Enhanced Geothermal Systems Update

SPE Houston Westside Study Group

Greg Leveille

March 19, 2025

Discussion Topics

- CERAWeek highlights
- Enhanced geothermal systems technology breakthrough overview
- Optimizing enhanced geothermal systems by avoiding potentially negative impacts caused by fluid injection into shear zones

CERAWeek highlights

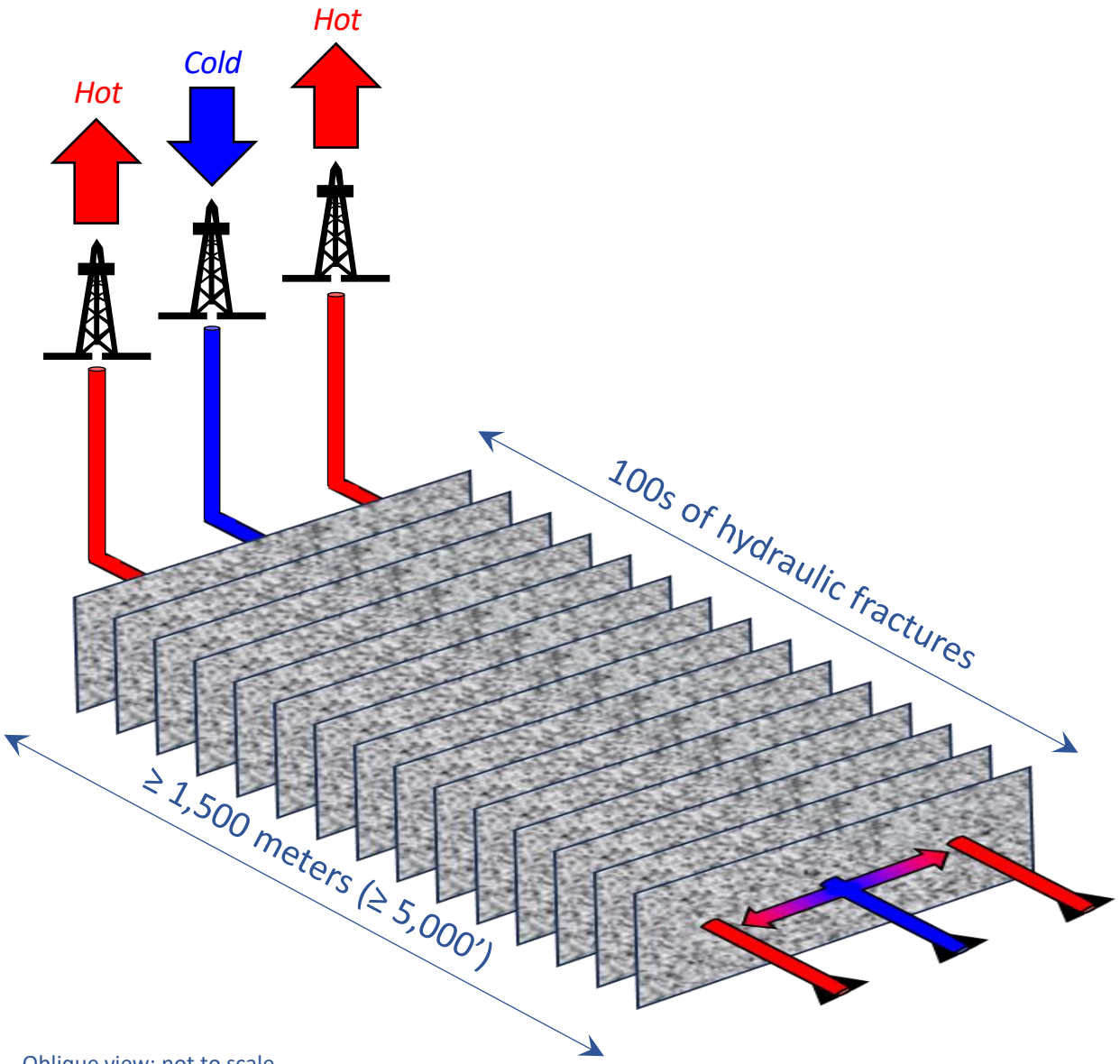
- "Energy realism" replaces "net zero energy" as the guiding mantra
  - *Energy affordability, energy abundance, energy security and low carbon*
- Power demand is surging, largely due to AI related data center buildout
- Natural gas will play a leading role in meeting near-term firm power demand
- Geothermal and nuclear striving to provide clean, firm power long-term

Discussion Topics

- CERAWeek highlights
- Enhanced geothermal systems technology breakthrough overview
- Optimizing enhanced geothermal systems by avoiding potentially negative impacts caused by fluid injection into shear zones

Technology transfer from the oil and gas industry has transformed EGS economics

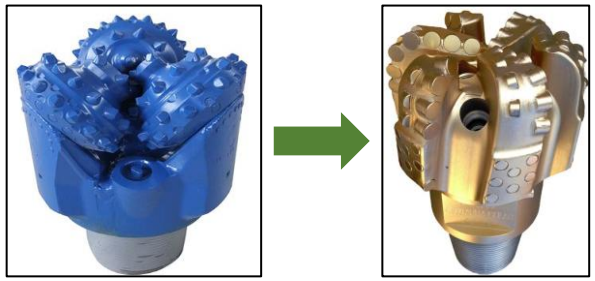
Hydraulically fractured horizontal wells



Oblique view; not to scale

Latest oil and gas drilling technologies

Drill bit design



Roller Cone → PDC

Physics-based drilling

Fred Dupriest
& Sam Noynaert

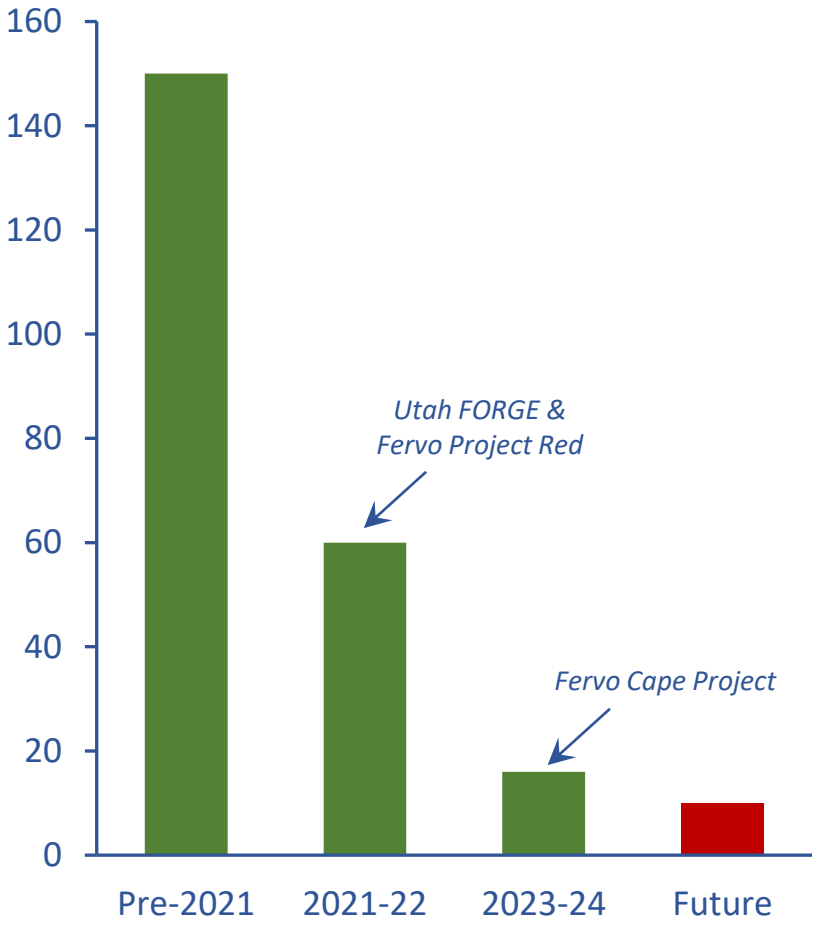
Texas A&M University

EGS = Enhanced geothermal systems; PDC = Polycrystalline diamond compact (bits)

