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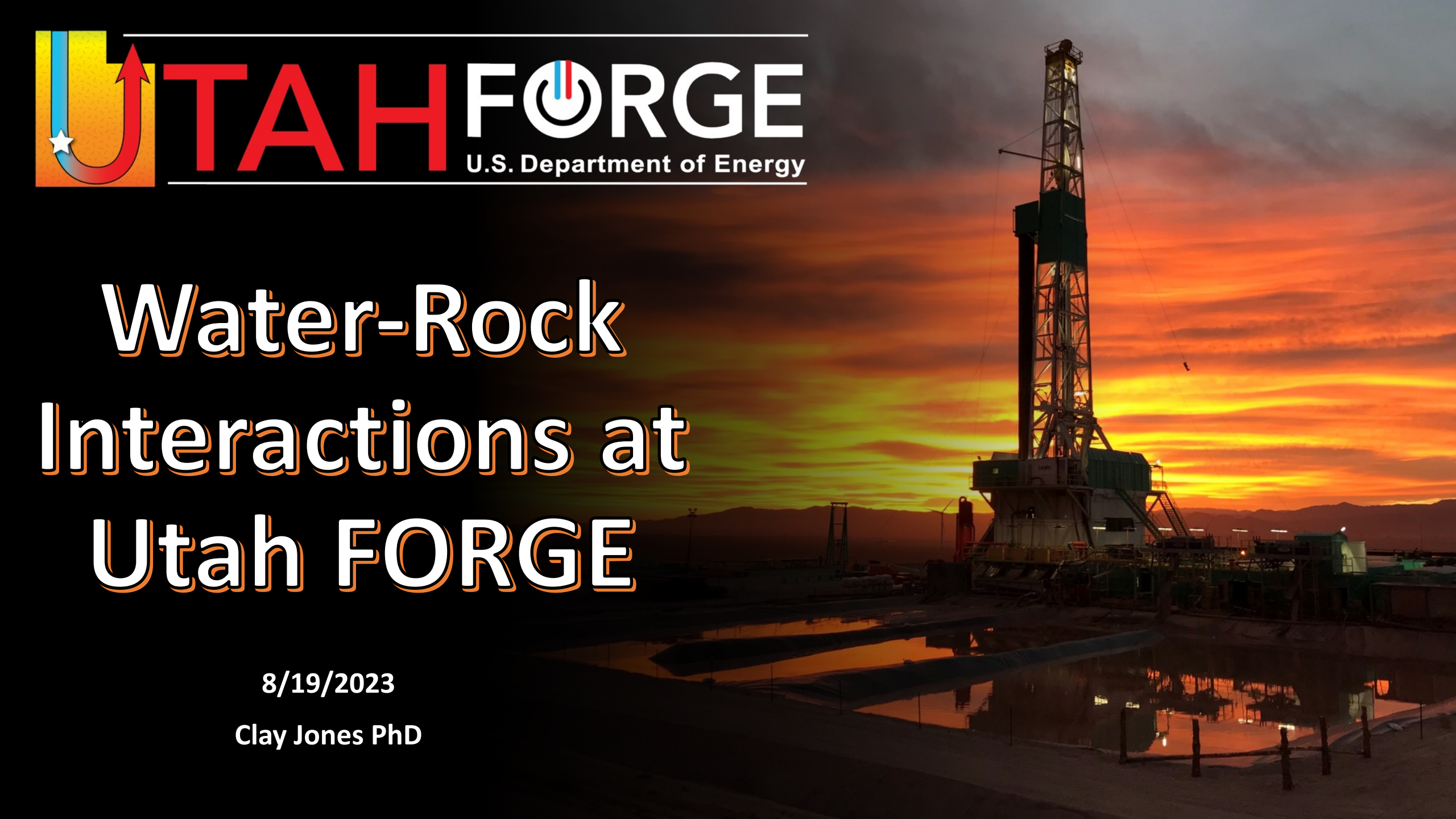
Water-Rock Interactions at Utah FORGE

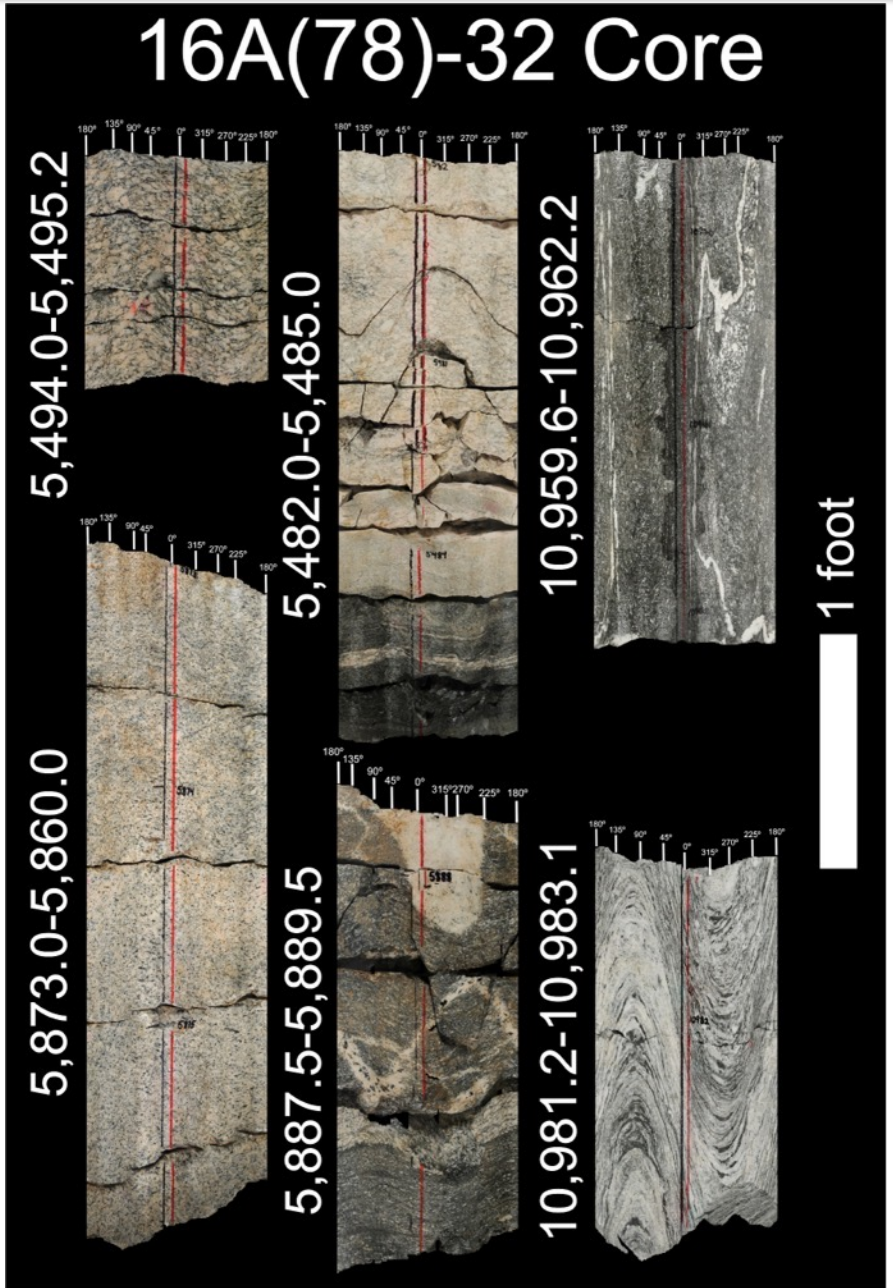


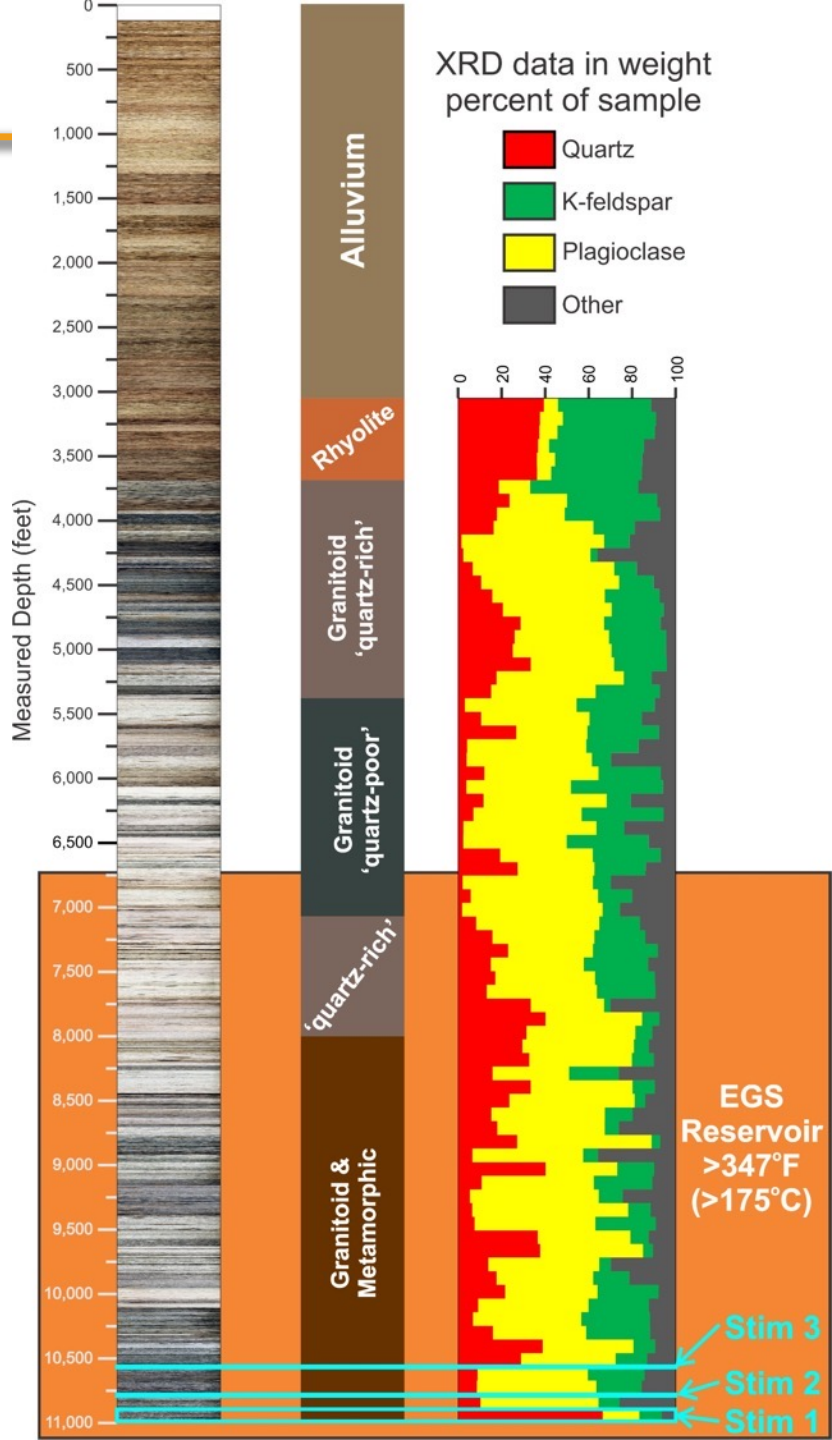
8/19/2023

Clay Jones PhD

The Utah FORGE EGS Reservoir Rock

- Mineral assemblages in both plutonic and the bulk of the metamorphic rocks are similar.
- Low porosity < 0.5 %
- Low permeability ~50 microdarcy's
- Open fractures in the reservoir to are not interconnected.
  - No loss or gain of fluids during drilling.
  - Static water levels in unstimulated wells.





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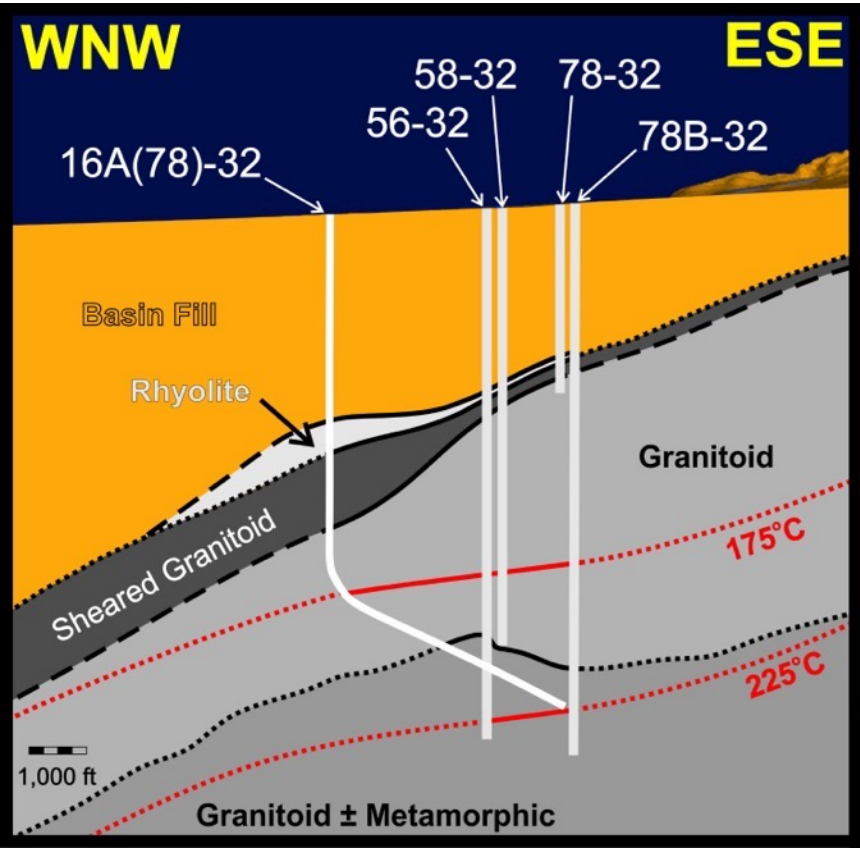
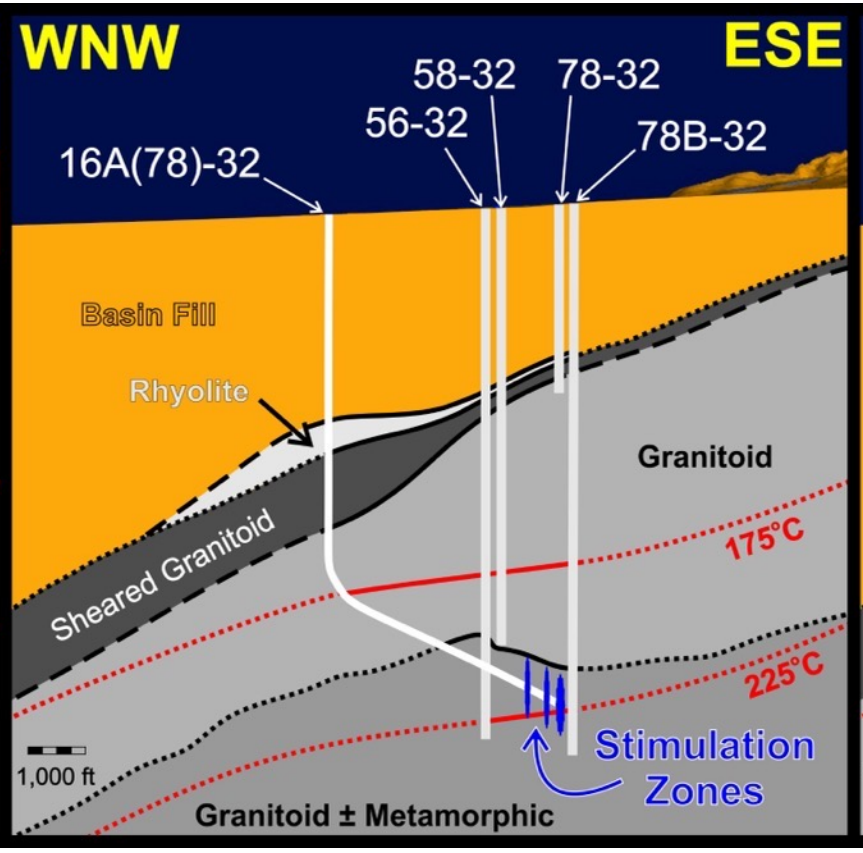
Building the Utah FORGE Heat Exchanger

