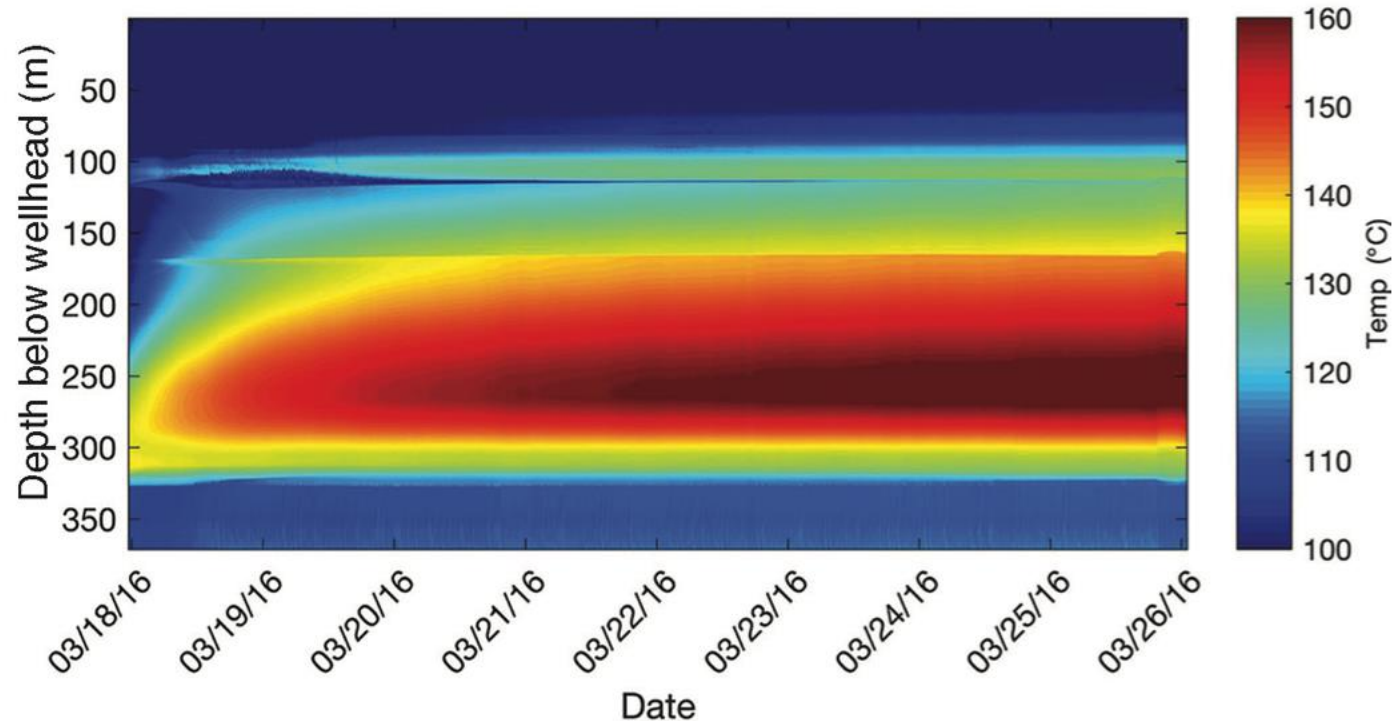
Other applications

- ❖ DAS can also be used for earthquake monitoring.
- ❖ This is an example of a **100 km** long DAS fiber in California.
- ❖ A magnitude 6 earthquake was detected.
- ❖ The P- and S-waves are clear – but there are so many more details!