These technological innovations have delivered game changing results

Spectacular drilling performance improvements

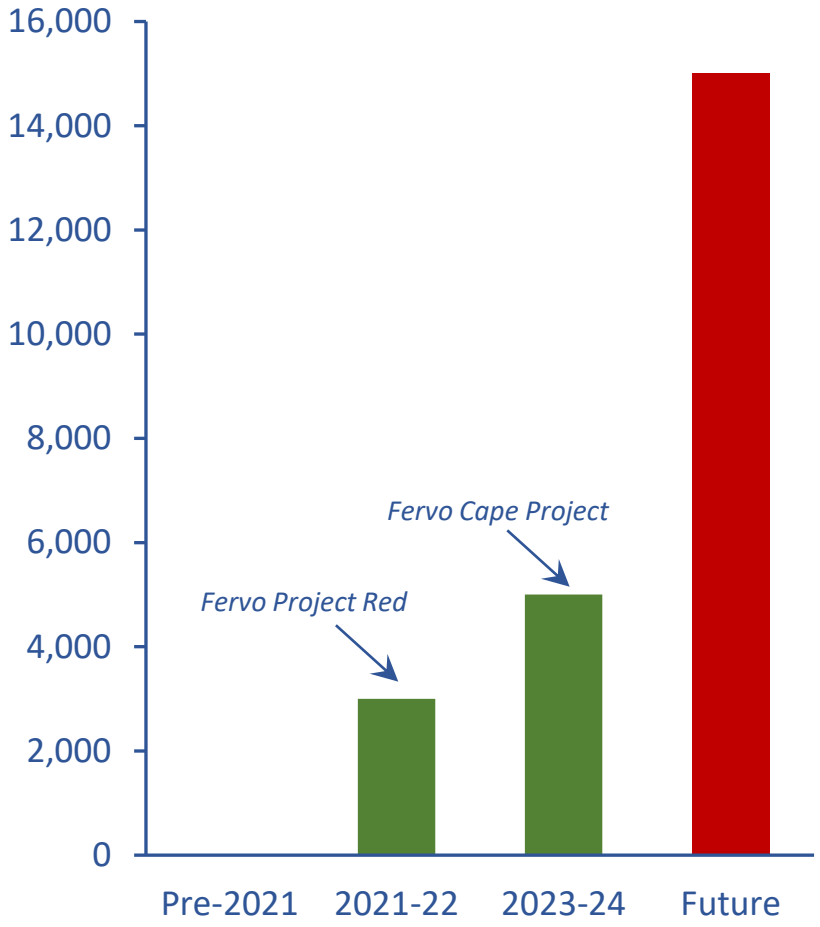
Drilling days to 12,000' MD (≈ 3,600 m)



Sources: El-Sadi et al, 2024, Review Of Drilling Performance In A Horizontal EGS Development; Winkler & Swearingen, 2021, Summary of Drilling Activities, Utah FORGE; MD = Measured depth

Ability to D&C horizontal EGS wells in basement rocks

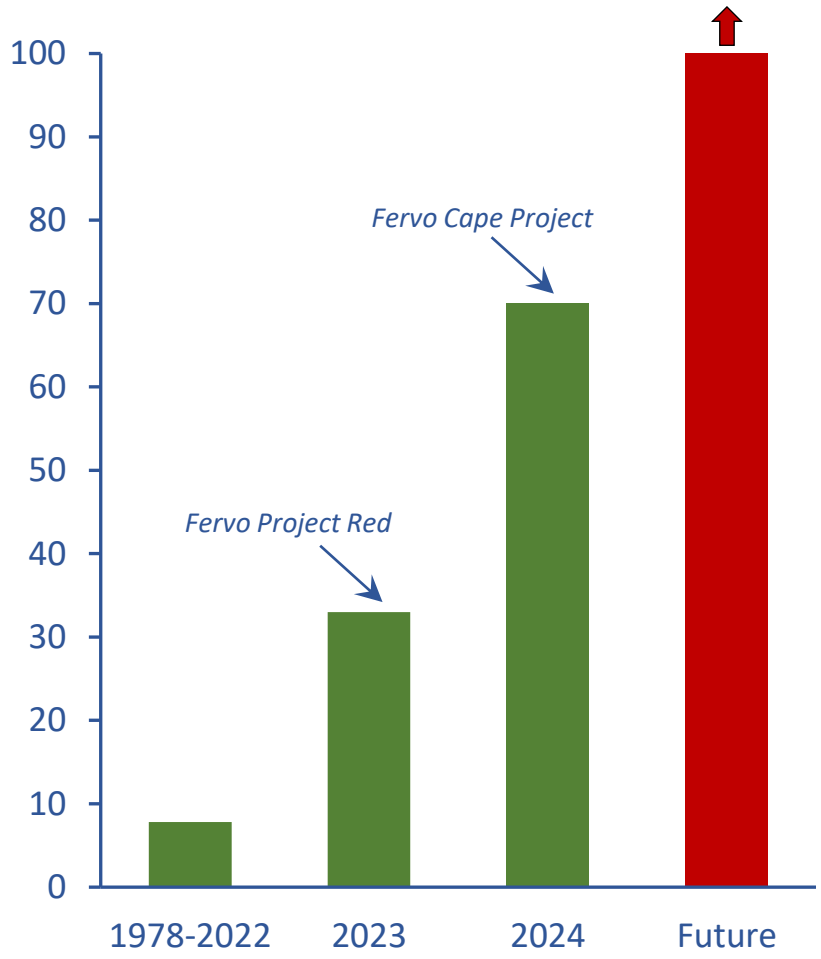
Lateral length (feet)



Note: The first fully horizontal EGS wells drilled were those drilled by Fervo at their Blue Mountain project in 2022. D&C = drill and complete

Near order-of-magnitude increase in per well production

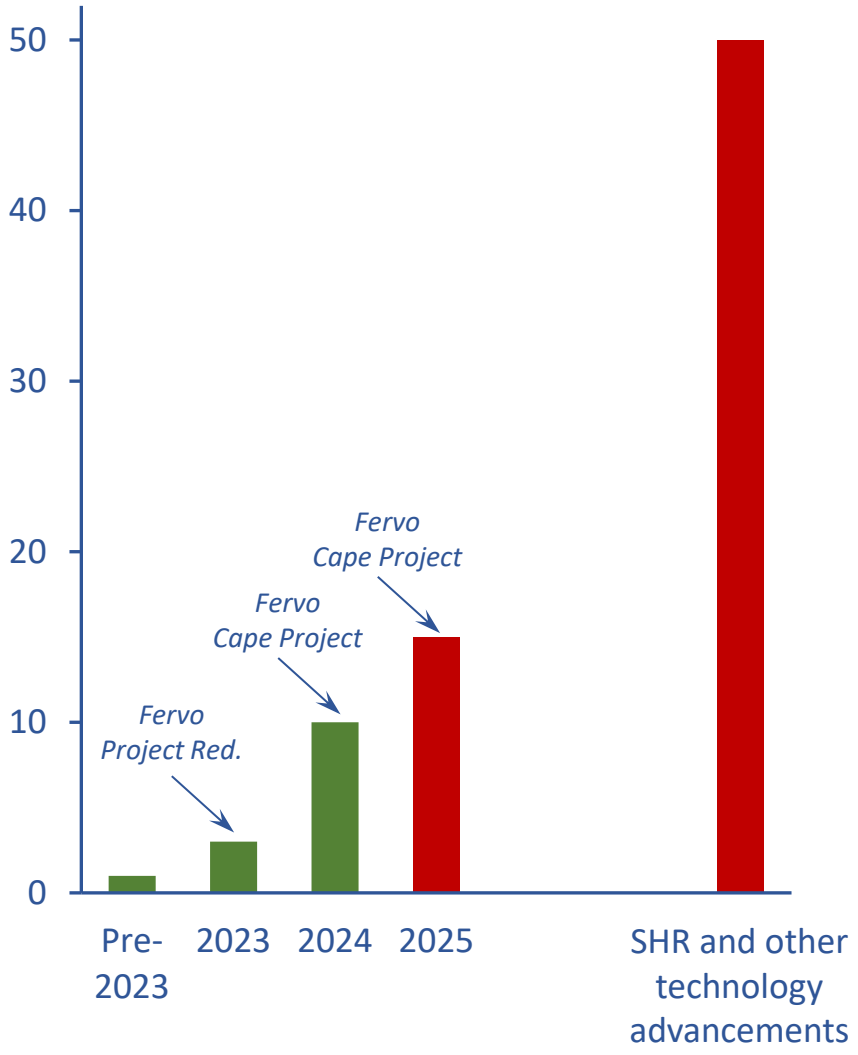
Peak production flow rate (MBFPD)



Note: 1978 – 2020 data from 11 projects; average peak flow rate shown (7,800 bfpd); range was from 2,700 to 16,300; MBFPD = thousands of barrels of fluid per day