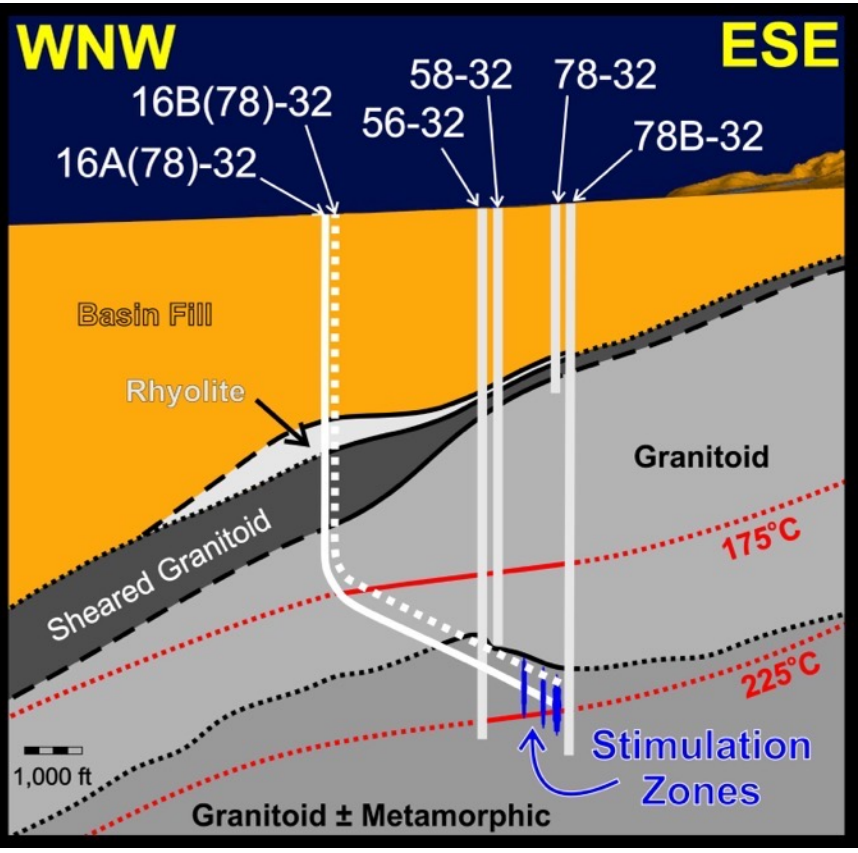
January 2021



April 2022



April-July 2023



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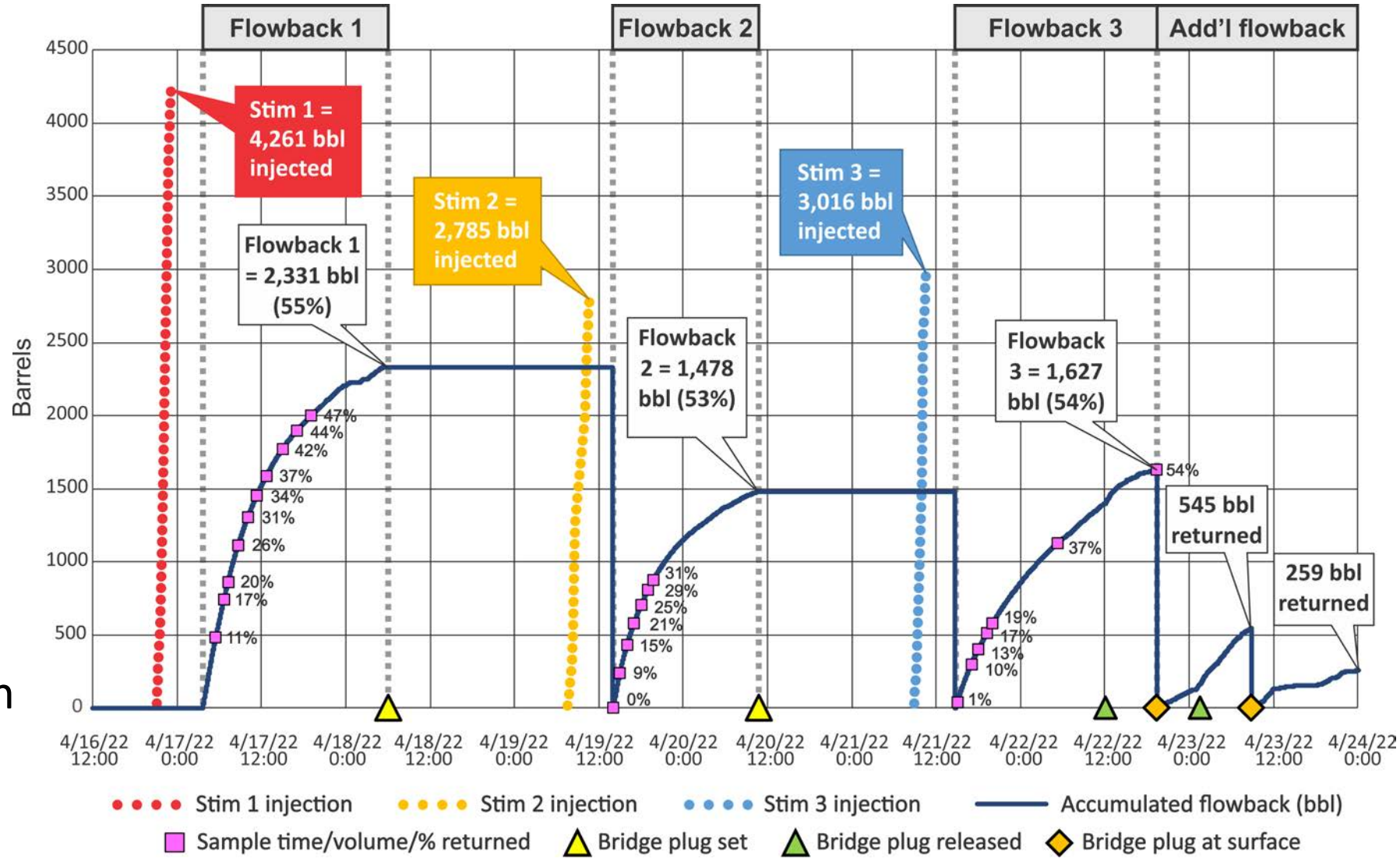
Stimulation & Flowback Summary

- Stage 1 open hole
- Stages 2&3 perforations
- **Stages 1&2 slick water**
- **Stage 3 viscosified fluid**
- **Sampling points in pink**
- Similar volumes of flowback in all three stages.
- Summary
  - 10,062 bbl injected,
  - 6,240 bbl (62%) recovered
  - 3,822 bbl (38%) left in the reservoir (21,471 ft^3, 608 m^3).



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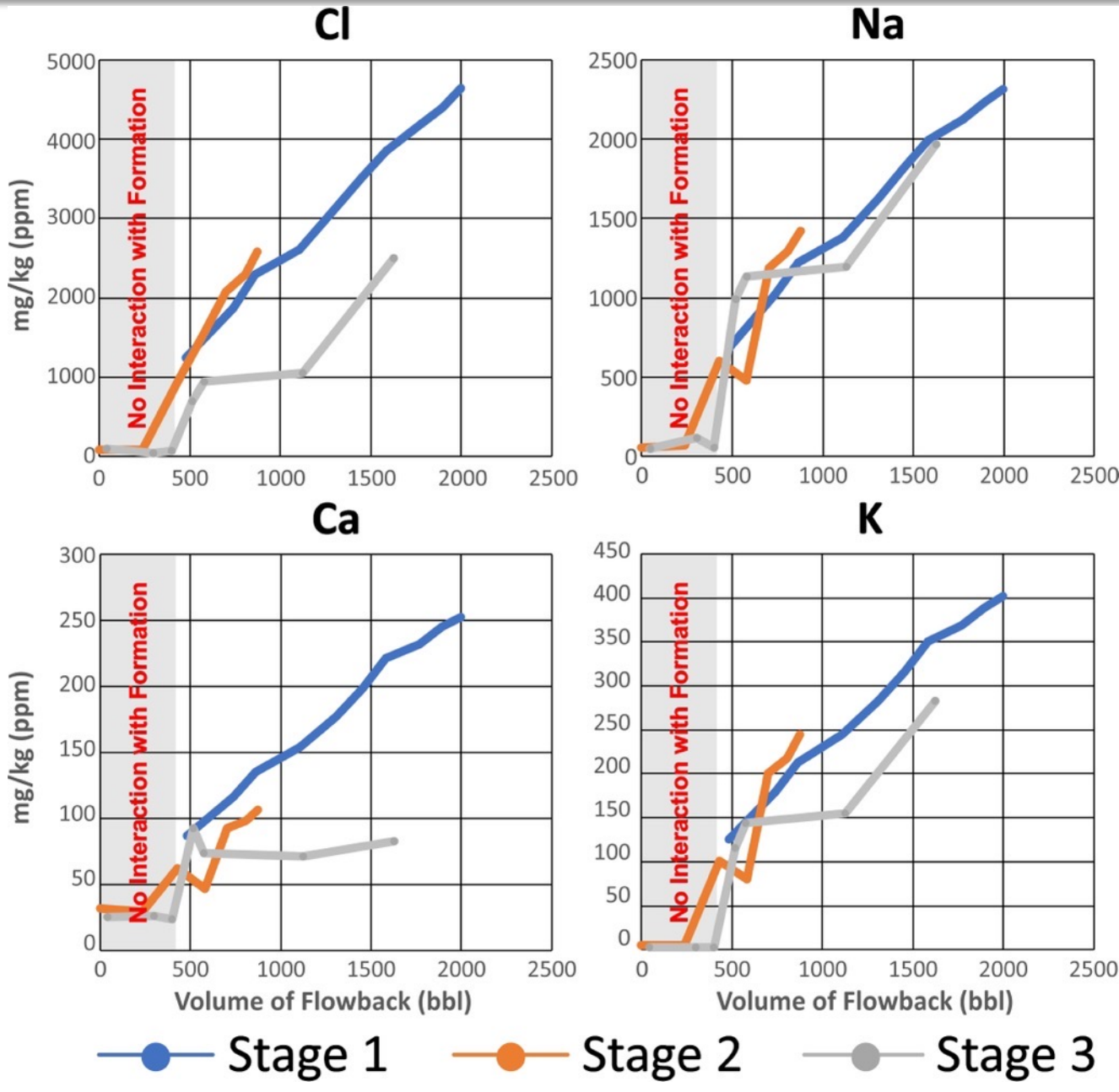
Flowback Water Geochemistry

- Drastic changes to water chemistry over short time scales (<30 hours).
- Fluid base = culinary grade, low salinity water.
- Early sampled returns did not interact with the formation = fluid baseline.
- Overall changes become more pronounced with time.
- Overall increase in TDS from 100s of ppm to 1,000s of ppm.
- The most pronounced increases are in **Cl** (51 to 4,643 mg/kg), **Na** (50 to 2,319 mg/kg), **K** (2 to 403 mg/kg), and **Ca** (24 to 253 mg/kg).
- ~5,000 kg of dissolved solids were mobilized during stage 1 flowback alone!



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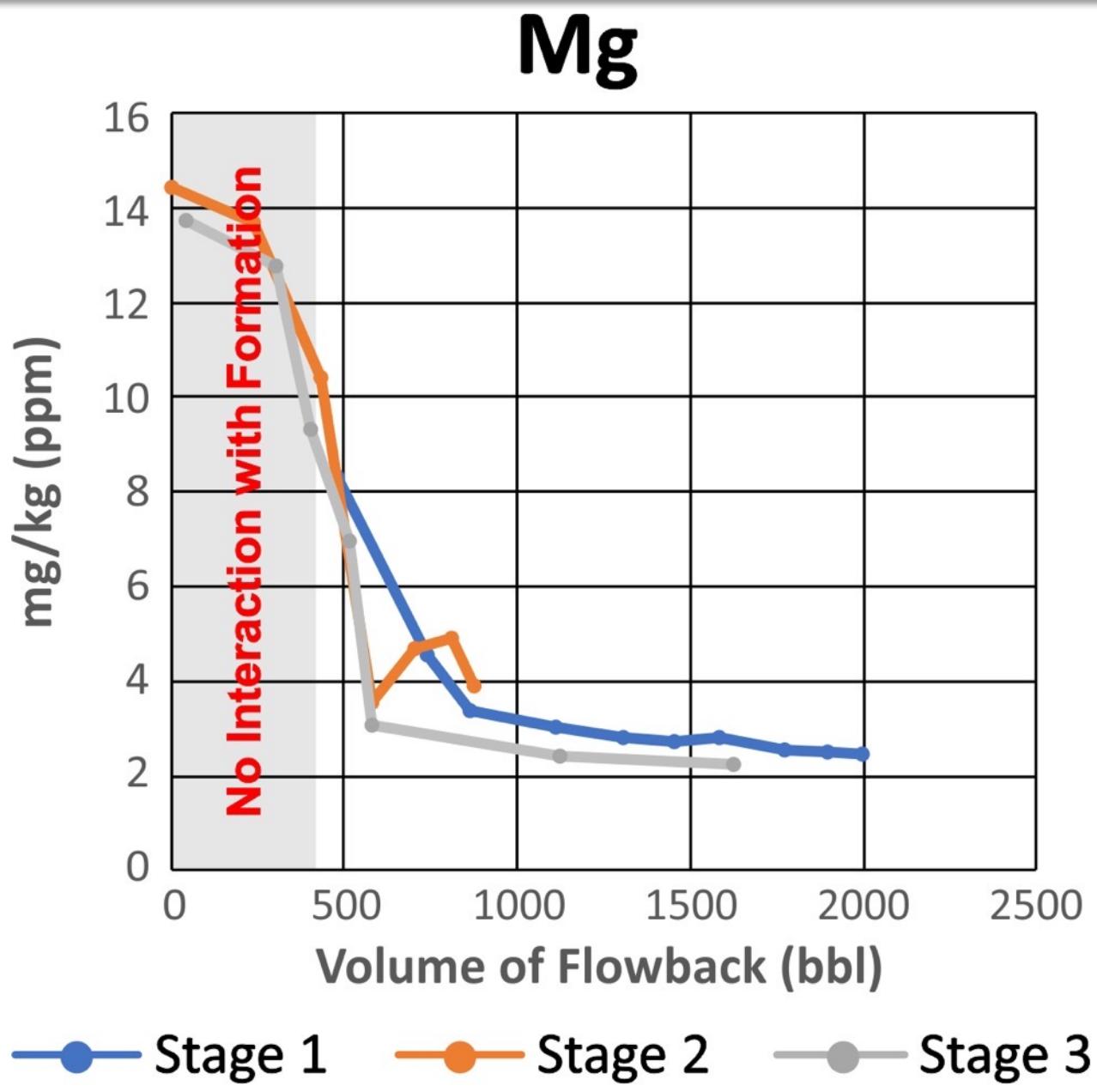
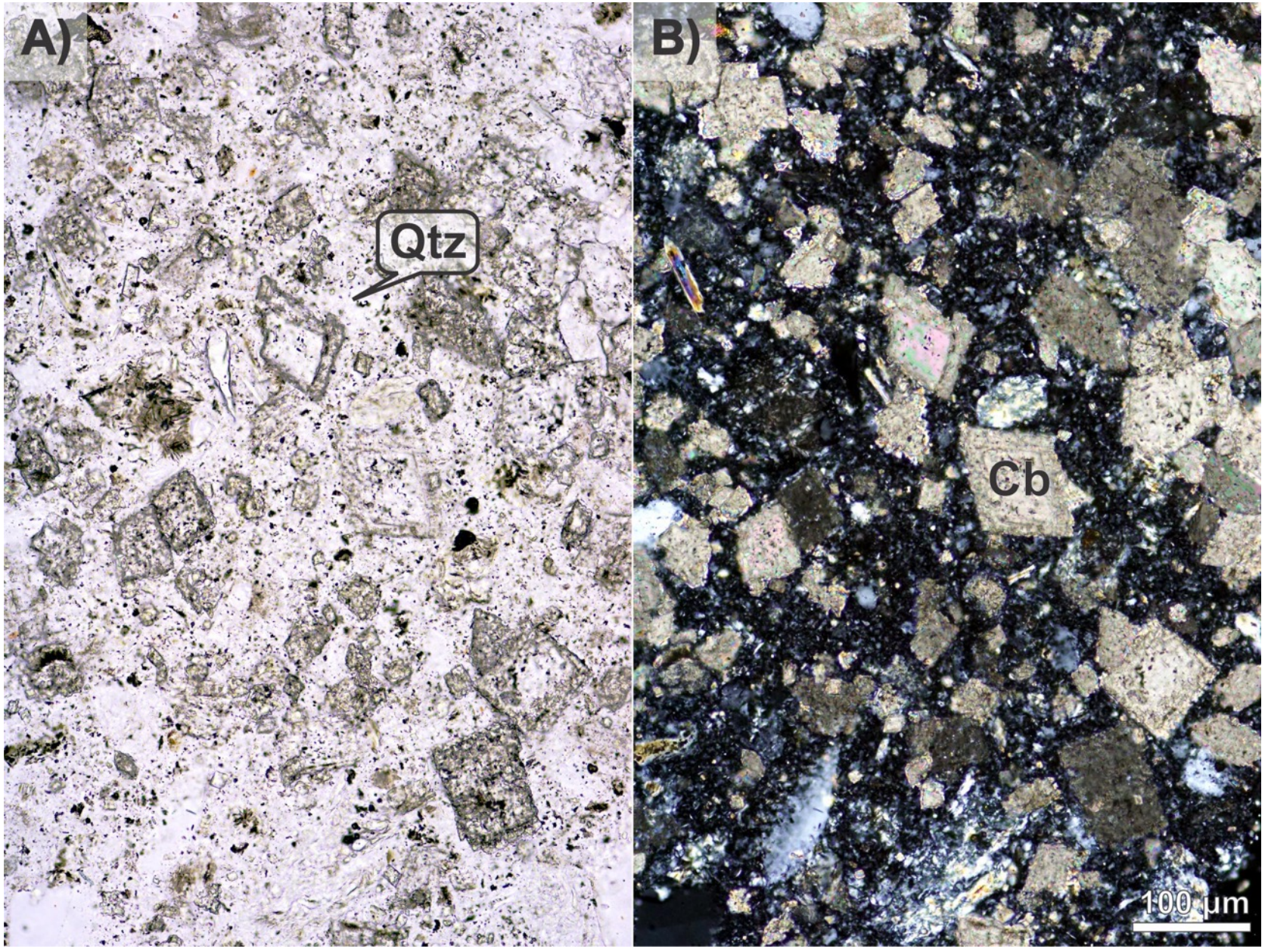
Flowback Water Geochemistry