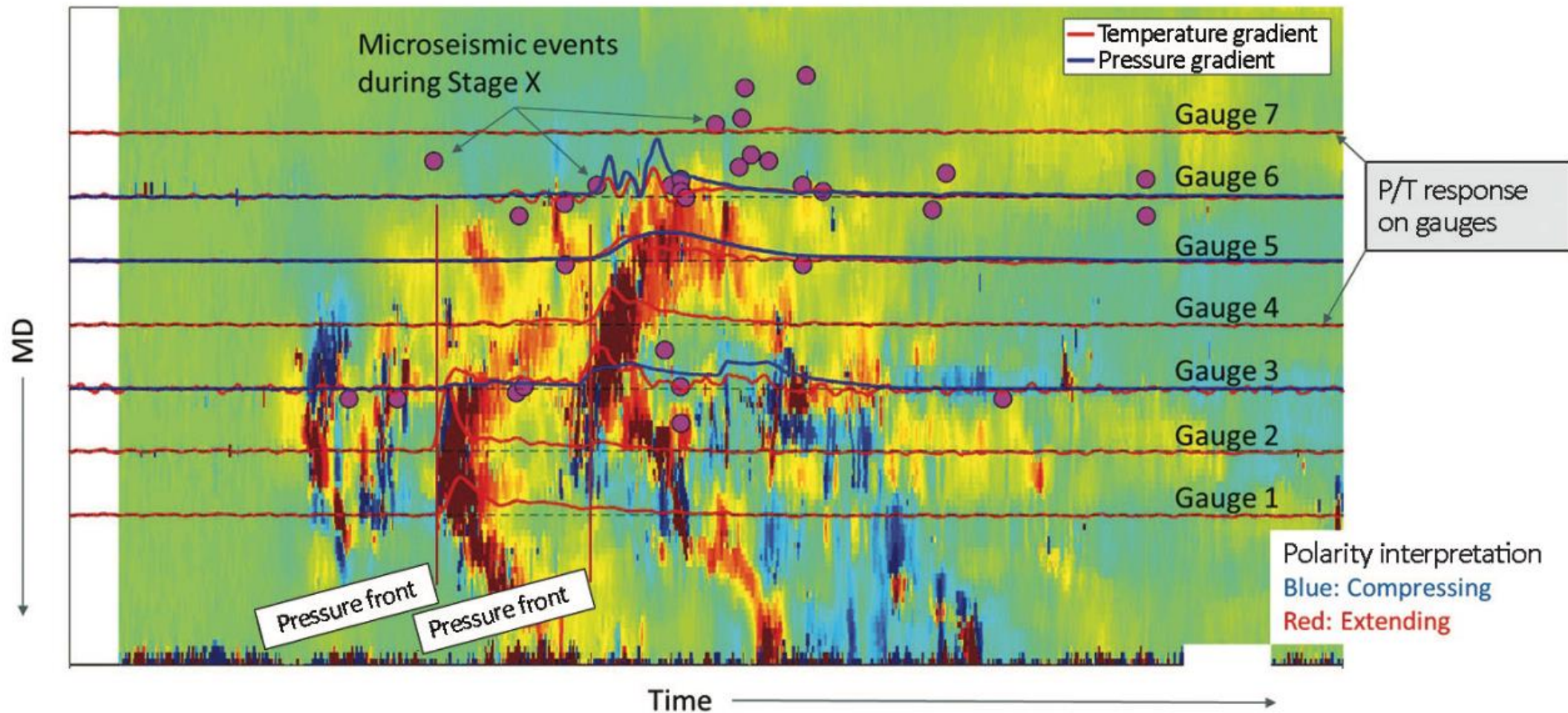
Other applications

- ❖ **Distributed temperature sensing (DTS)** is a similar technology where laser pulses are sent along a fiber optic cable, but the parameter that is recovered is temperature.
- ❖ Example from a shallow geothermal system in Nevada – the depth range of the hot water is 200-300 m.



Other applications

- ❖ Low-frequency DAS, microseismic and temperature can also be combined to form a full picture of how the fracture and the fracturing fluid moves in the subsurface.
- ❖ This is a powerful tool with a lot of research currently being done!



Next Time

- ❖ Next time: Texas induced seismicity and **in-class discussion** on hydraulic fracturing induced seismicity.

Further reading

- ❖ Required:
 - Video on DAS: https://www.youtube.com/watch?v=Q2XyMu_3fqY
 - The video is ~1 hour long, but you only need to watch the from **0:00 to 23:05**
- ❖ Optional:
 - Jin & Roy, 2017 on distributed acoustic sensing for hydraulic fracturing