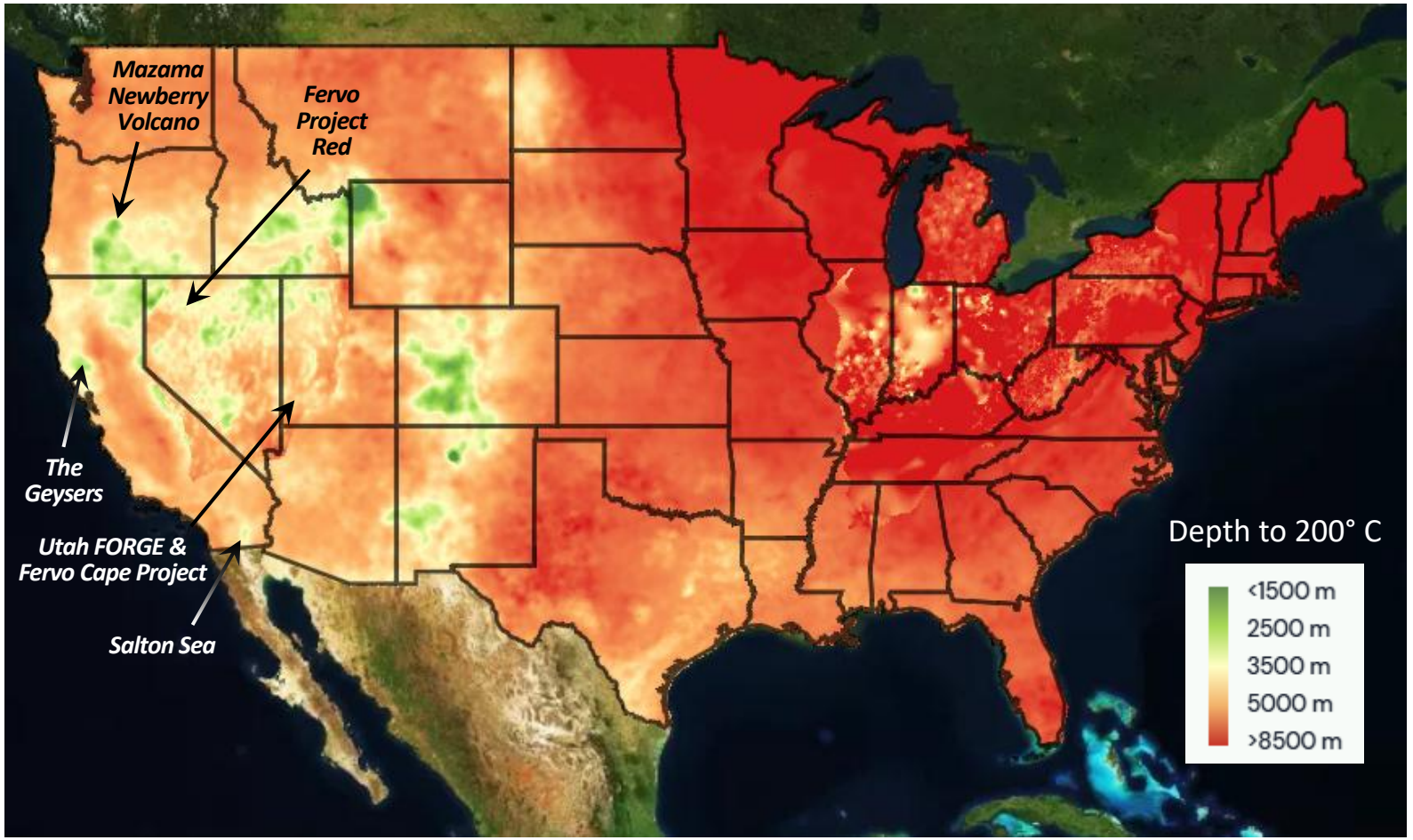
Remaining EGS upsides are significant; the U.S. is well positioned to lead the way

Per well power output (MW)



MW = Megawatts (one million watts); SHR = Super hot rocks

The U.S. possesses considerable geothermal resources



The U.S. is currently the world's largest producer of geothermal power

Map copied from Project Innerspace's website, February 2025

Remaining key subsurface related uncertainties

- **Water chemistry** (scaling, corrosion)

- **Water losses** (percentage of injected water recovered)
- **Thermal longevity** (heat output over time; ultimate recovery; need for "make-up wells")

Uncertainties potentially impacted by the presence of natural occurring fractures

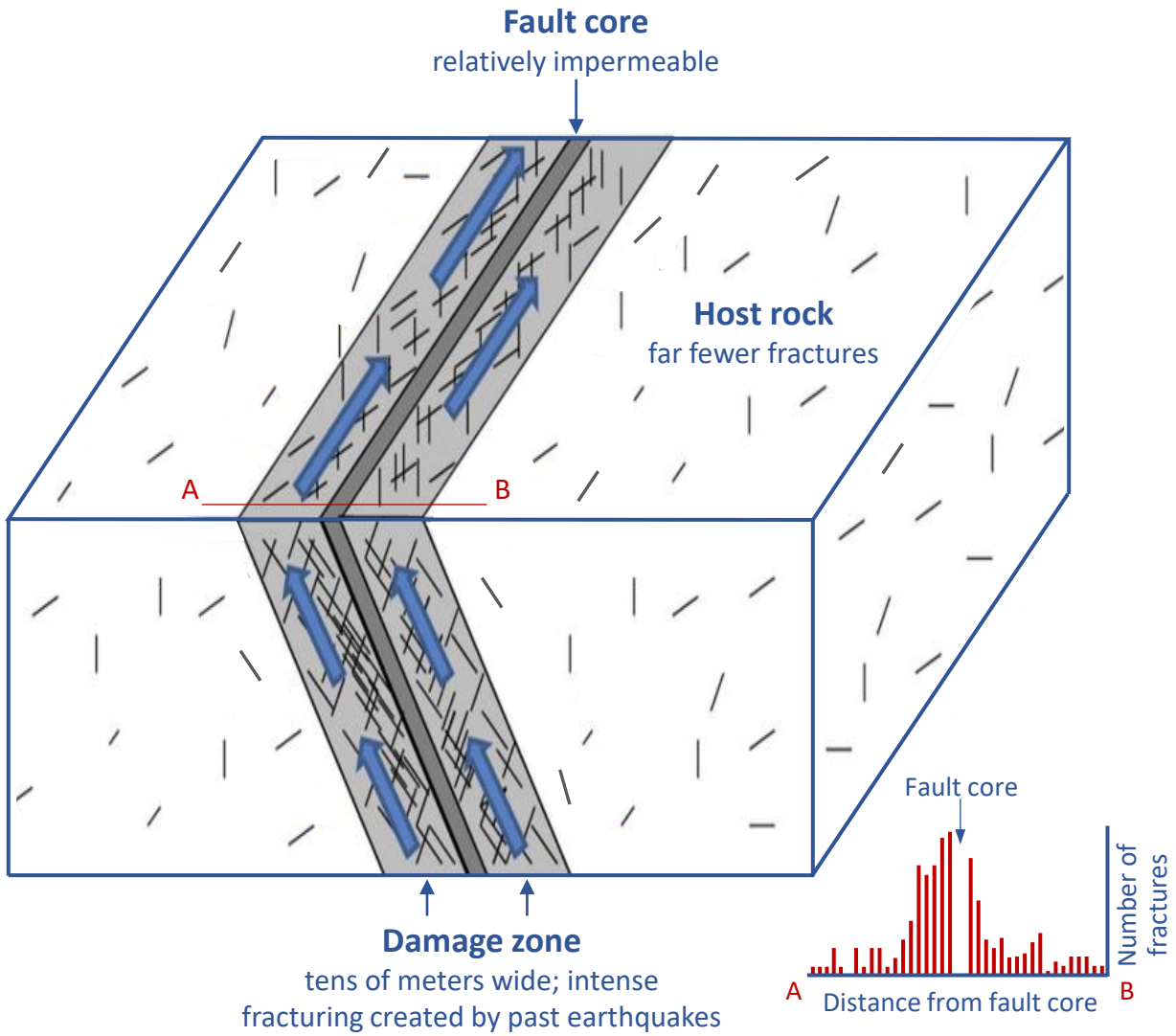
Discussion Topics

- CERAWeek highlights
- Enhanced geothermal systems technology breakthrough overview
- Optimizing enhanced geothermal systems by avoiding potentially negative impacts caused by fluid injection into shear zones[1]

[1] Presentation slightly modified from paper presented at the 2025 Stanford Geothermal Workshop; Leveille and Zoback, Impacts of Shear Zones on Enhanced Geothermal Systems (EGS): Best Practices for Avoiding Induced Seismicity, Premature Thermal Breakthrough, and Excessive Leakoff

Fractures are not homogeneously distributed in the Earth's crust

Shear zones can be pervasively fractured



Main figure after Johri et al. (2014), inset after Gudmundsson (2022)