- Mg declines with time from ~14 to ~2 mg/kg.
- Geothermal fluids are Mg-poor.
- Mg-bearing phases have been observed filling fractures within the reservoir.
- The decline in Mg with time is interpreted as the result of water-rock interaction in the EGS reservoir.



Mg-Bearing Open-Space Filling Minerals in the Reservoir

- Open-space filling mineralization in a fracture zone at ~8,010 ft in 16A(78)-32.
- Fe-bearing dolomite rhombs in a matrix of fine-grained quartz



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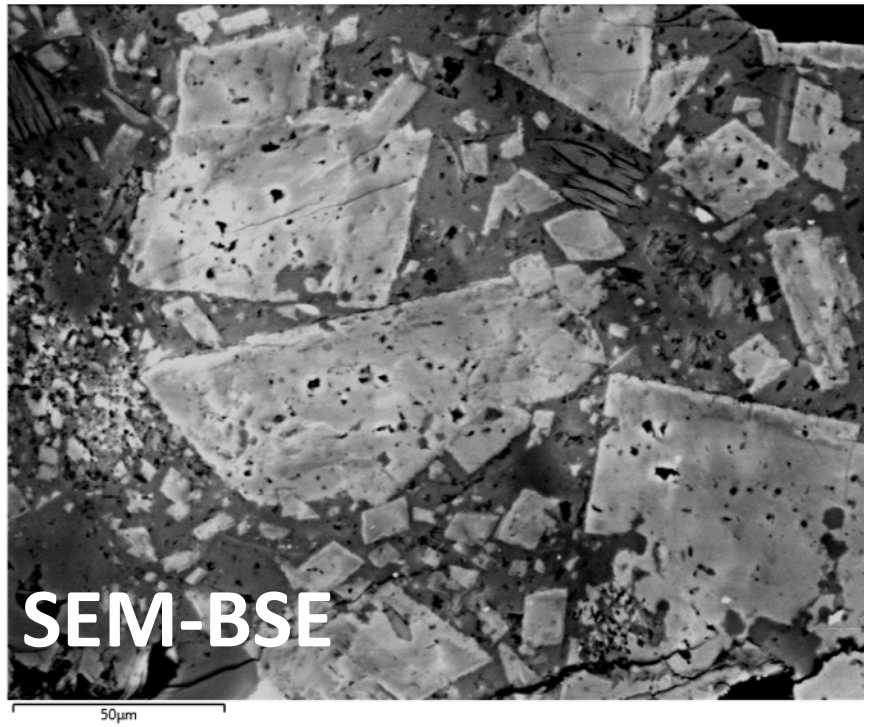
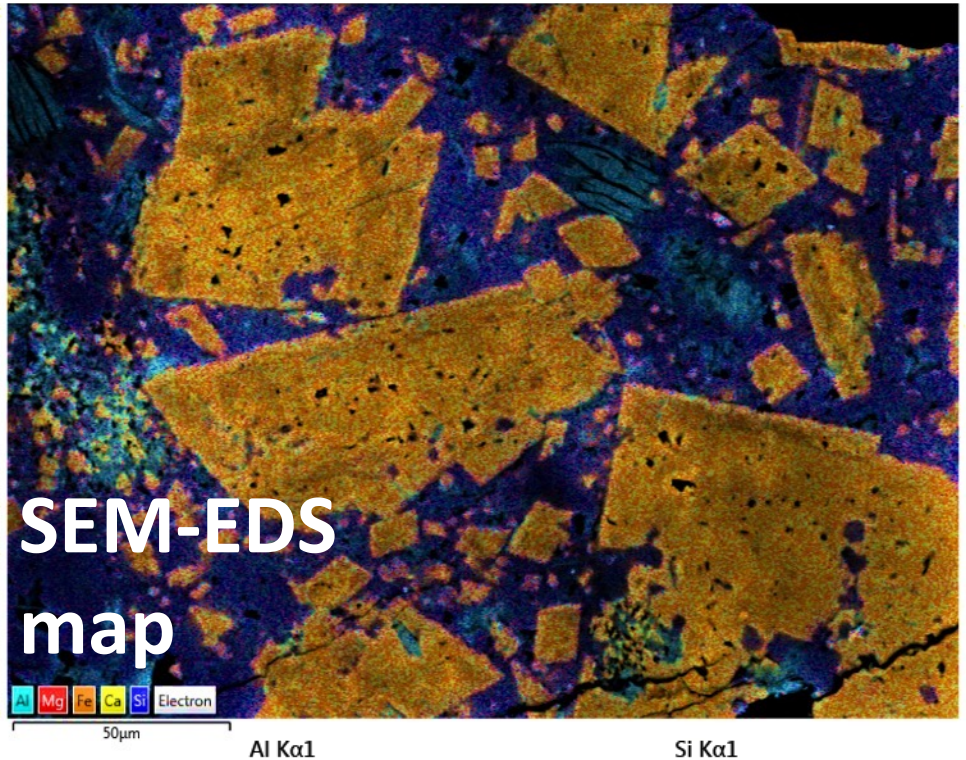
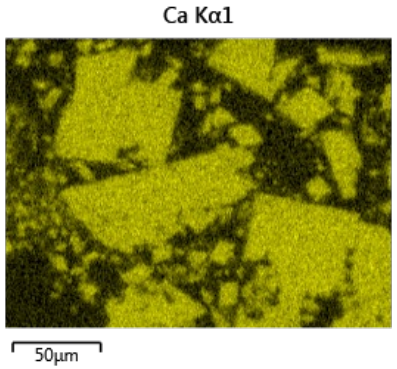
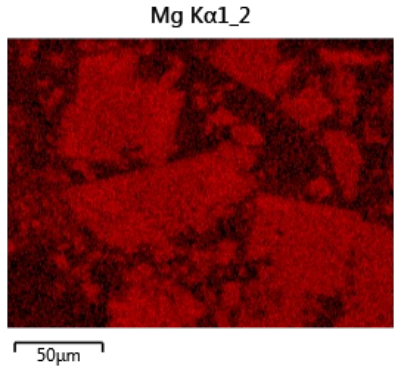
Mg-Bearing Open-Space Filling Minerals in the Reservoir

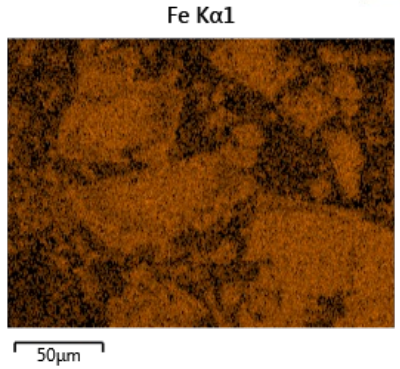
16A(78)-32 Fracture Zone 8,000 – 8,010 ft

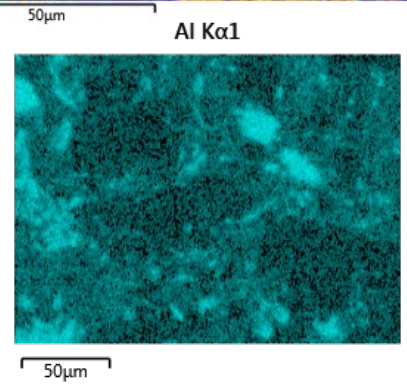


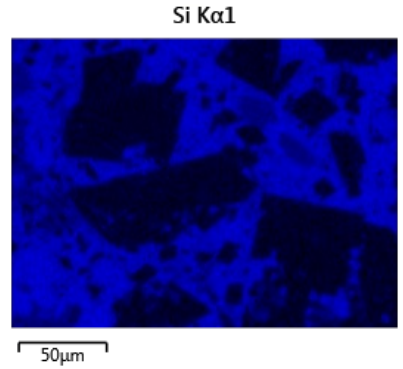


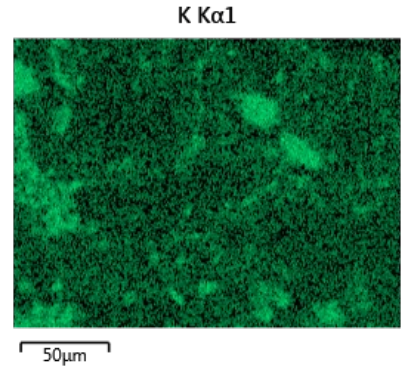












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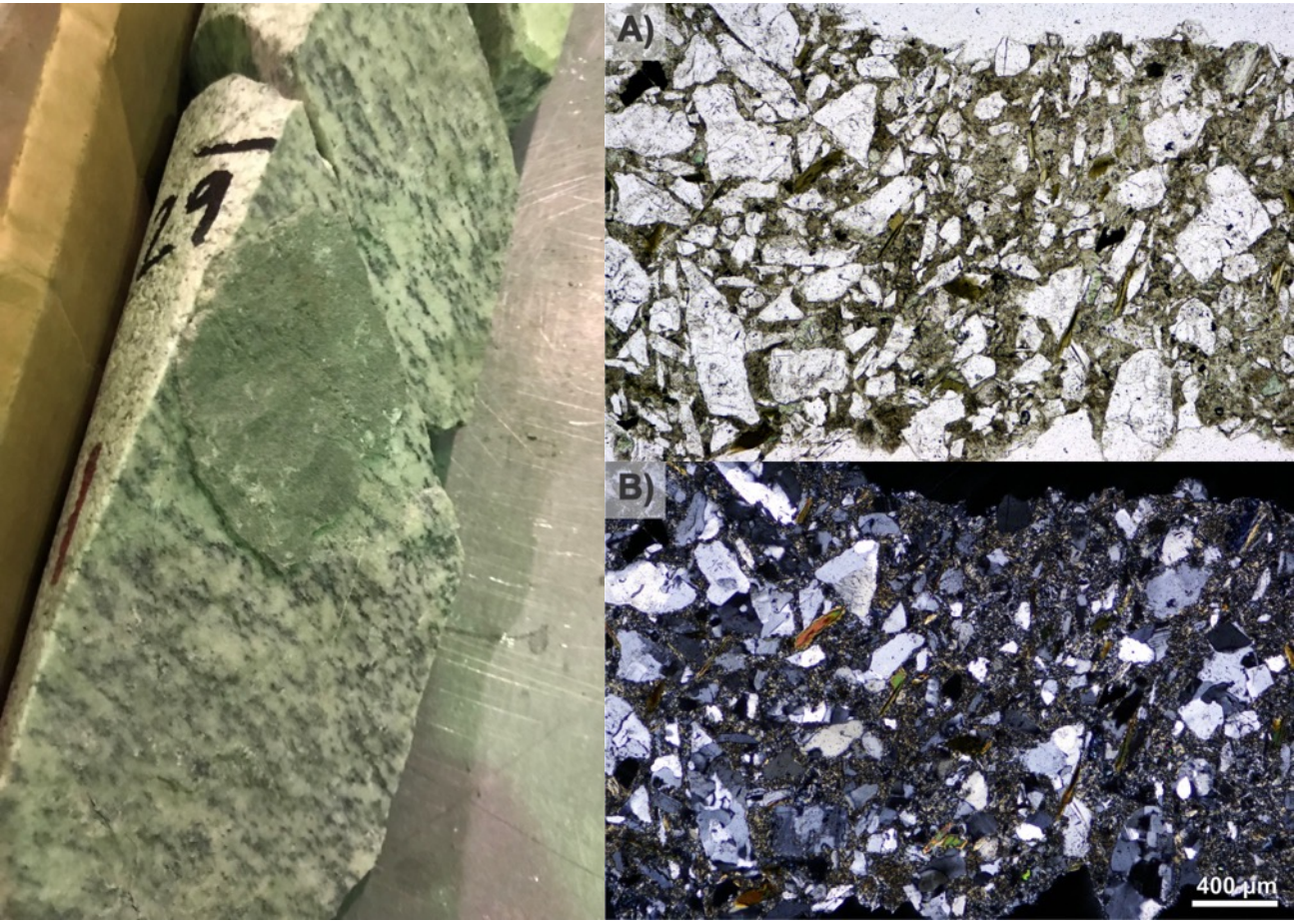
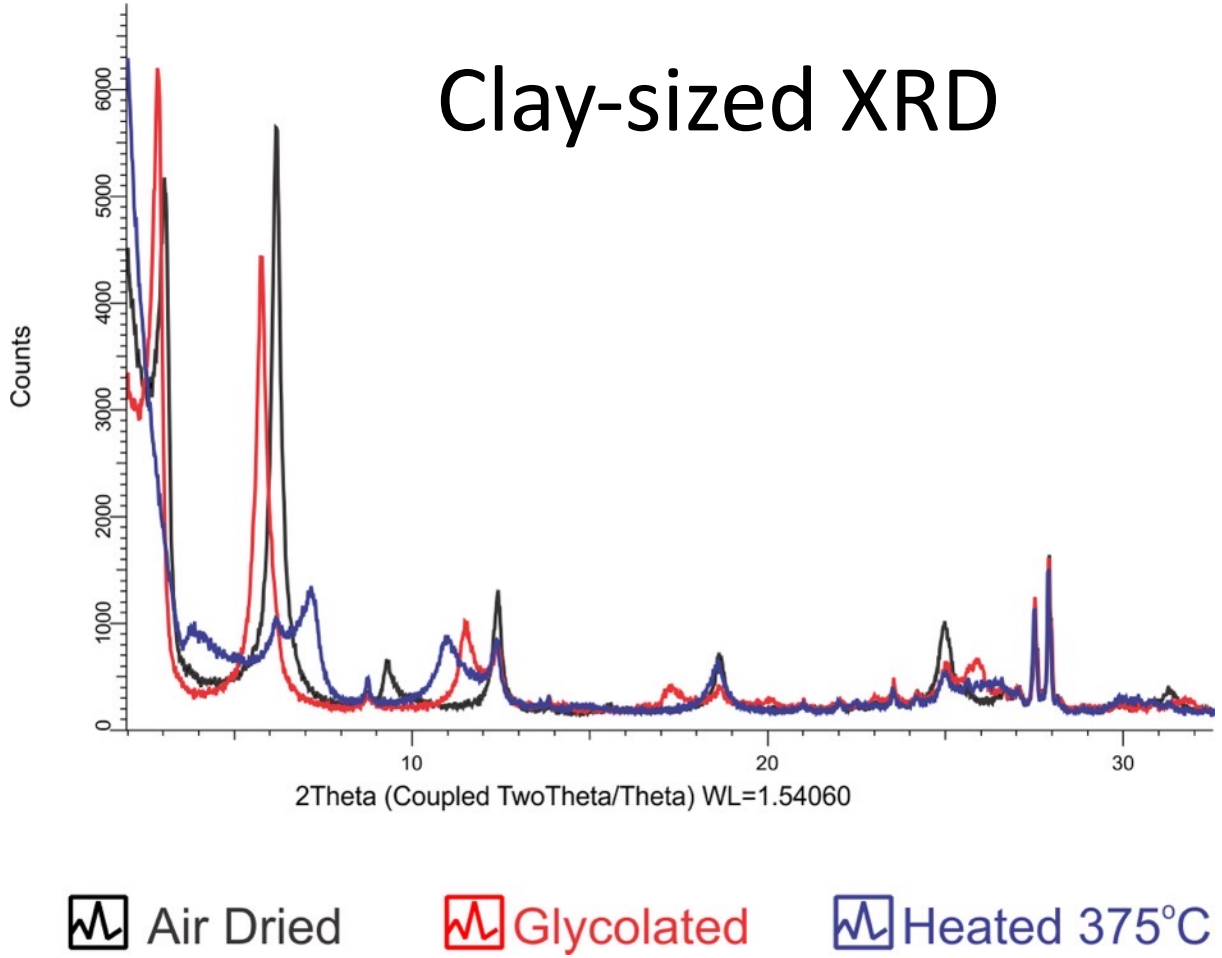
Mg-Bearing Open-Space Filling Minerals in the Reservoir