Impact of critically stressed fractures on flow

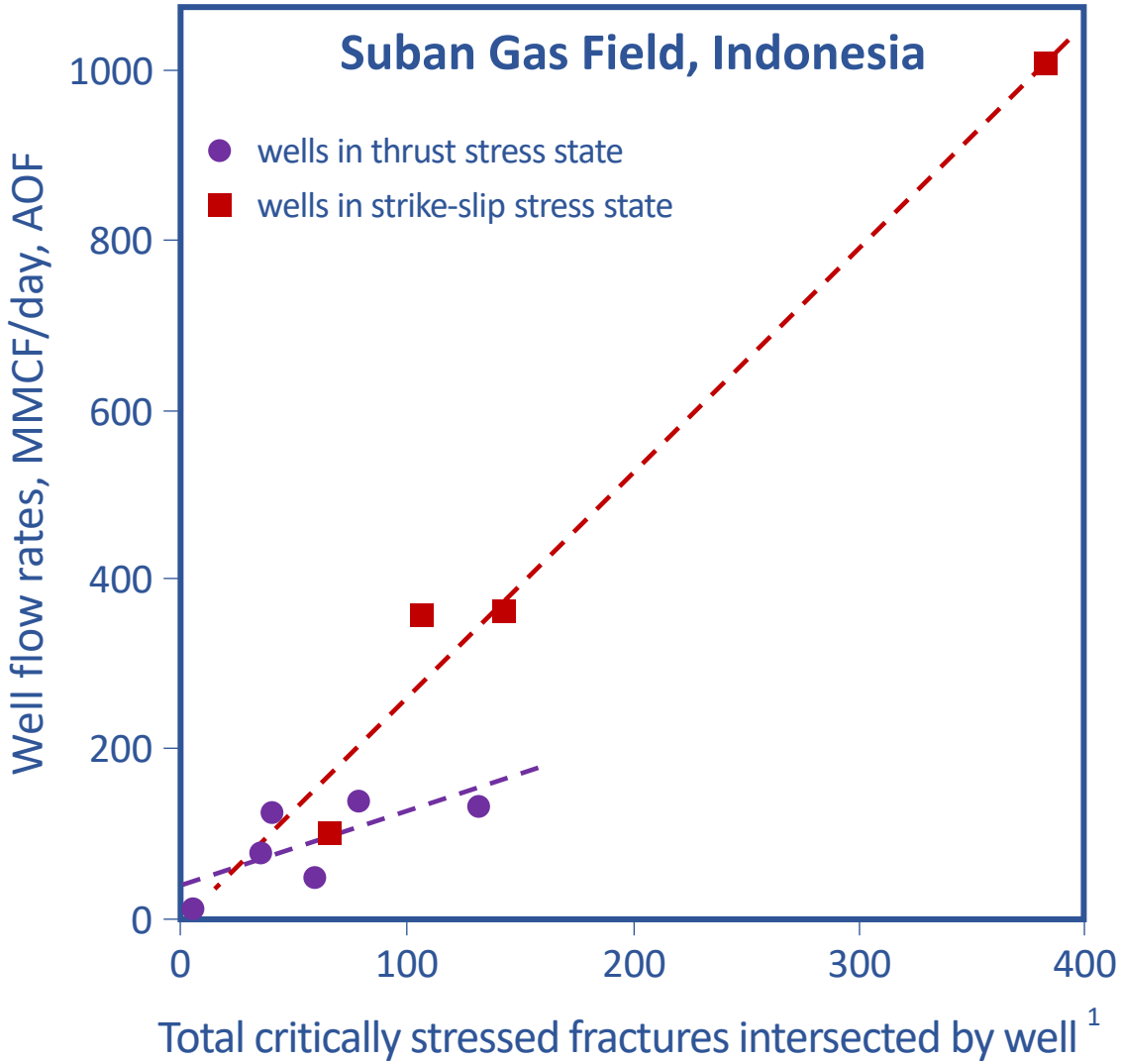


Figure after Hennings et al. (2012). MMCF = million cubic feet, AOF = absolute open flow, [1] from image logs.

Outcomes from hydraulically fracturing critically stressed shear zones

Faults can hijack hydraulic fracturing stages

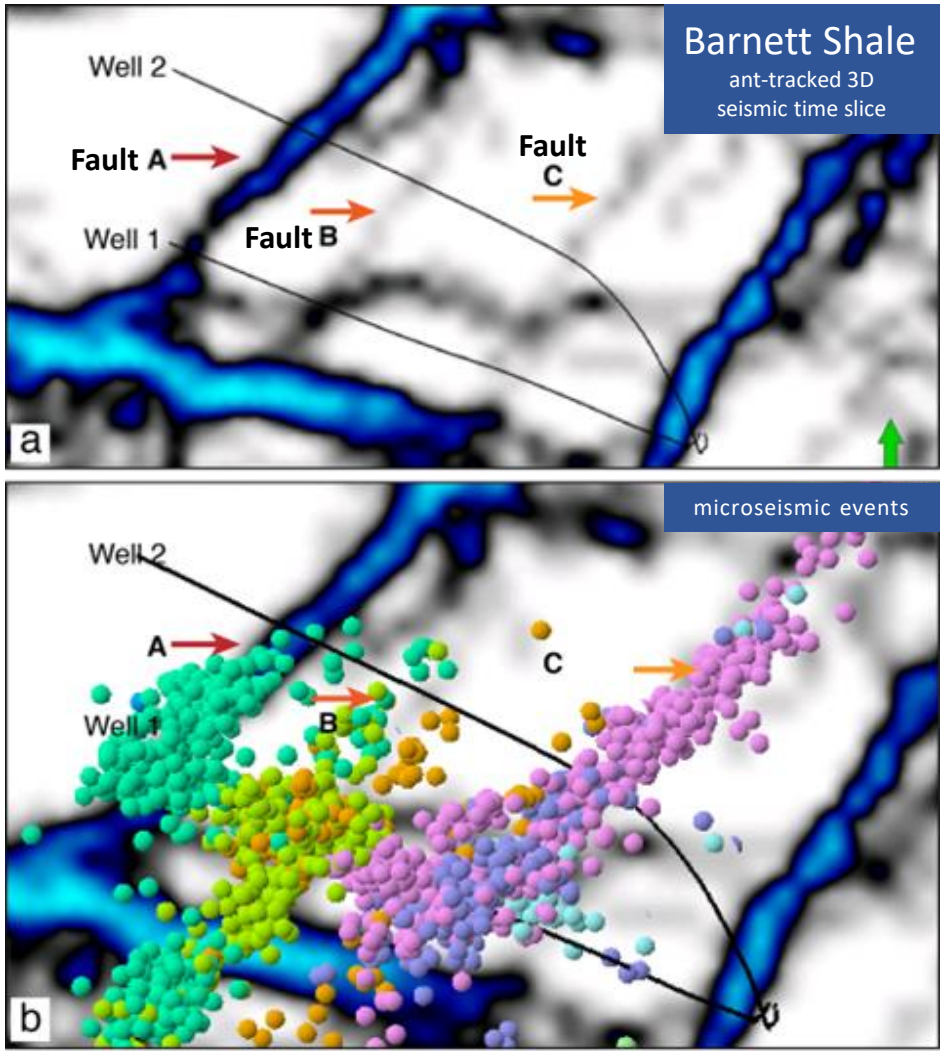


Figure after Farghal and Zoback (2016)

Hydraulic fracturing can induce seismicity

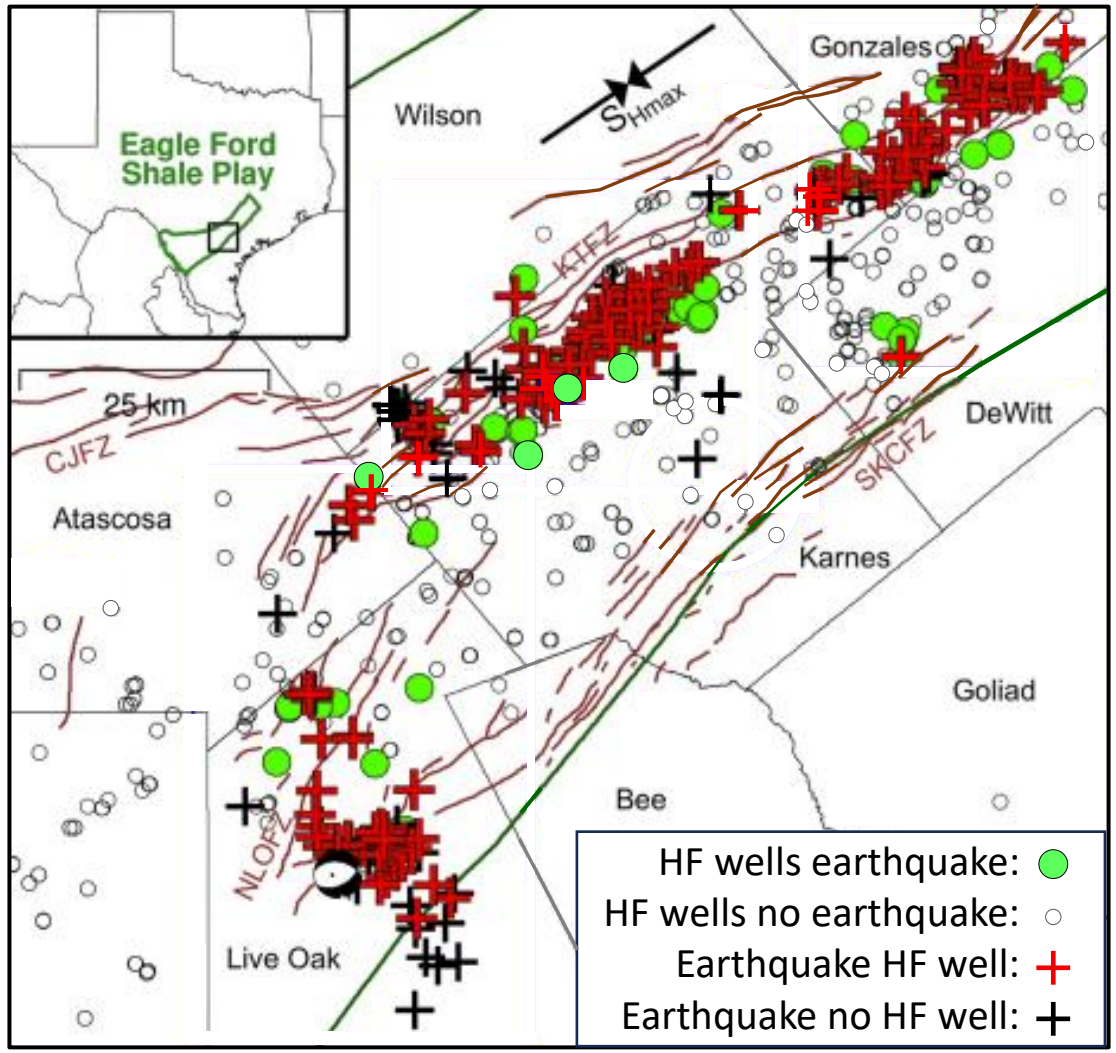
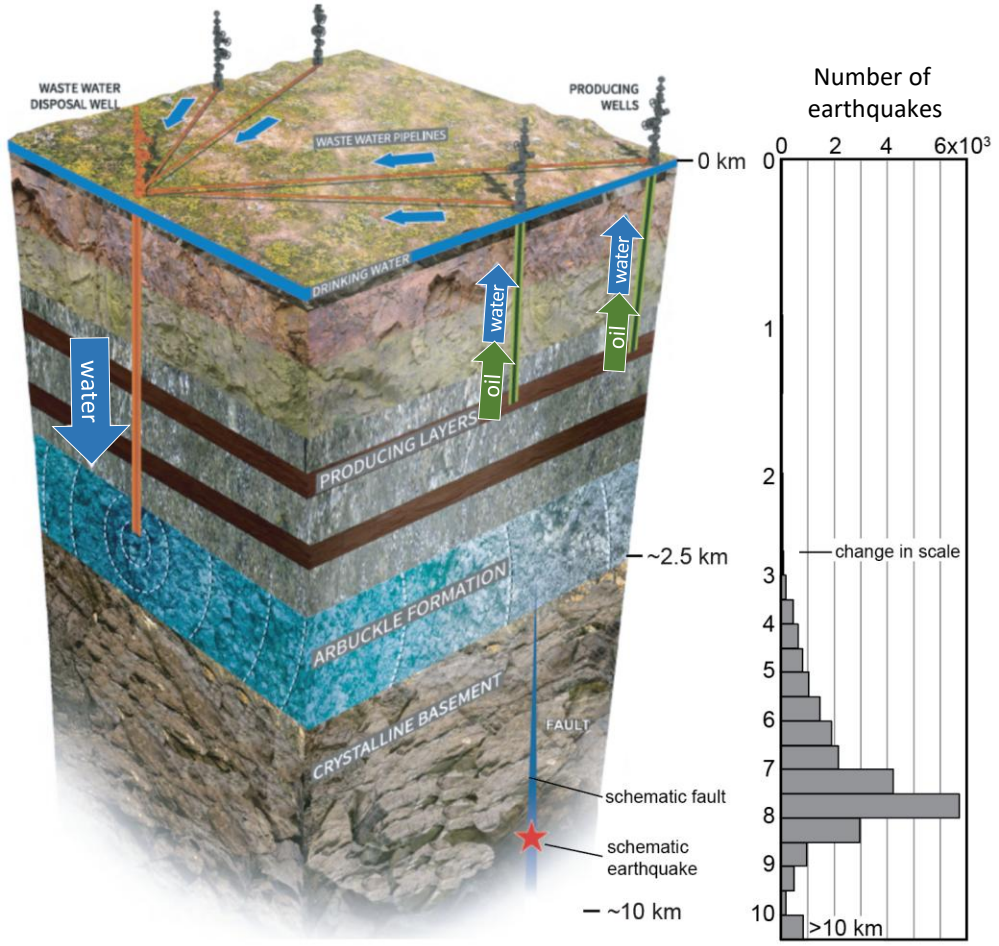


Figure after Fasola and Brudzinski (2022); HF = hydraulically fractured; Earthquakes up to Mw 4.8 induced by HF

Oil field produced water disposal has activated critically stressed basement faults



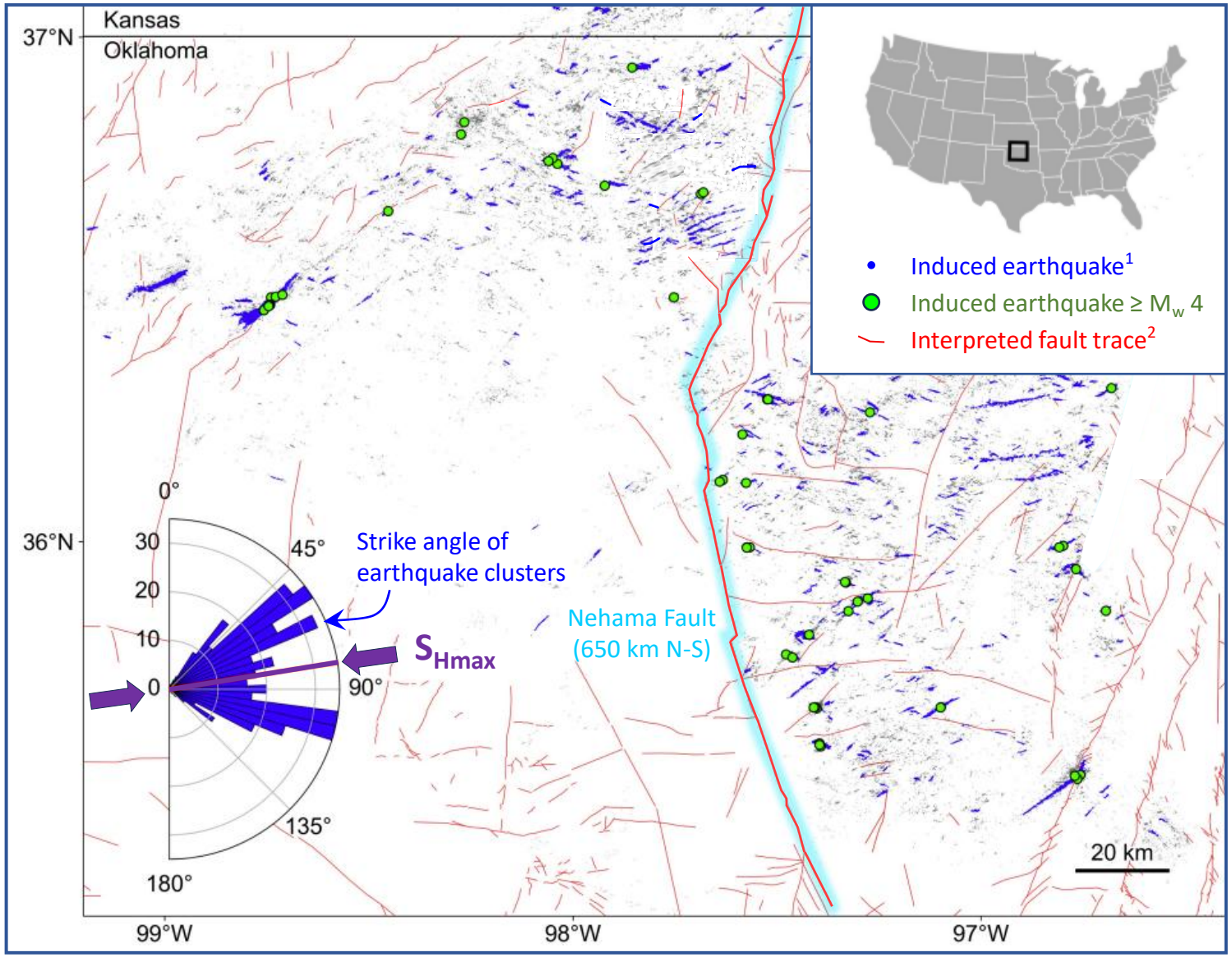
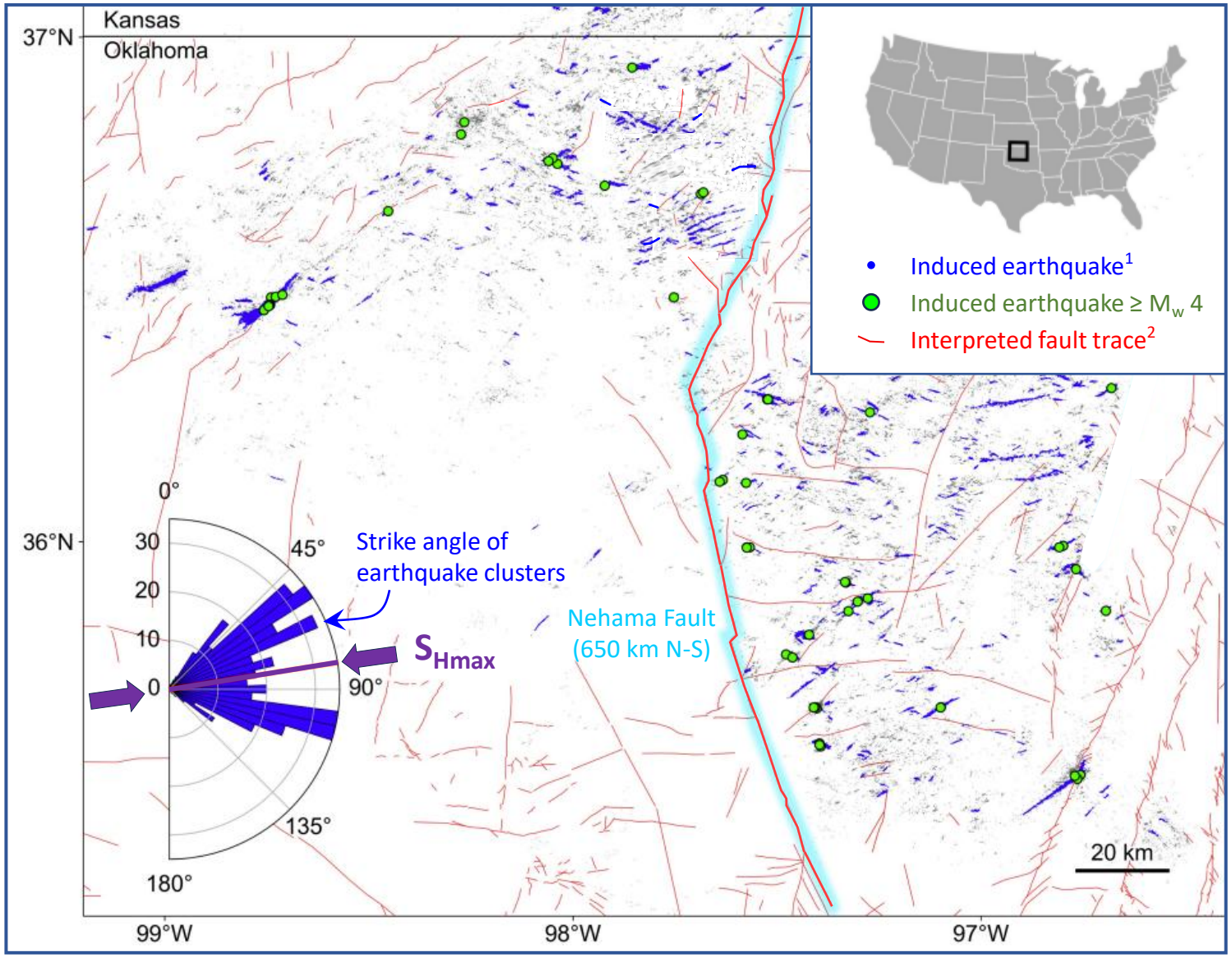