78B-32 Microbreccia 6,728.5 to 6,729.8 ft
Cemented dominantly by interlayered chlorite/smectite





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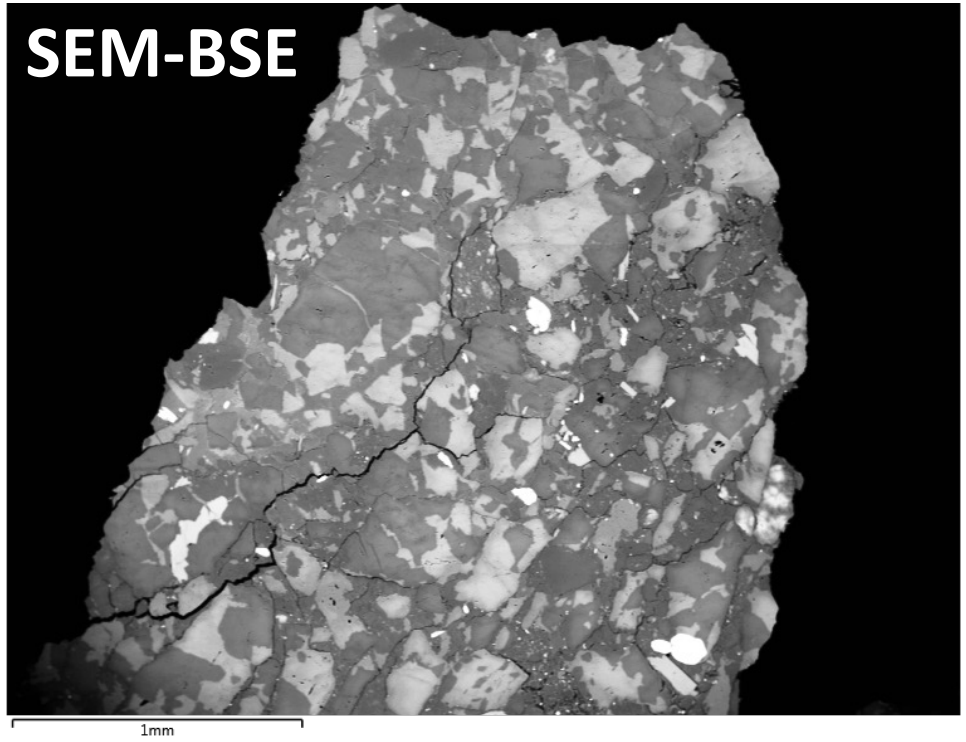

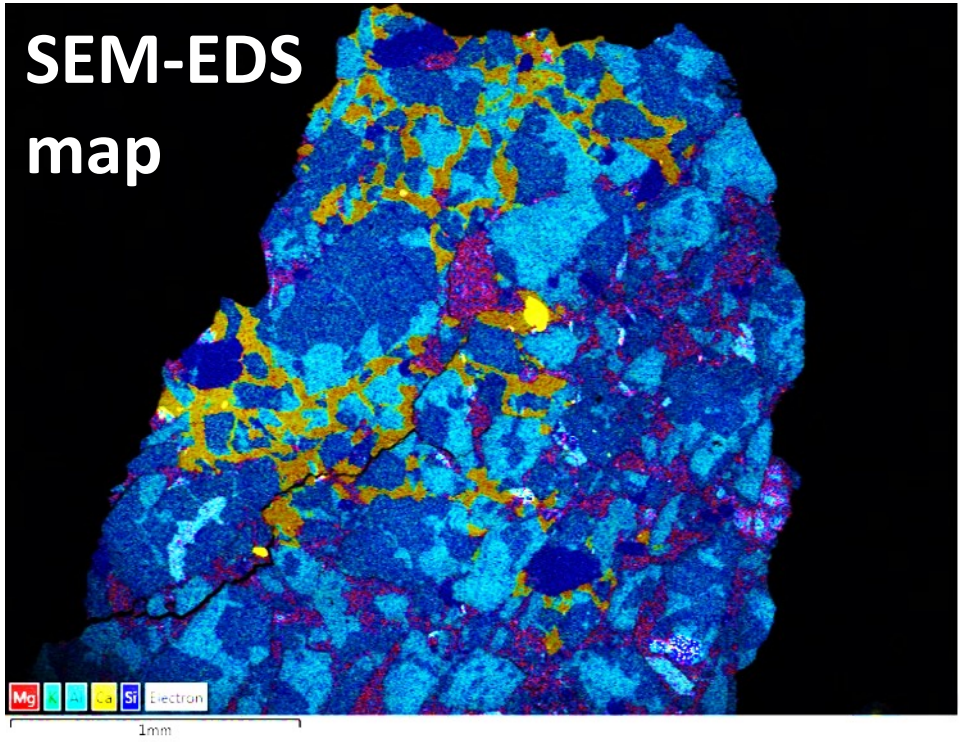

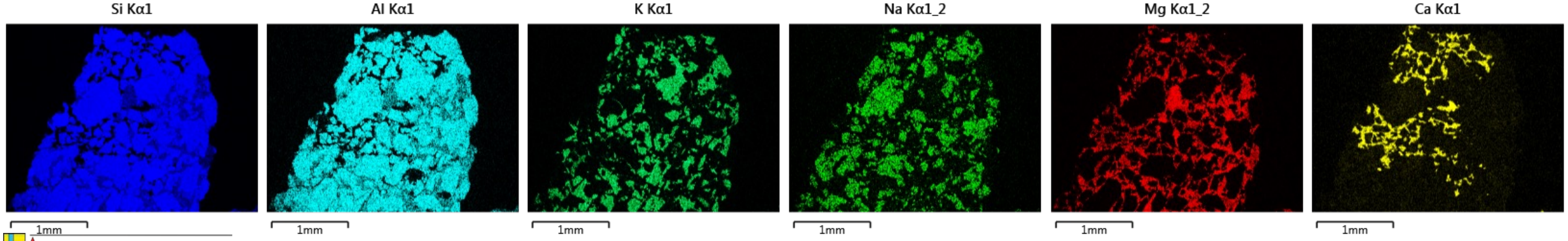

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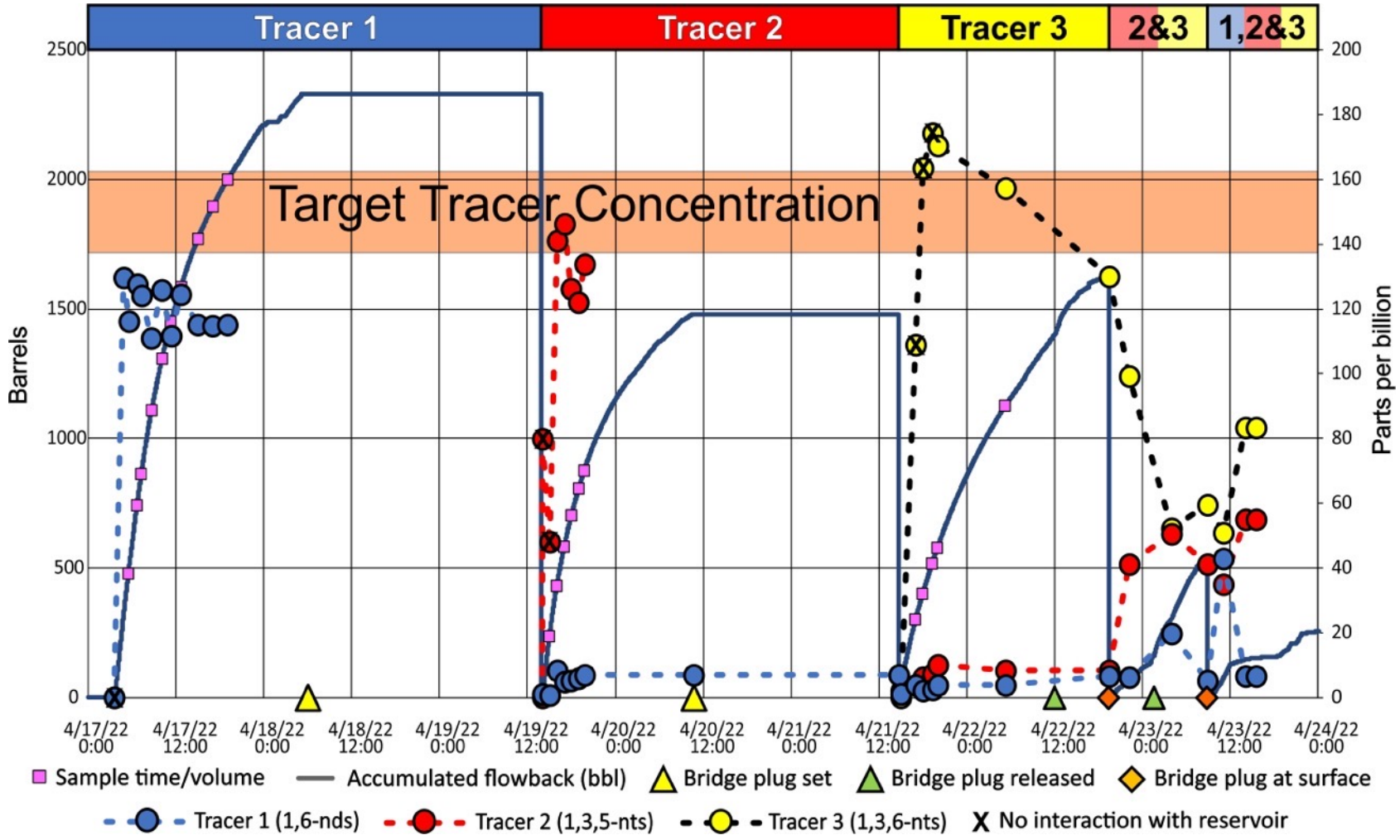
Naphthalene Sulfonate Tracer Returns

- Stage 1&2 return concentrations are relatively **consistent/stable** after ~400 bbl of untagged fluid are recovered.
- Stage 3 declines with time.



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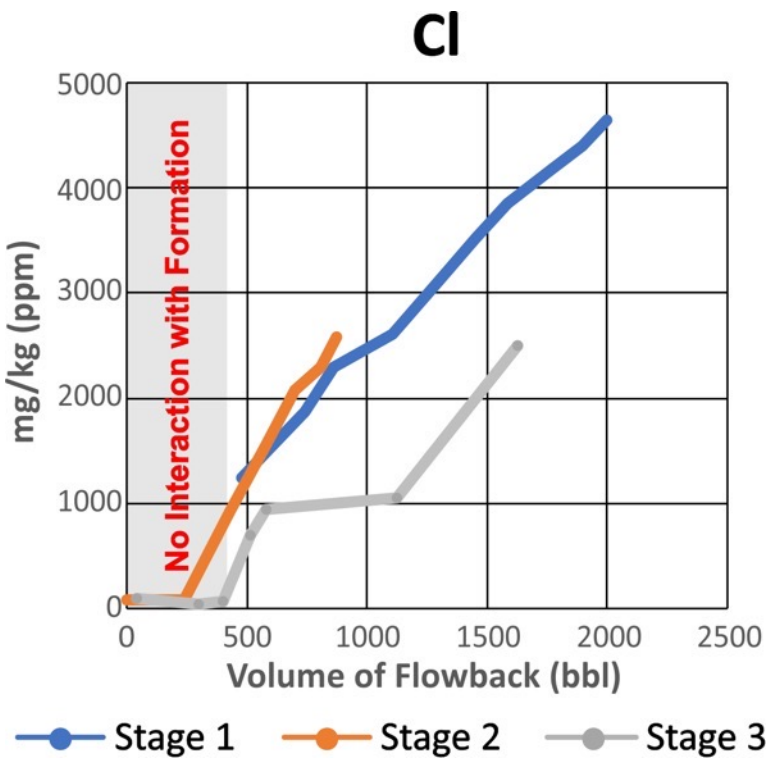
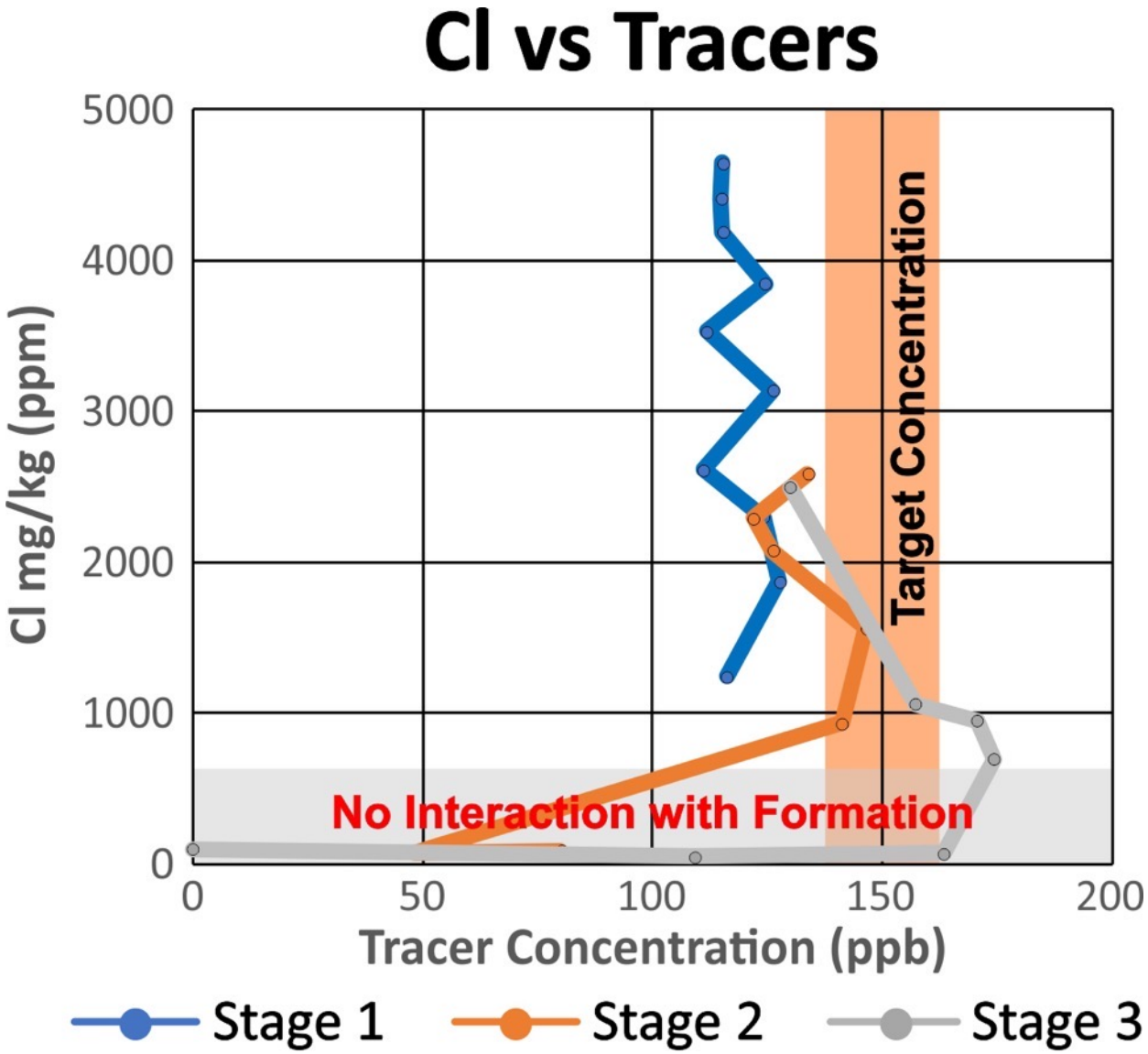
Naphthalene Sulfonate Tracer Returns

- Tracer concentrations remain fairly stable as Cl increases drastically.
- Mixing with a saline formation water should result in a decrease in tracer concentration paired with an increase in Cl (not observed).





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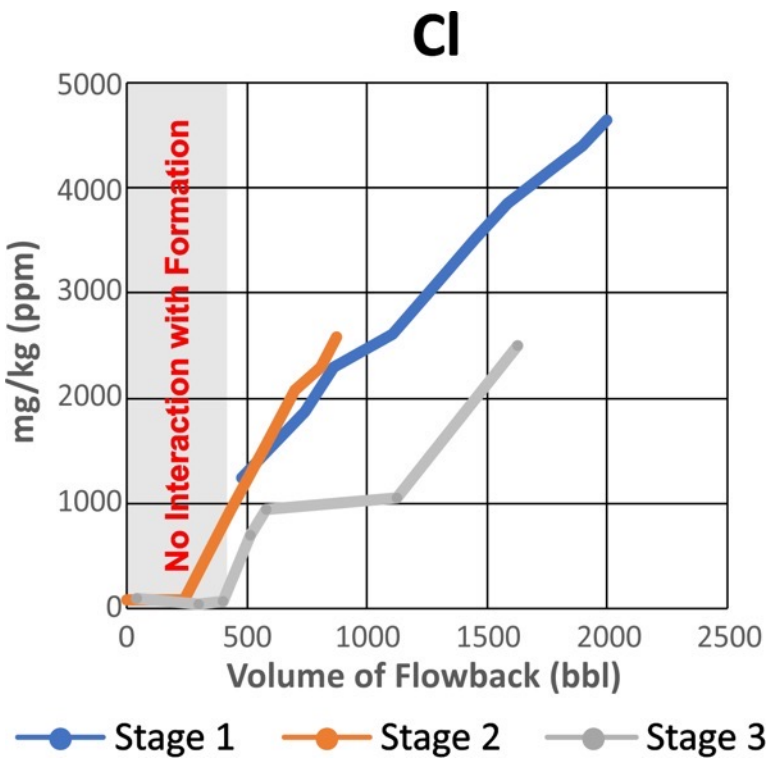

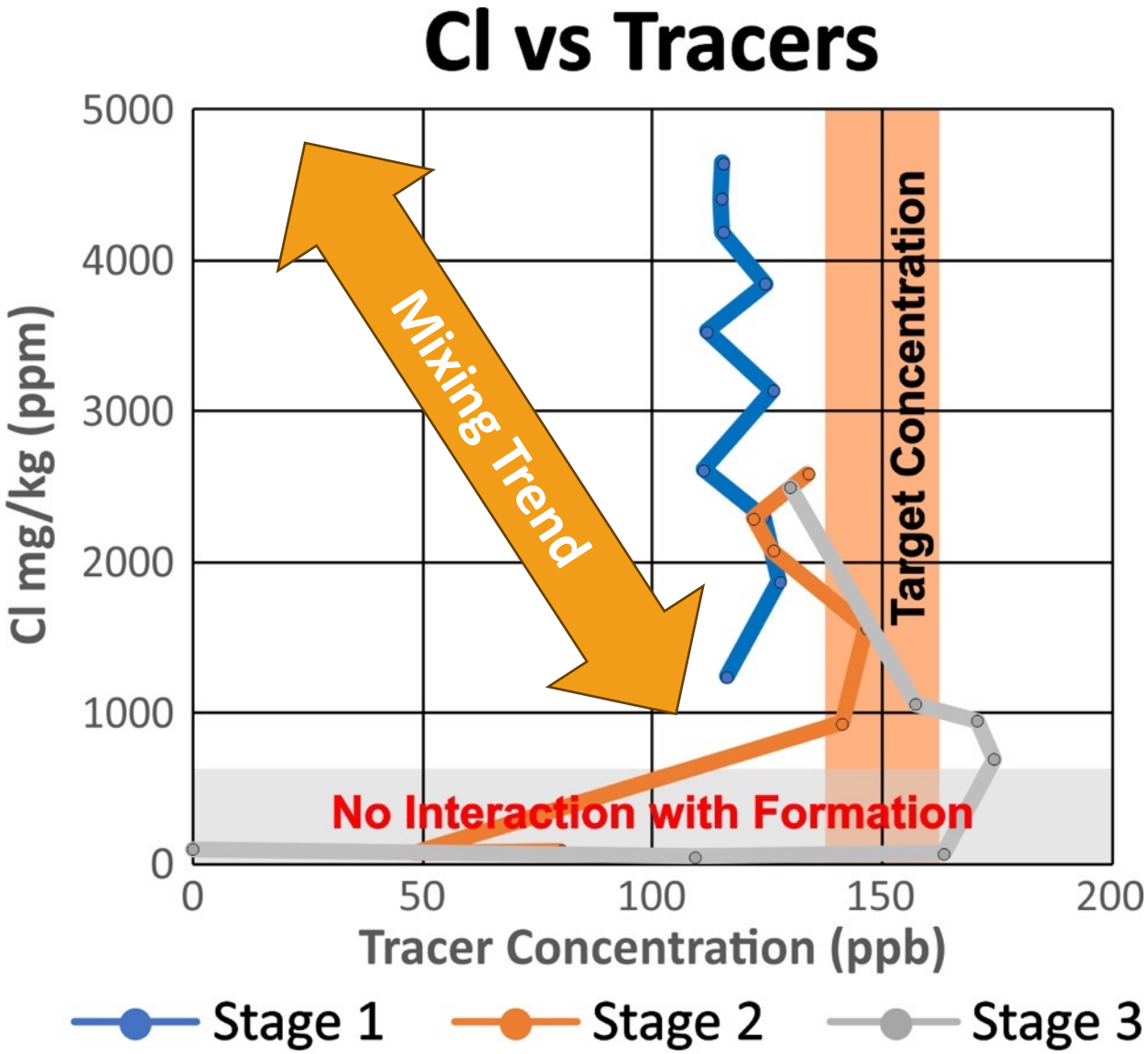

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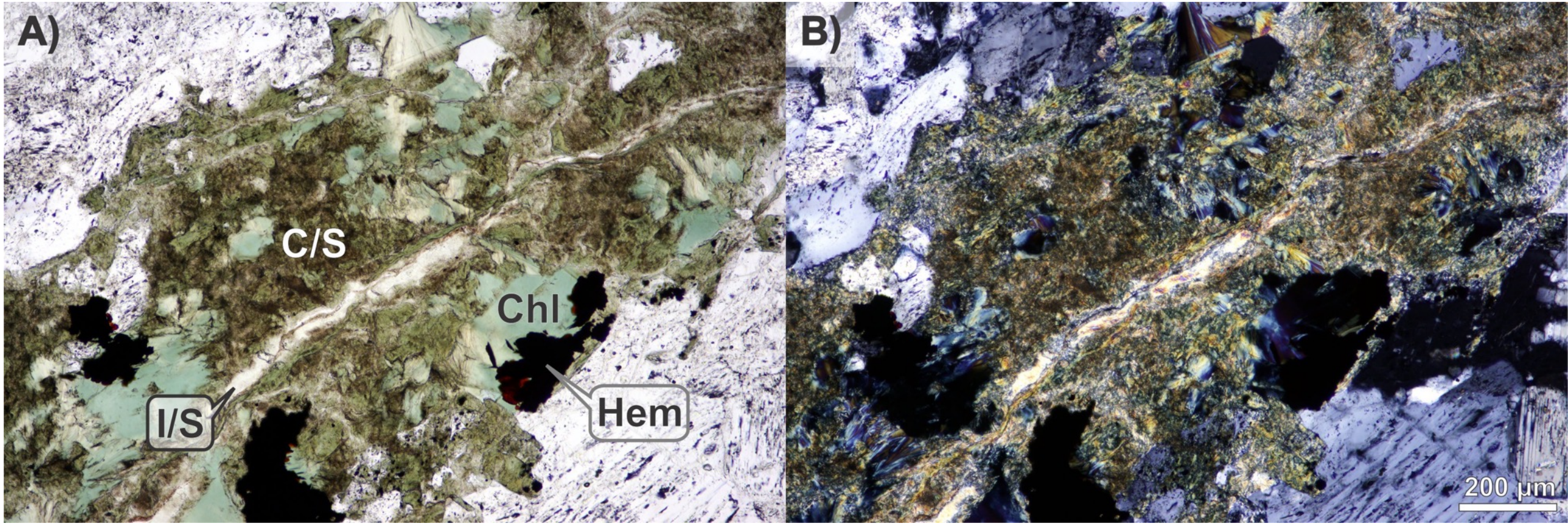
Halite in Veins

Vein from 5,850 ft in the 16A(78)-32 core filled by chlorite (Chl), interlayered chlorite/smectite (C/S) and hematite (Hem). A late fracture bisects the vein and is filled by lighter colored interlayered illite/smectite (I/S).



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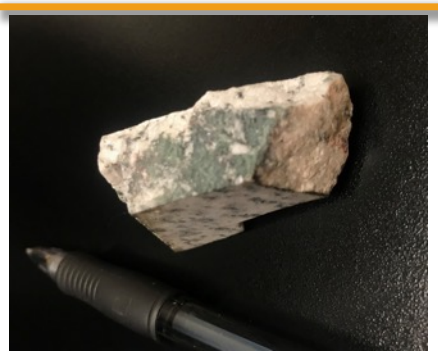
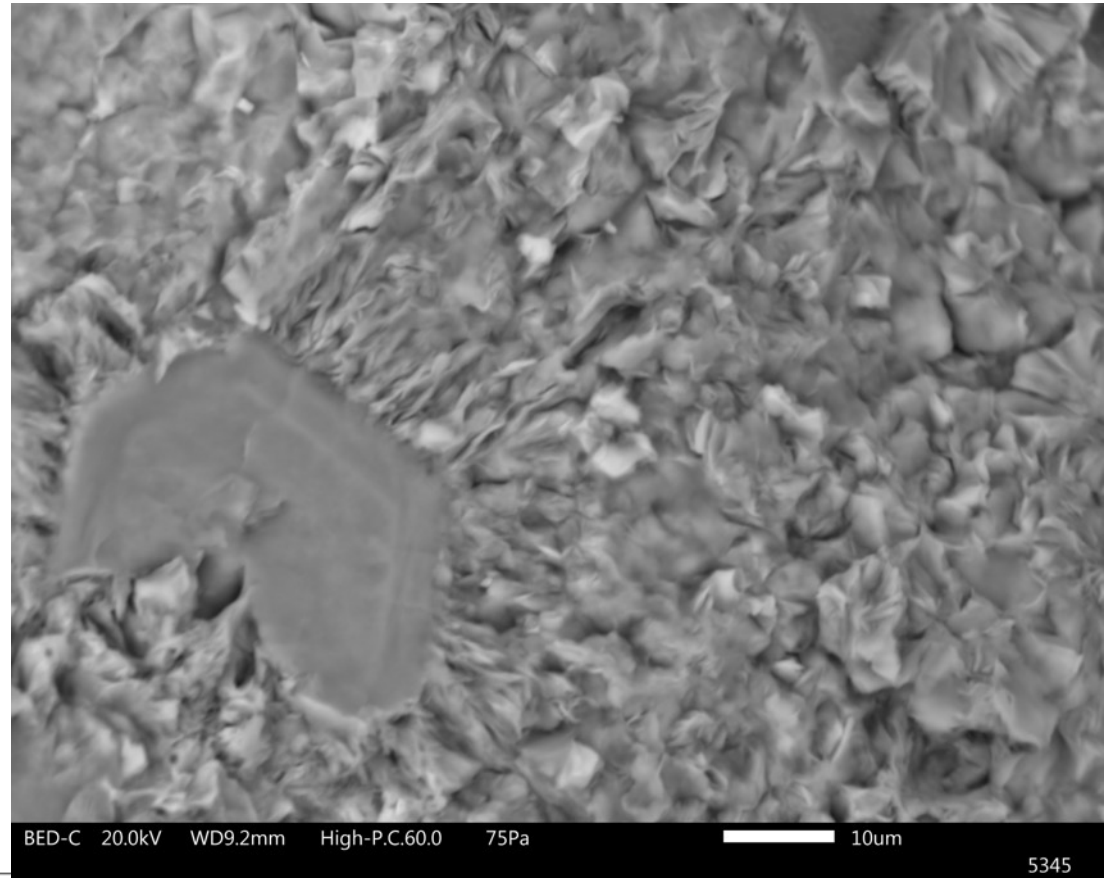
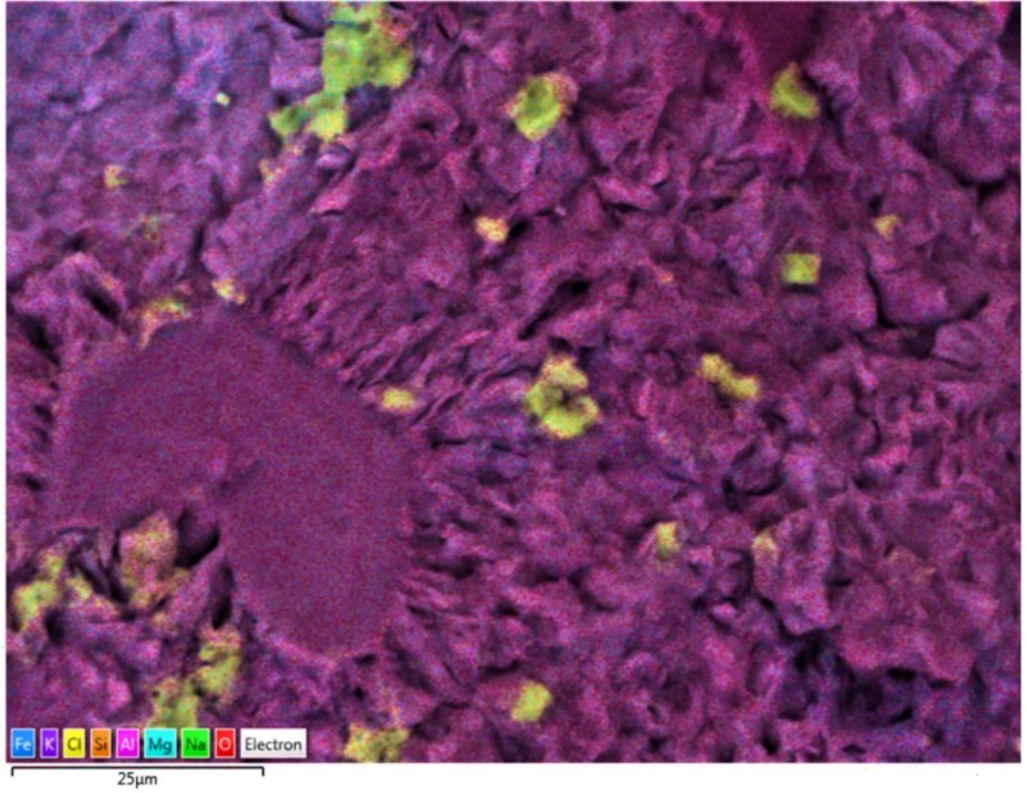
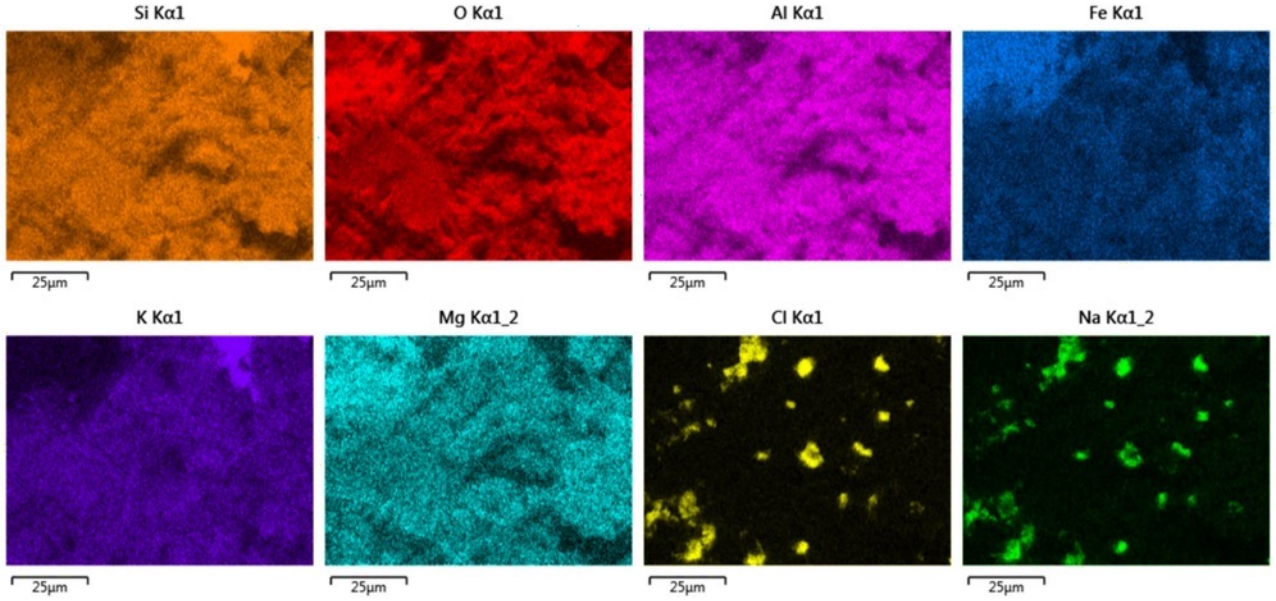