Diagram on left from Zoback and Kohli (2019); Figure on right modified after Park et al. (2022); [1] Earthquakes that belong to clusters with sufficient scale to host a Mw ≥ 4 event shown by blue dots, rest by gray dots; [2] from Marsh and Holland (2016)

The current stress field defines which fault orientations are potentially active



- ≈ 400,000 earthquakes induced by an ≈ 1 MPa pressure change in the Arbuckle Formation; events up to M5.8; $S_{Hmax} \geq S_V > S_{hmin}$
- Favorably-oriented faults in crystalline basement rocks are in frictional failure equilibrium
- Faults not favorably oriented relative to the current stress field did not fail
- Few of the faults in the crystalline basement rocks that failed were recognized prior to failure

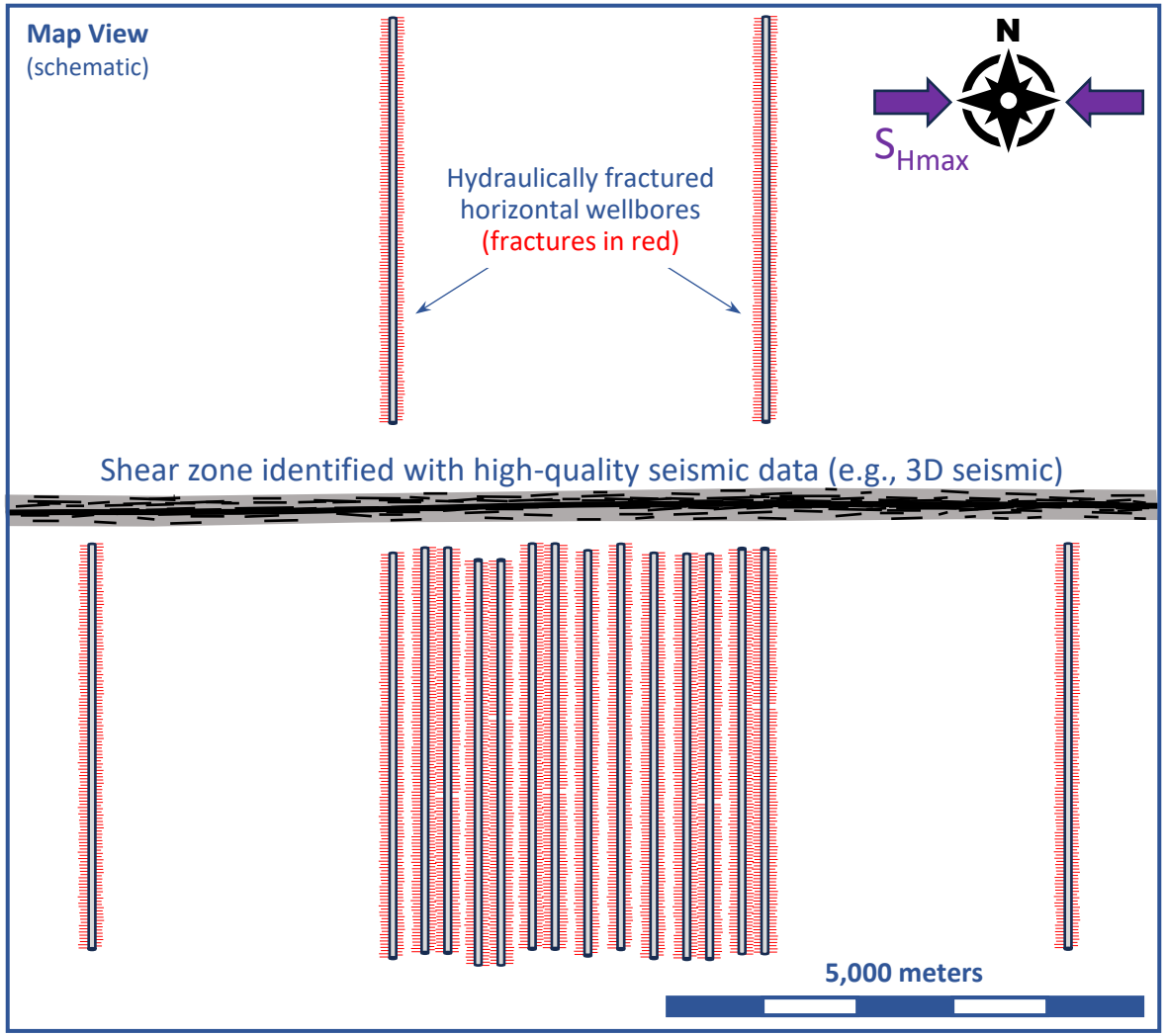
Figure modified after Park et al. (2022); [1] Earthquakes that belong to clusters with sufficient scale to host an Mw ≥ 4 shown by blue dots, rest by gray dots; [2] from Marsh and Holland (2016)

Shear zones in an EGS development area will be problematic if:

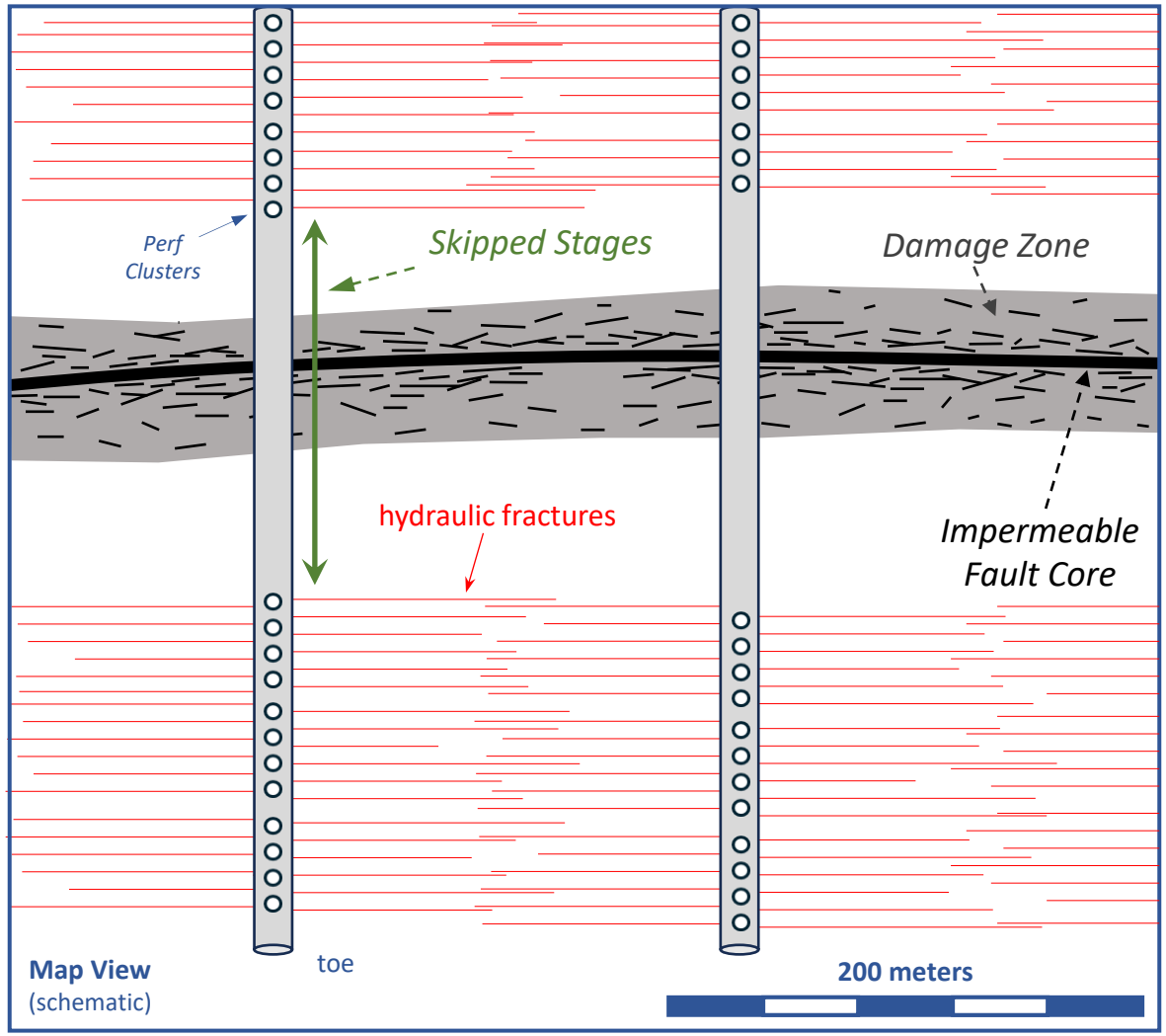
- they act as conduits that cause excessive water losses
- create pathways that take a disproportionate amount of the injected fluid, leading to premature thermal breakthrough ("short circuiting")

O&G industry approach to problematic shear zones[1] – detect and avoid

Avoidance via well placement



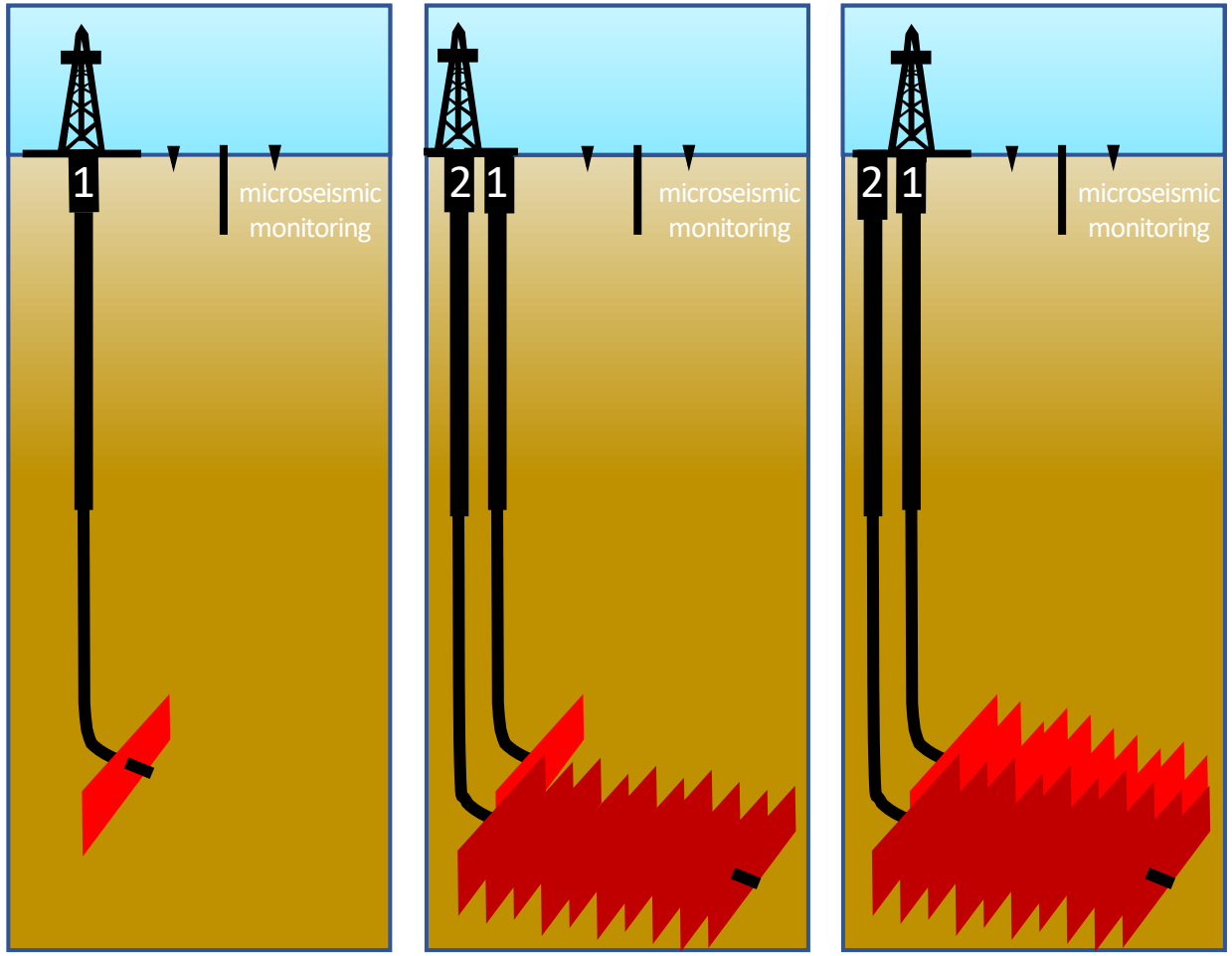
Avoidance by skipping frac stages



[1] That is, problematic shear zones in areas being developed using hydraulically fractured horizontal wells (e.g., the Eagle Ford play in south Texas and Montney play in British Colombia)

For EGS in crystalline rocks, operations should be phased to detect shear zones

Haute-Sorne project, Switzerland



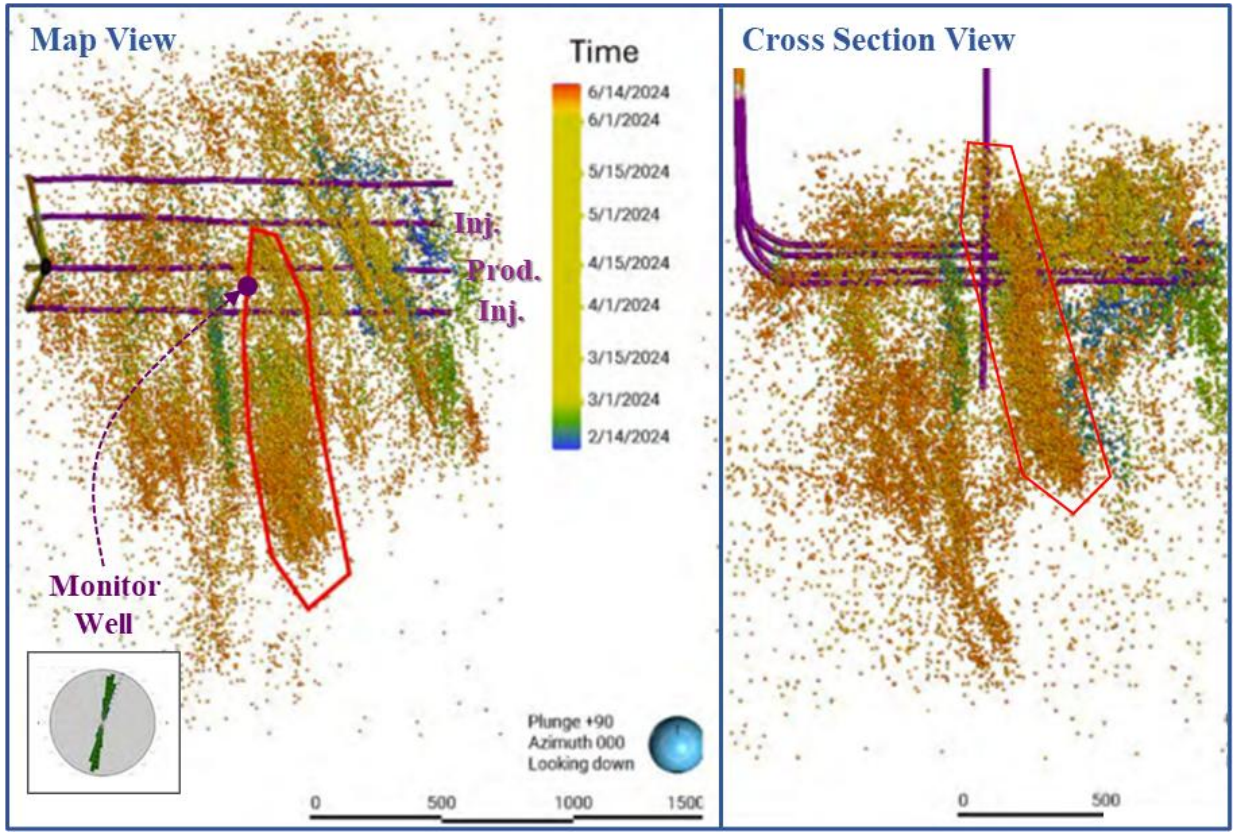
Drill, Frac, Assess Data

Drill, Frac, Assess Data

Drill, Frac, Assess Data, Produce

Figure simplified from one included in Meier et al. (2024)