SEM-EDS analyses of a broken vein surface.







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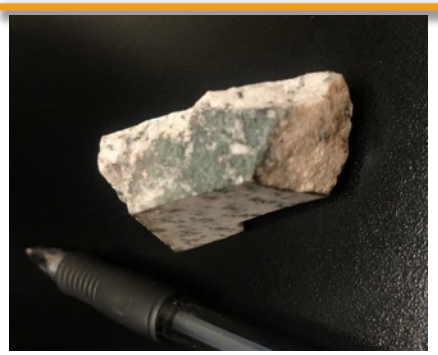

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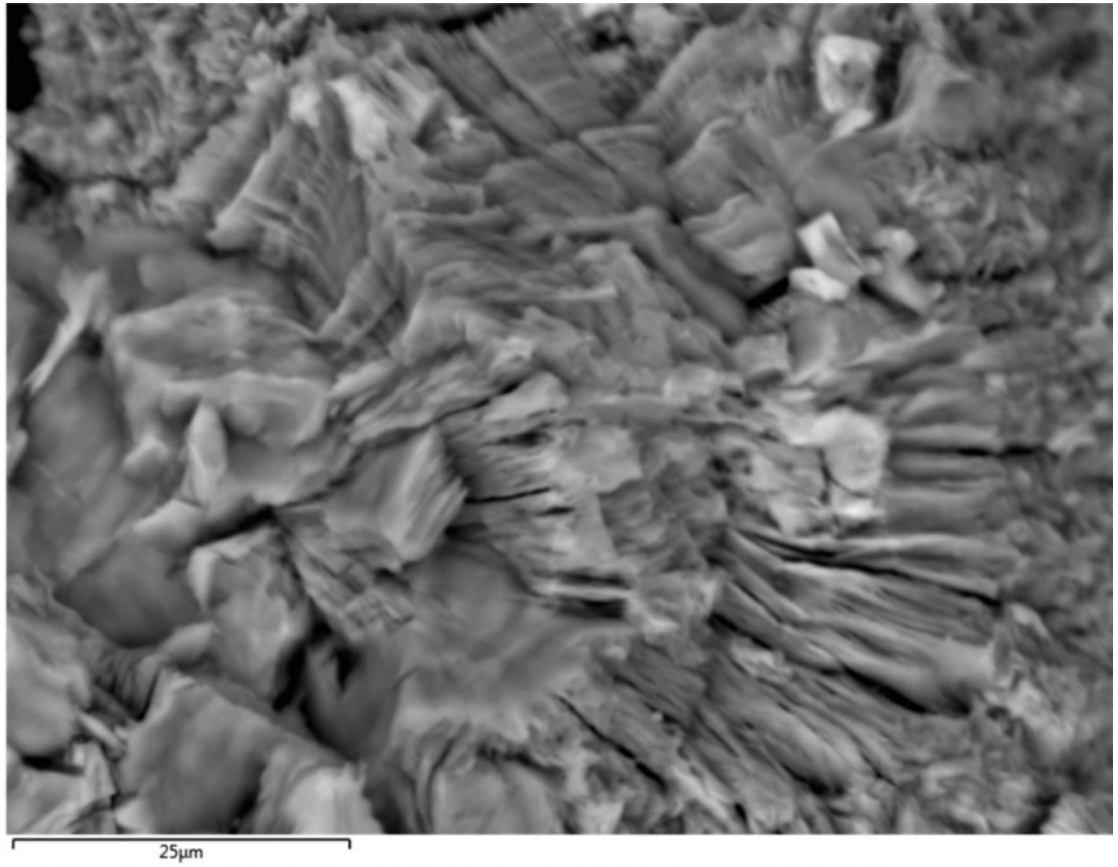

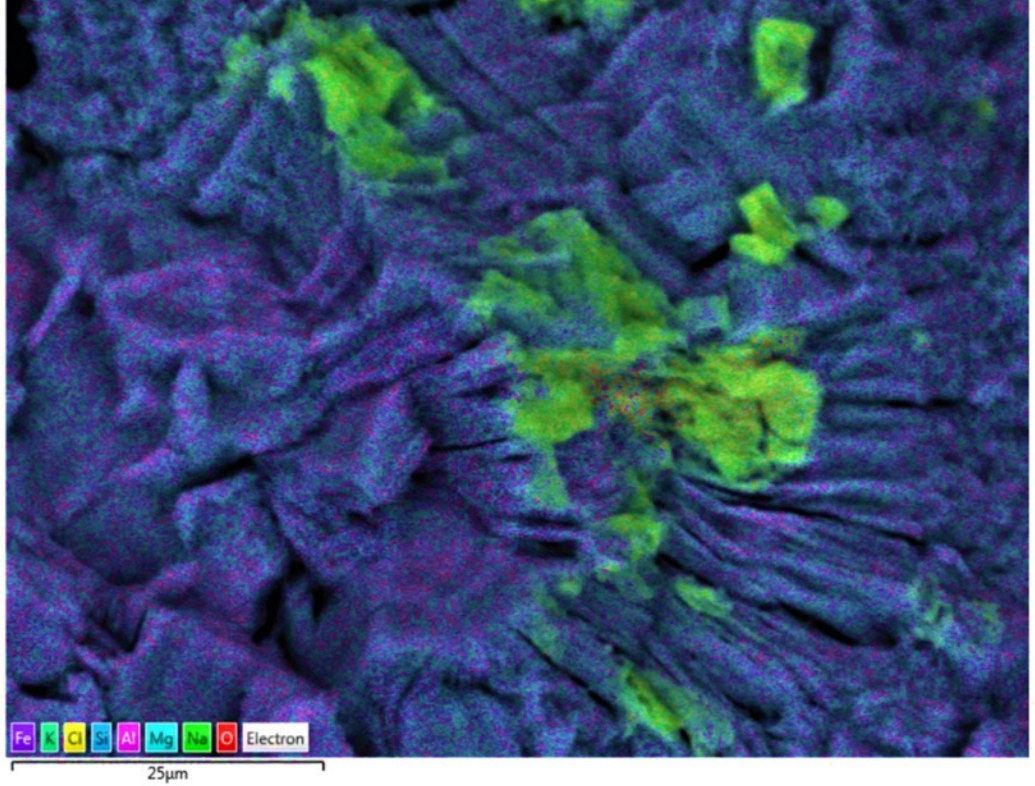

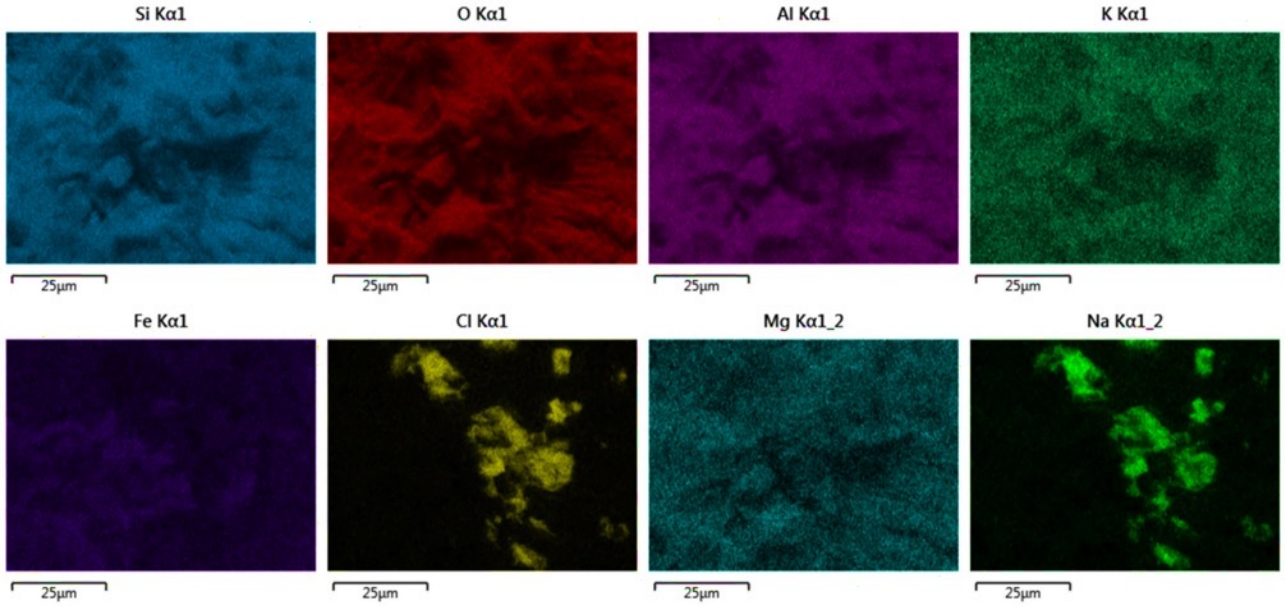

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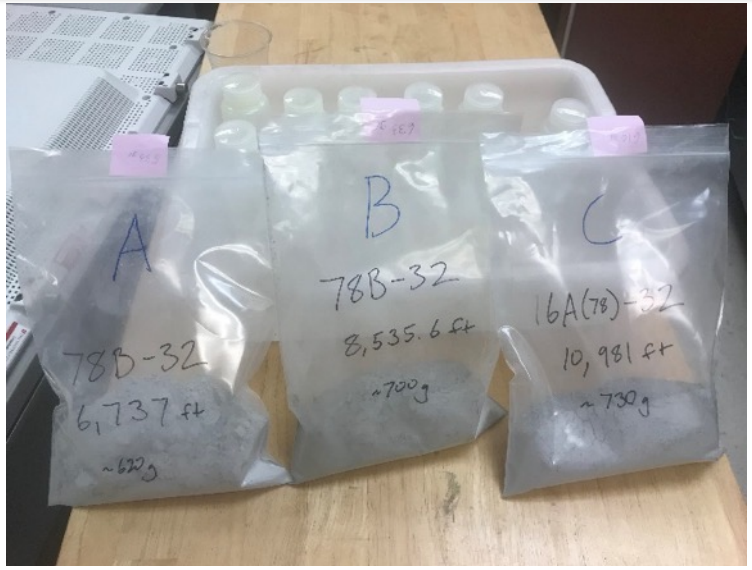
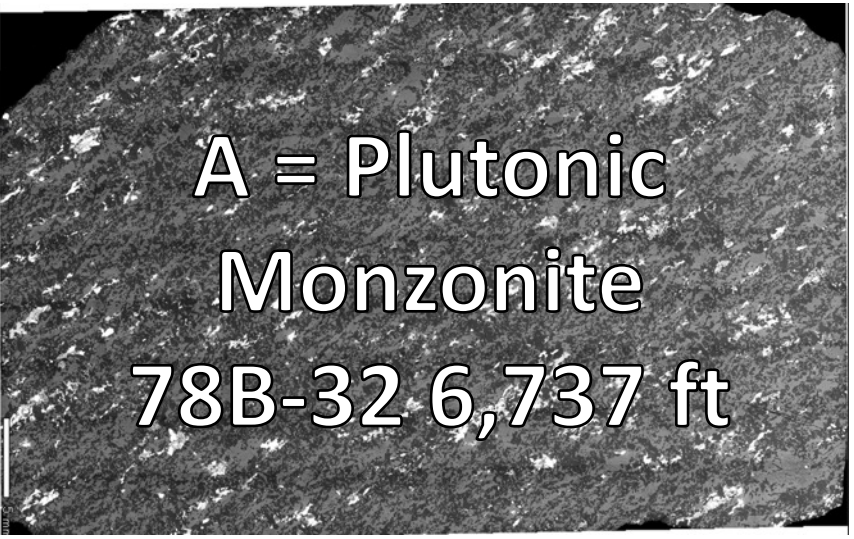
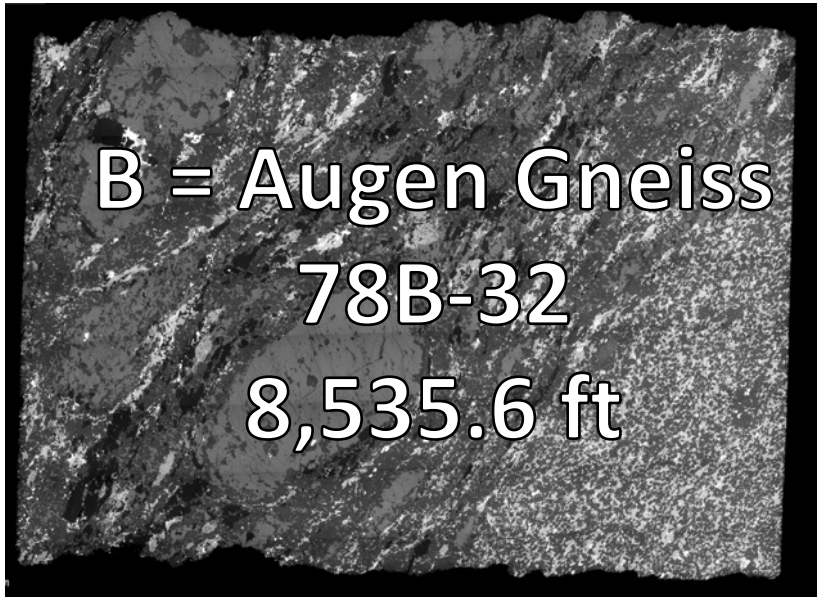
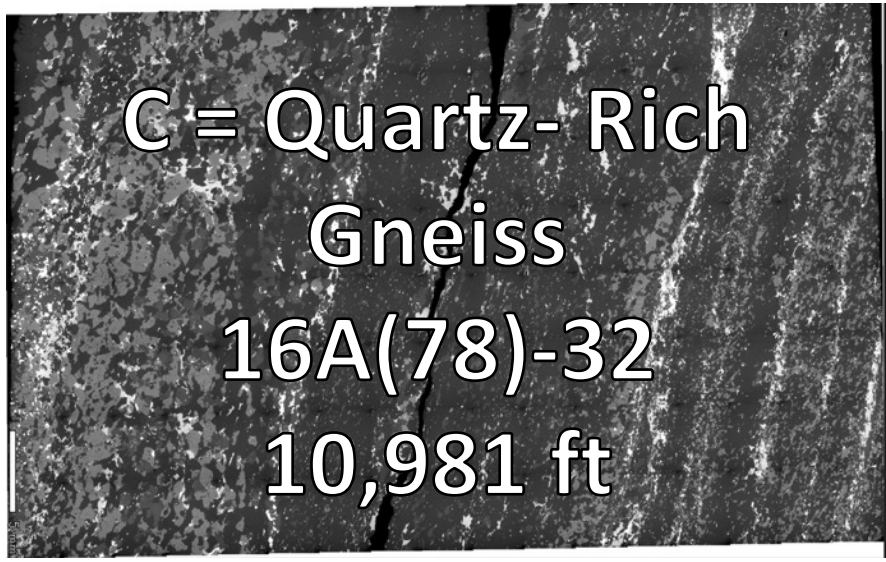
Simple Water-Rock Interaction Experiments