Cape Station project, Utah USA



Hydraulic fracturing performed on three of first four wells drilled, followed by a thirty-day flow test (max. rate 70,000 bwpd)

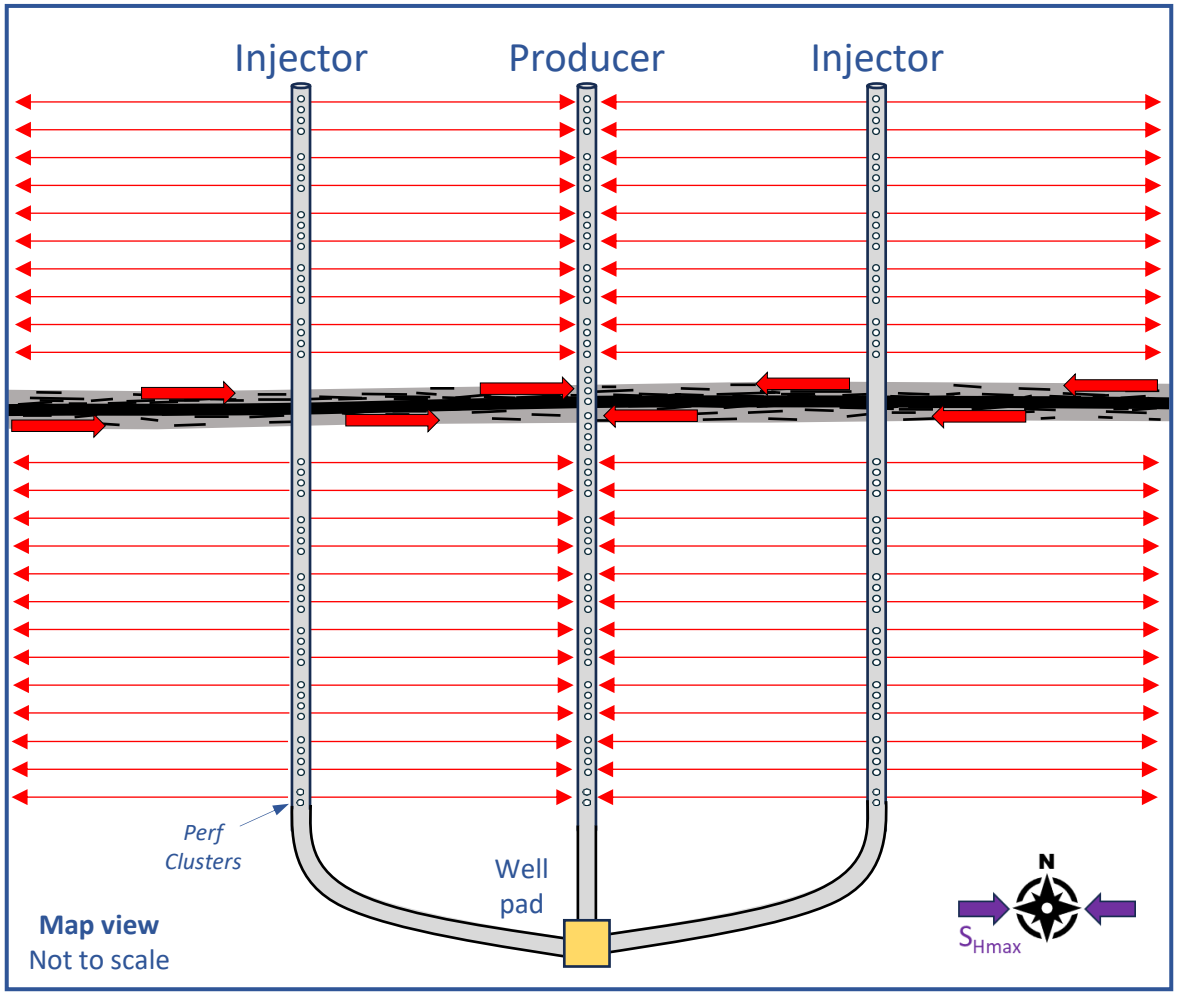
Figures slightly modified after Dadi et al. (2024)

Acquiring data about shear zones early on is essential for maximizing project value

Probability-weighted value maximization[1]

- Avoid penetrating critically stressed shear zones with wells
- Skip frac stages in all wells that penetrate critically stressed shear zones
- Skip frac stages only in the injection wells (see figure on the right)
- Fracture everything; attempt to shut-off problematic zones if negative outcome

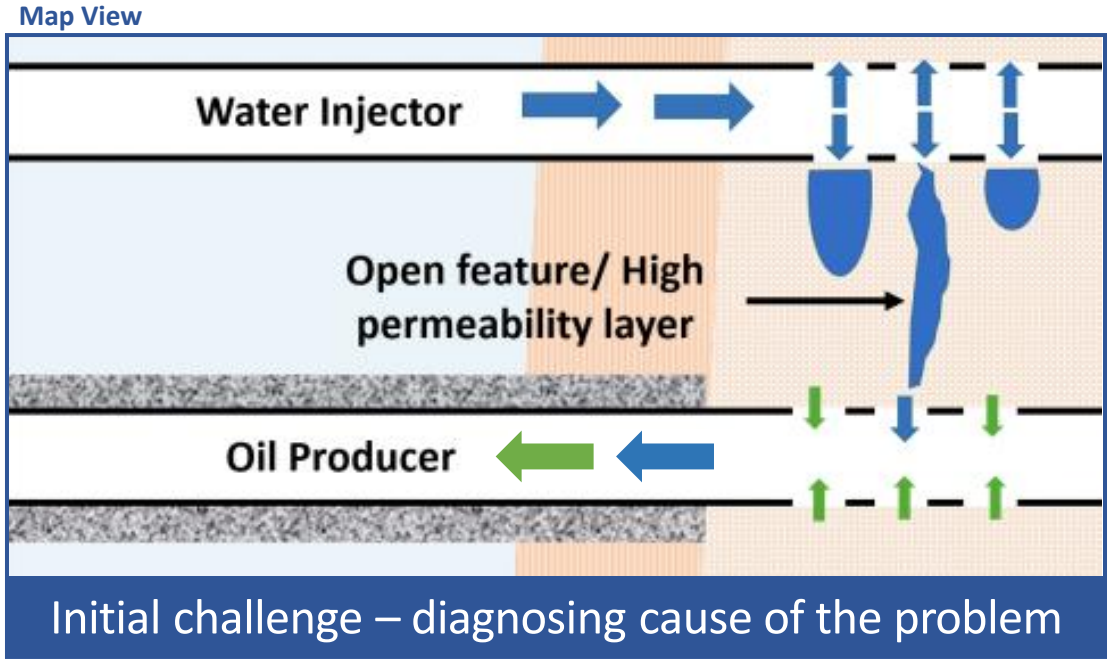
Combined EGS / hydrothermal production



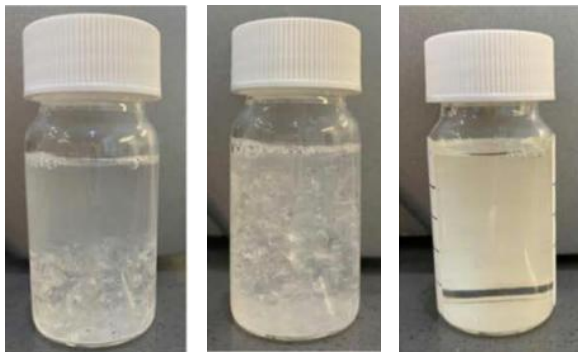
Potential unintended consequence - Perfing producers could create cross-flow risk

[1] Actions listed from least risky to most risky; conversely, actions are listed in inverse order as far as potential upside

Shutting off problem zones can be problematic



Initial challenge – diagnosing cause of the problem



Oil and gas industry solutions

- Mechanical devices, plugging agents, chemical treatments
- Pre-installed or deployed later
- Inflow, outflow, or both
- Challenges abound:
  - Cost, reliability, effectiveness
  - Harsh operating environments
  - Limited diagnostics; impaired "vision"
- Problem avoidance value is non-trivial

Figure at top from Taha and Amani (2019); bottom left picture from Sun and Bai (2017); pictures on bottom right from Targac et al. (2020)

Impact of shear zones on EGS: key take-away messages

- Understanding the nature of shear zones encountered in an EGS development area is crucial for optimizing project economics
- Critically stressed shear zones should be considered as potentially active faults and highly conductive fluid flow pathways
- As shear zones are nearly impossible to detect geophysically in crystalline basement rocks, operations should be phased so that microseismic, fiber optic and other data can be acquired in appraisal wells before moving to full development
- If critically stressed shear zones are encountered, employing a probability-weighted risk management approach can help maximize value

Enhanced Geothermal Systems Update

SPE Houston Westside Study Group

Greg Leveille

March 19, 2025

Website where you can access a copy of this slide deck