- Crushed core fragments w/o veins from three lithologies (A-C)
- Reacted with deionized water
- Water:Rock ratios of 1:1 and 2:1
- Thoroughly mixed
- Left for ~24 hrs at room temperature
- Decanted and centrifuged
- Water analyzed





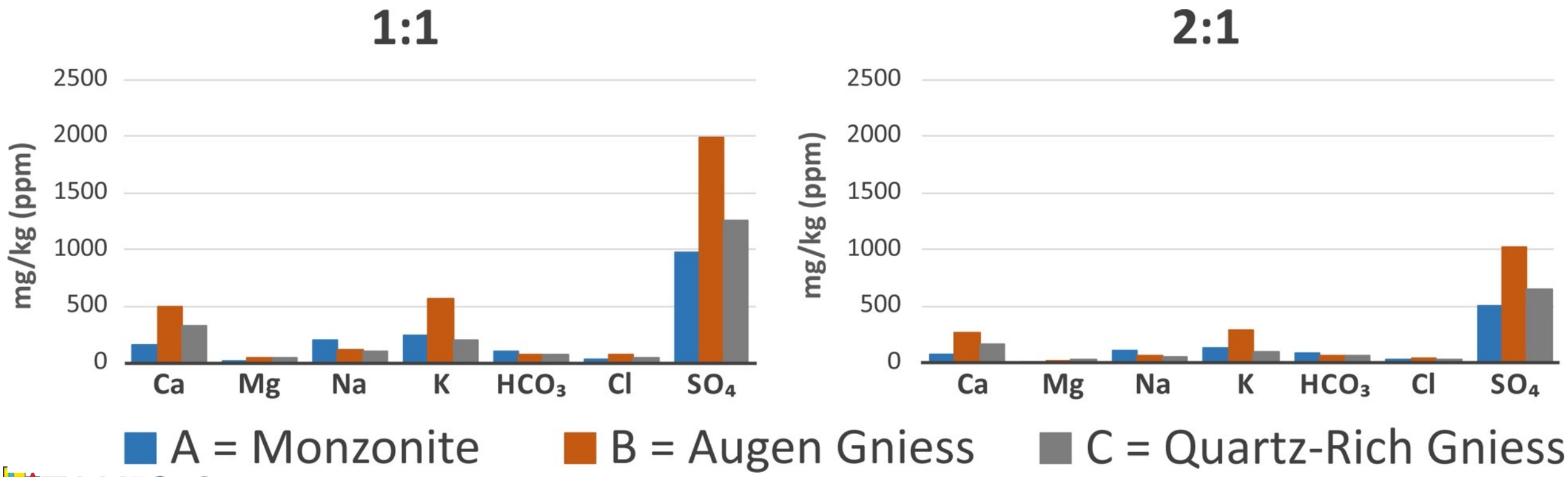




Simple Water-Rock Interaction Experiments

Water Analyses Results:

- Smaller water:rock ratios = more leached solids
- Similar results for all three rock types (plutonic and metamorphic)
- Most abundant = SO_4 > K, Ca
- Low Na & Cl



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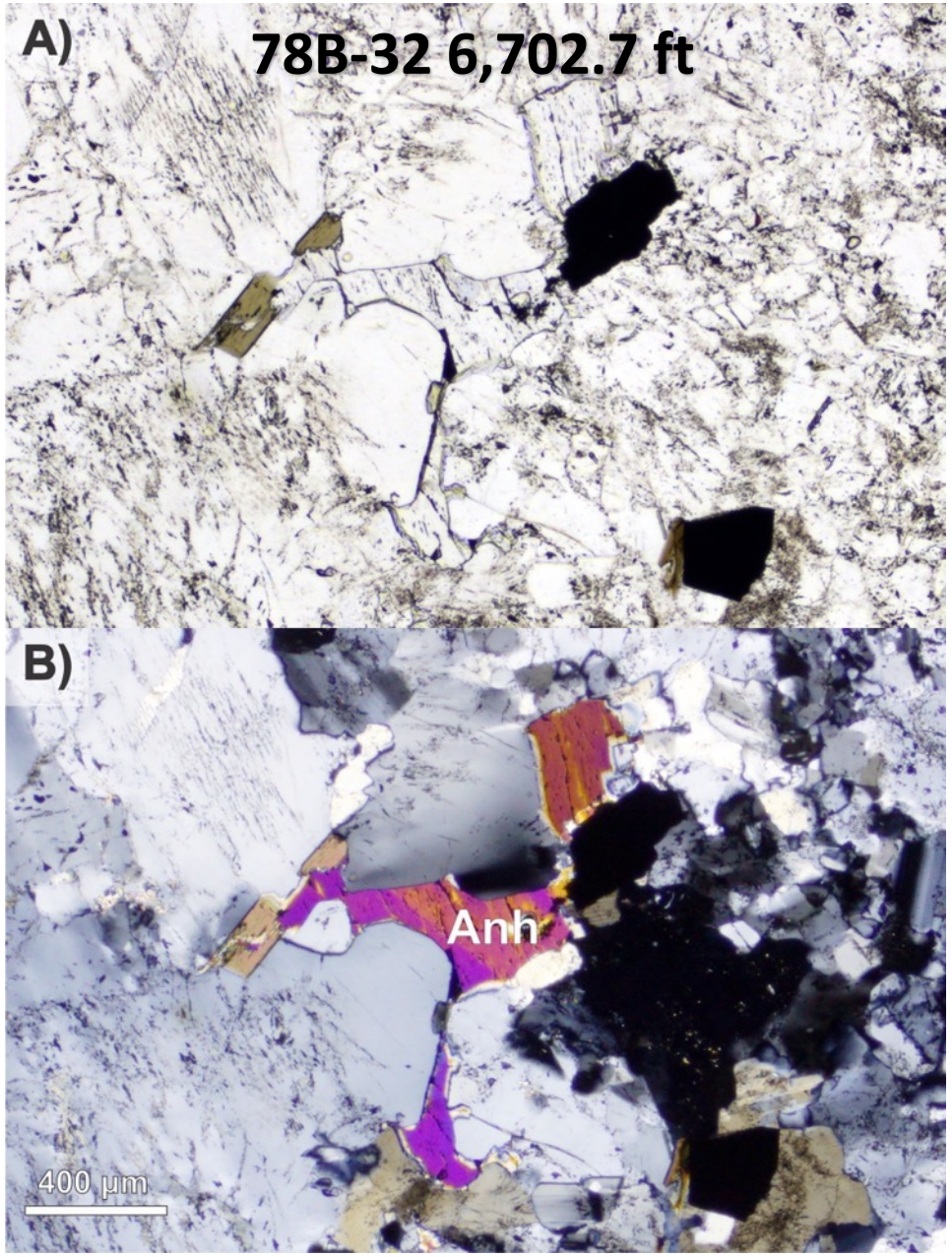
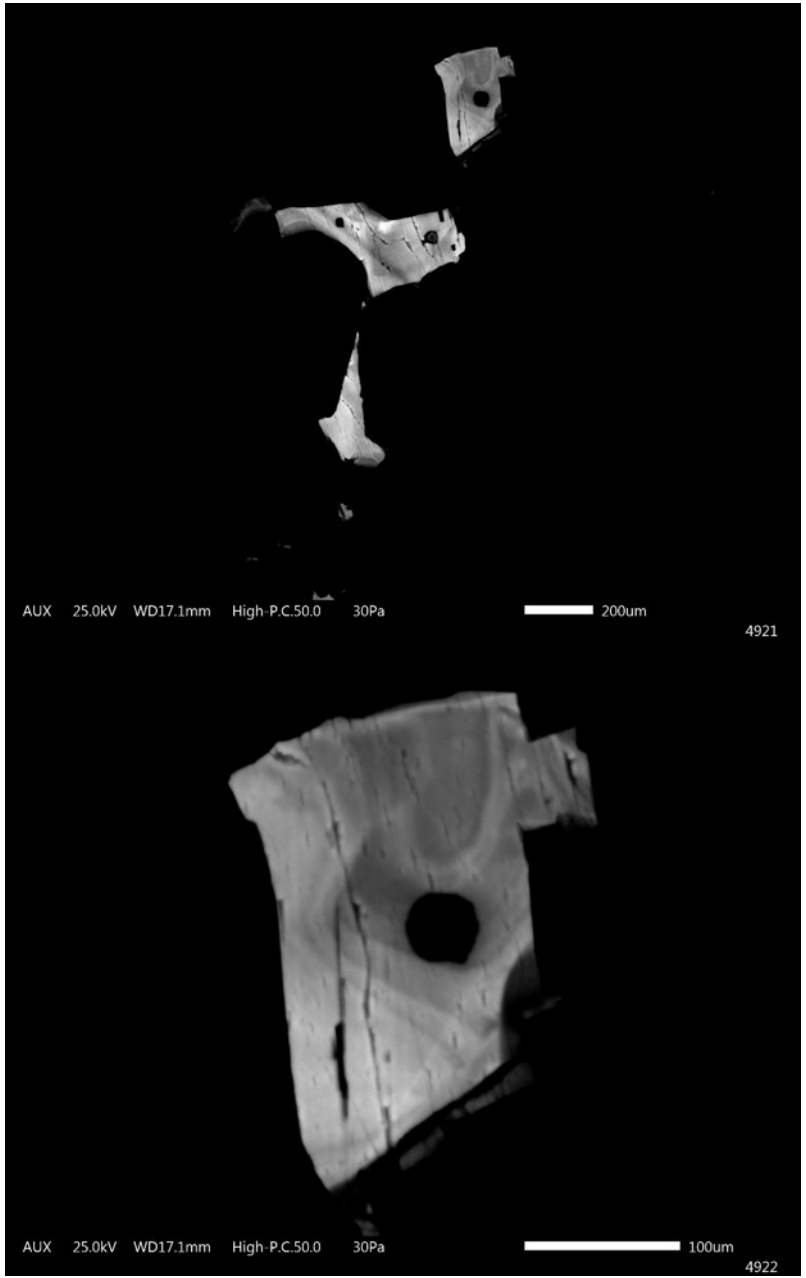
Anhydrite

- Widespread accessory phase (< 1 wt%) in both plutonic and metamorphic lithologies.
- Filling pore spaces? (not connected to veins)
- Rare occurrences as an open-space/ vein filling phase.





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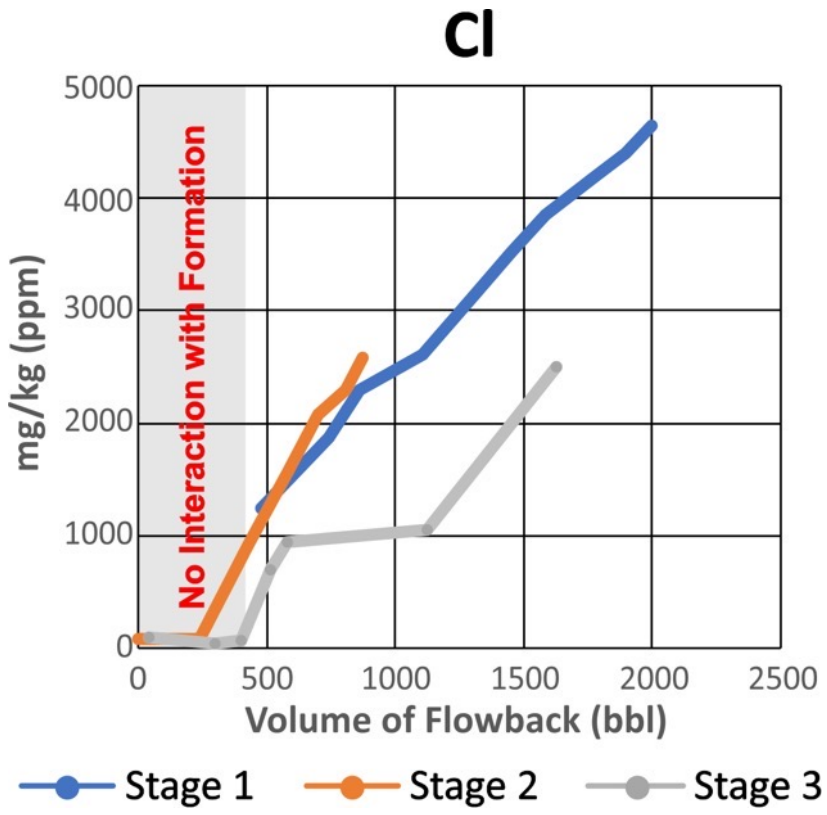
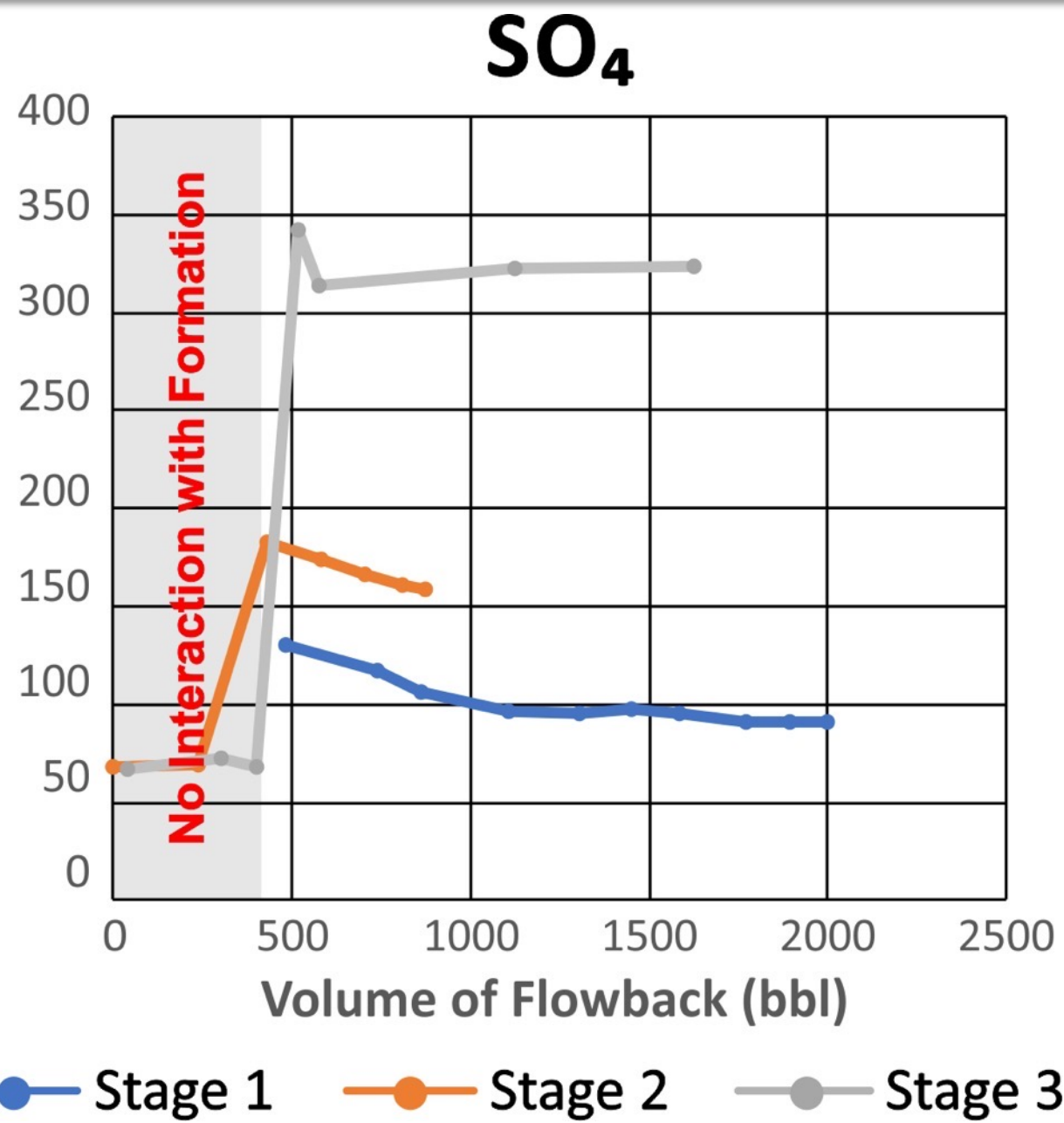
Flowback Chemistry

- SO_4 ~2 to 3 times more abundant in flowback from stage 3 (viscosified fluid).
- Cl concentrations lowest in flowback from stage 3.





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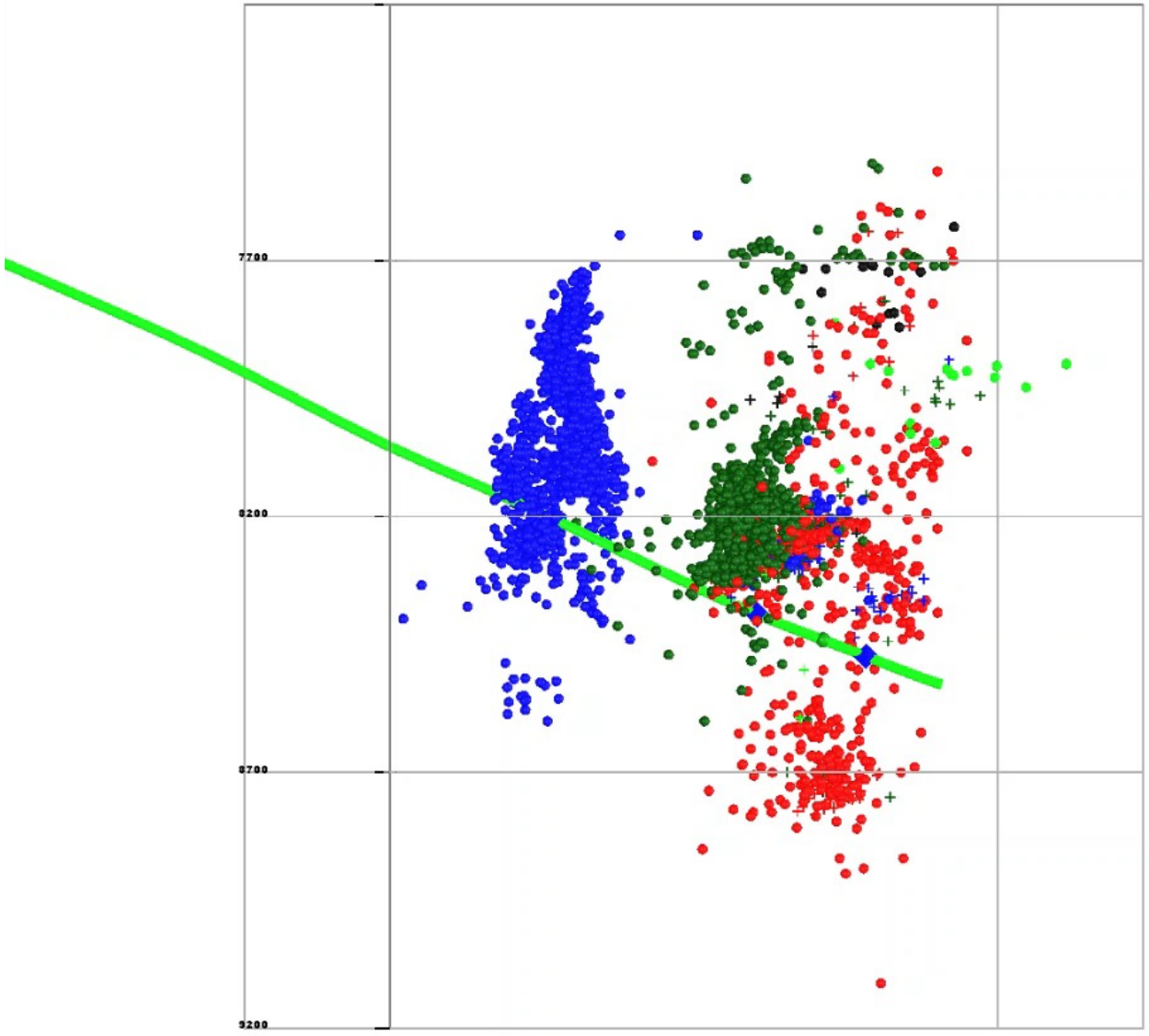
Microseismic Data

- Microseismic data plotted as a function of time.



Data recorded and analyzed by our partners at:

GEO ENERGIE SUISSE

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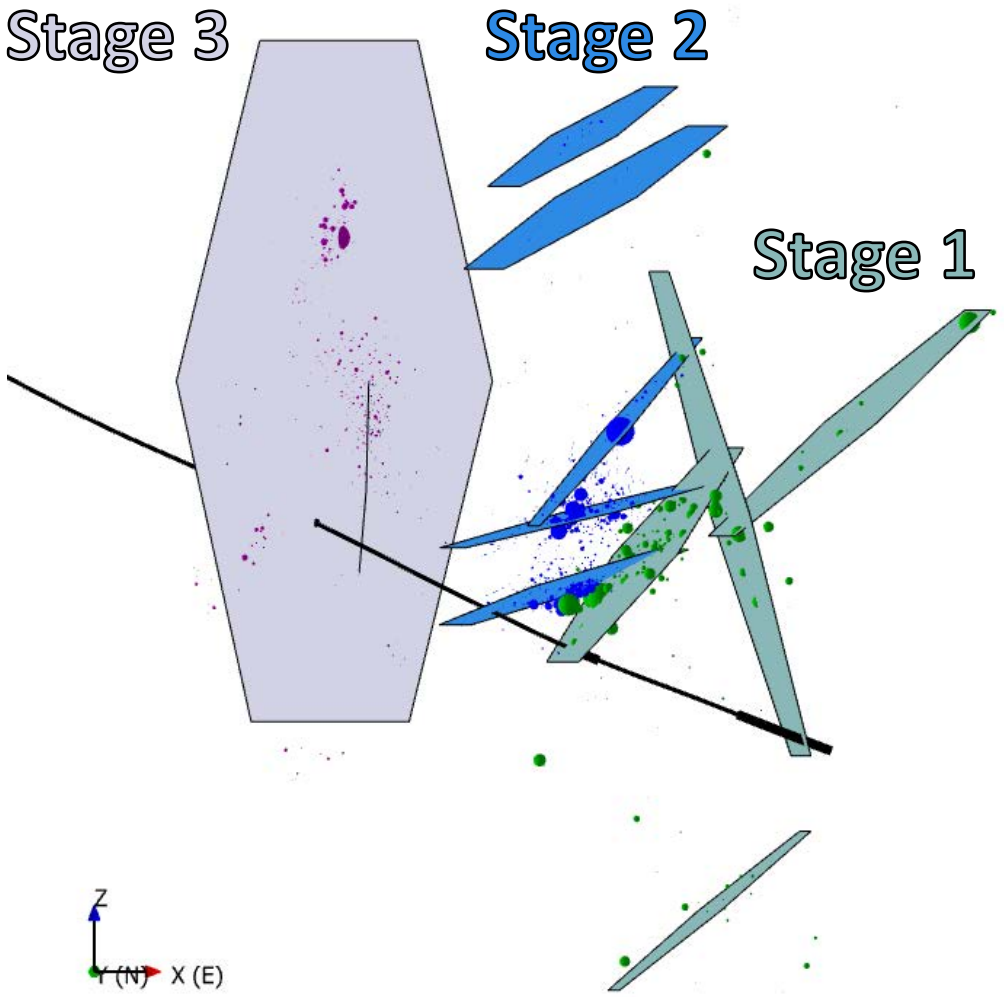
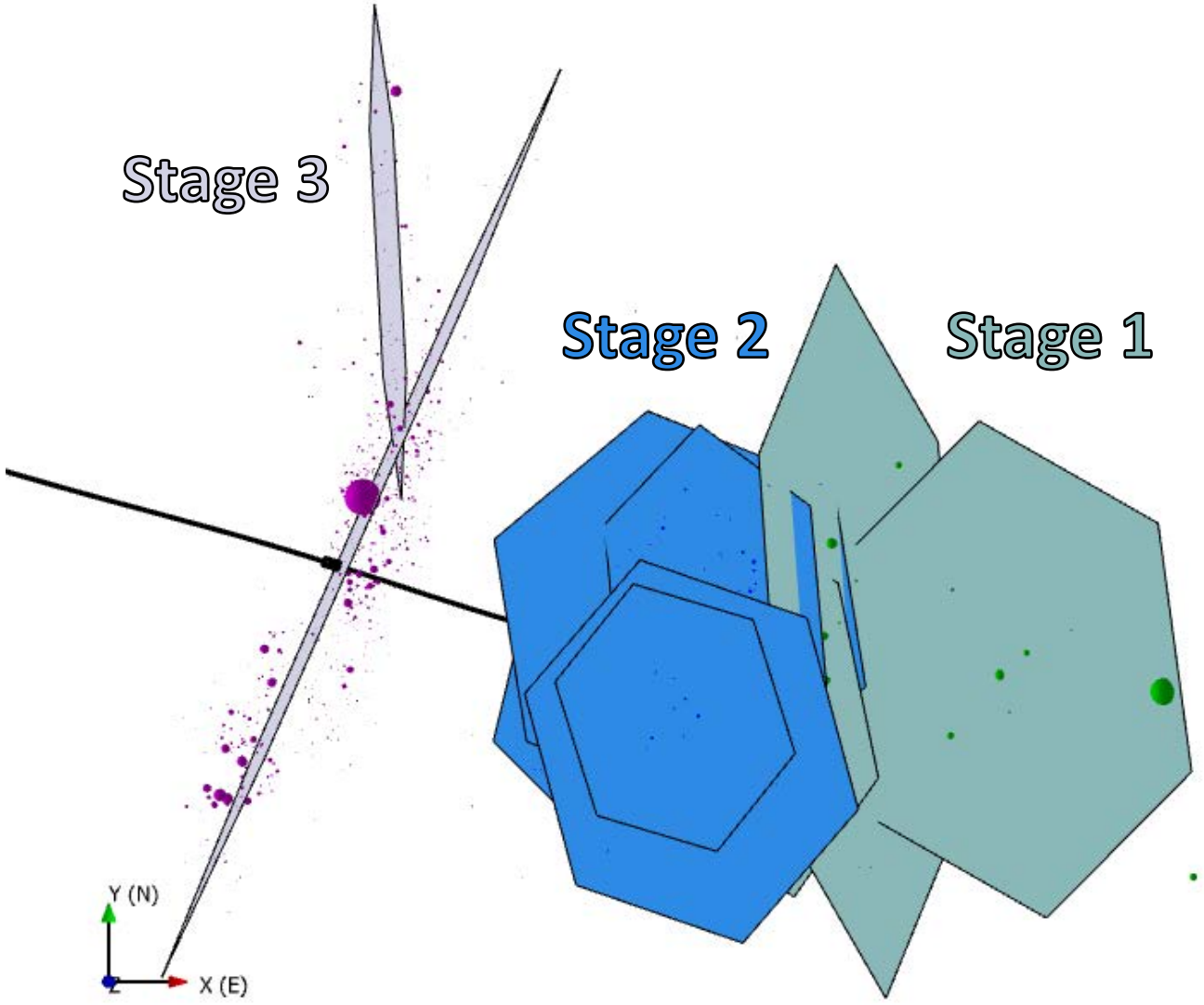
Planes Fit to Microseismic Data

Looking North



Looking Down



Images courtesy of Aleta Finnila PhD, WSP

Correlation of Flowback Chemistry with Stimulation Type

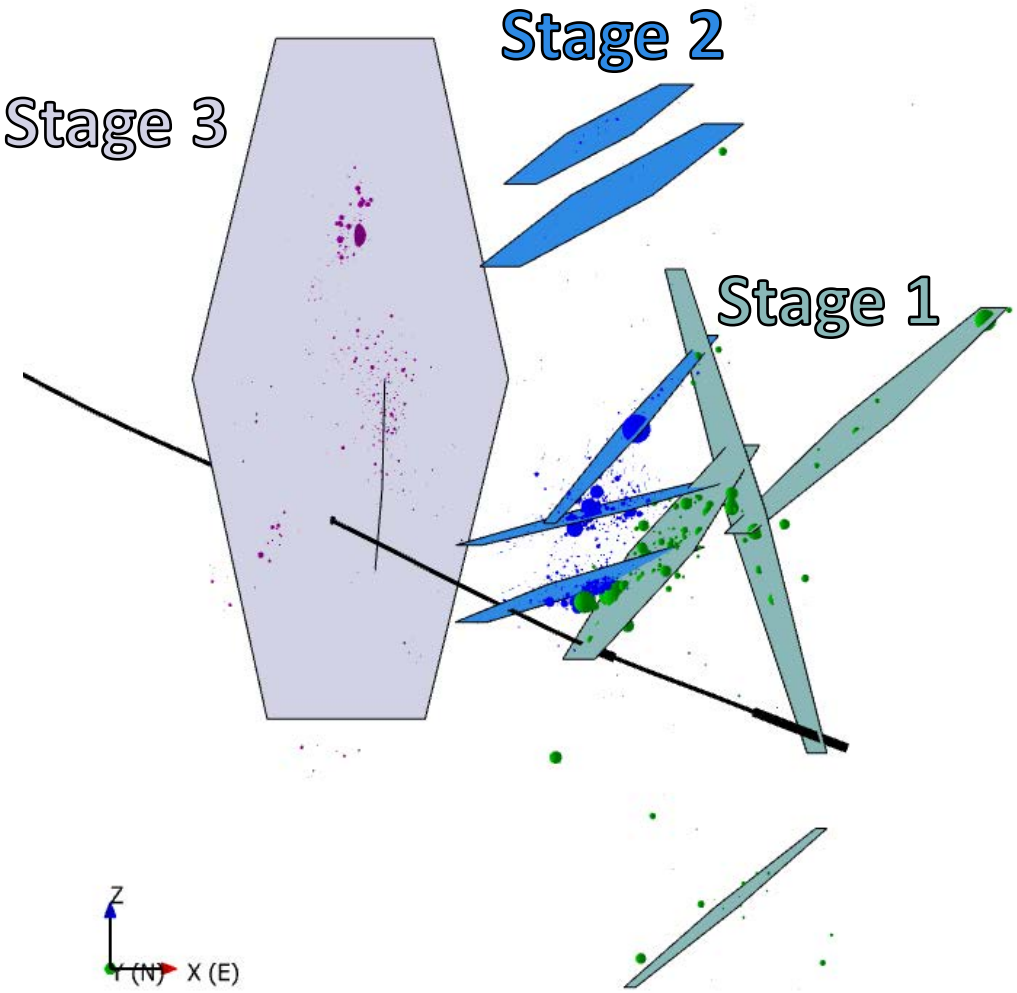
Stages 1&2:

- Slickwater.
- Diffuse seismicity.
- Reactivation of natural fractures?
- High Cl concentrations due to dissolution of halite in veins?

Stage 3:

- Viscosified fluid.
- Seismicity can be fit by fewer planes.
- Propagated hydraulic fracture?
- High SO_4 concentrations due to dissolution of anhydrite in the wall rocks?

Looking North



Images courtesy of Aleta Finnila PhD, WSP

Thankyou! Questions?

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