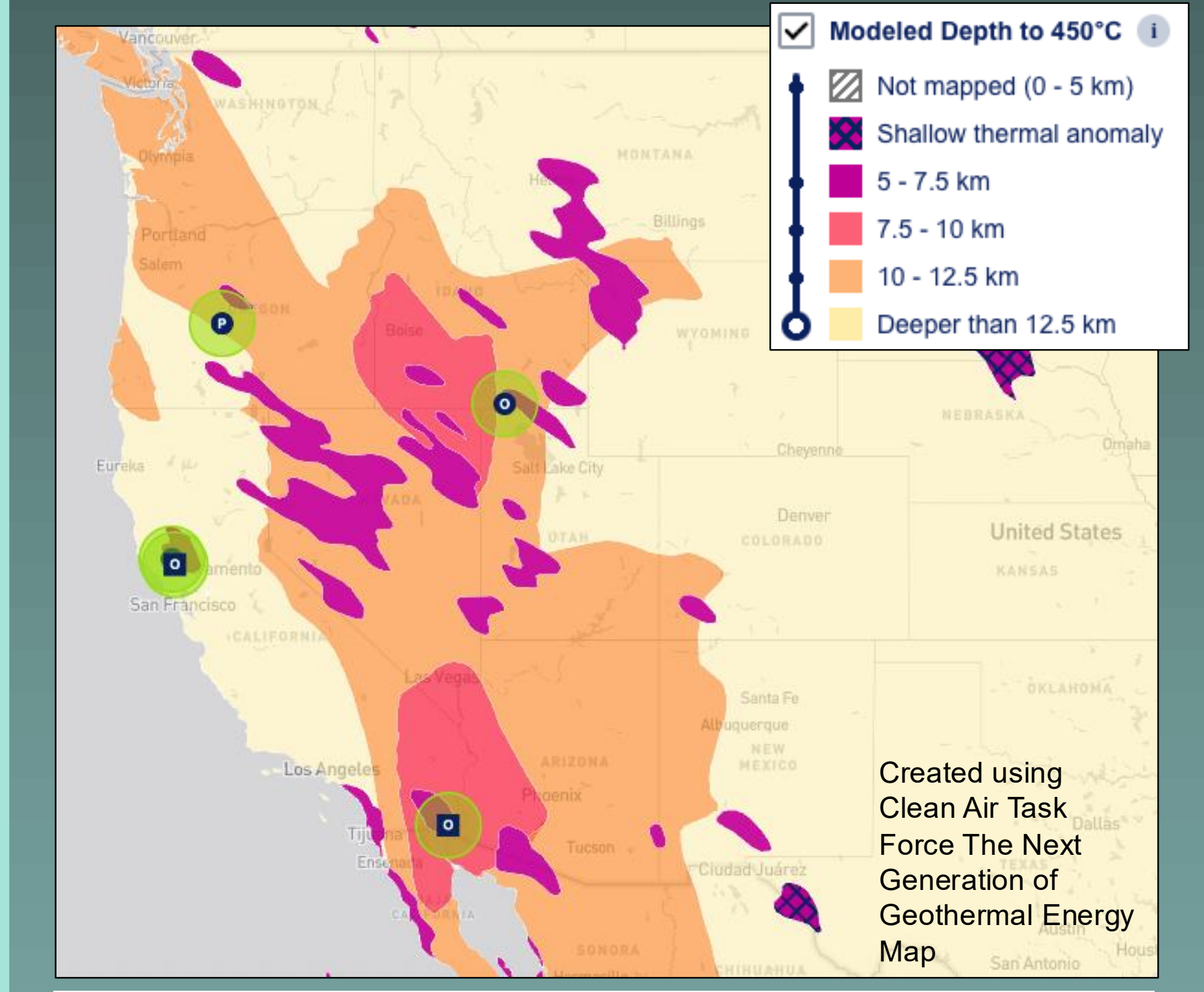
Superhot Testing: Using Methods in Experimental Petrology for Geothermal Research

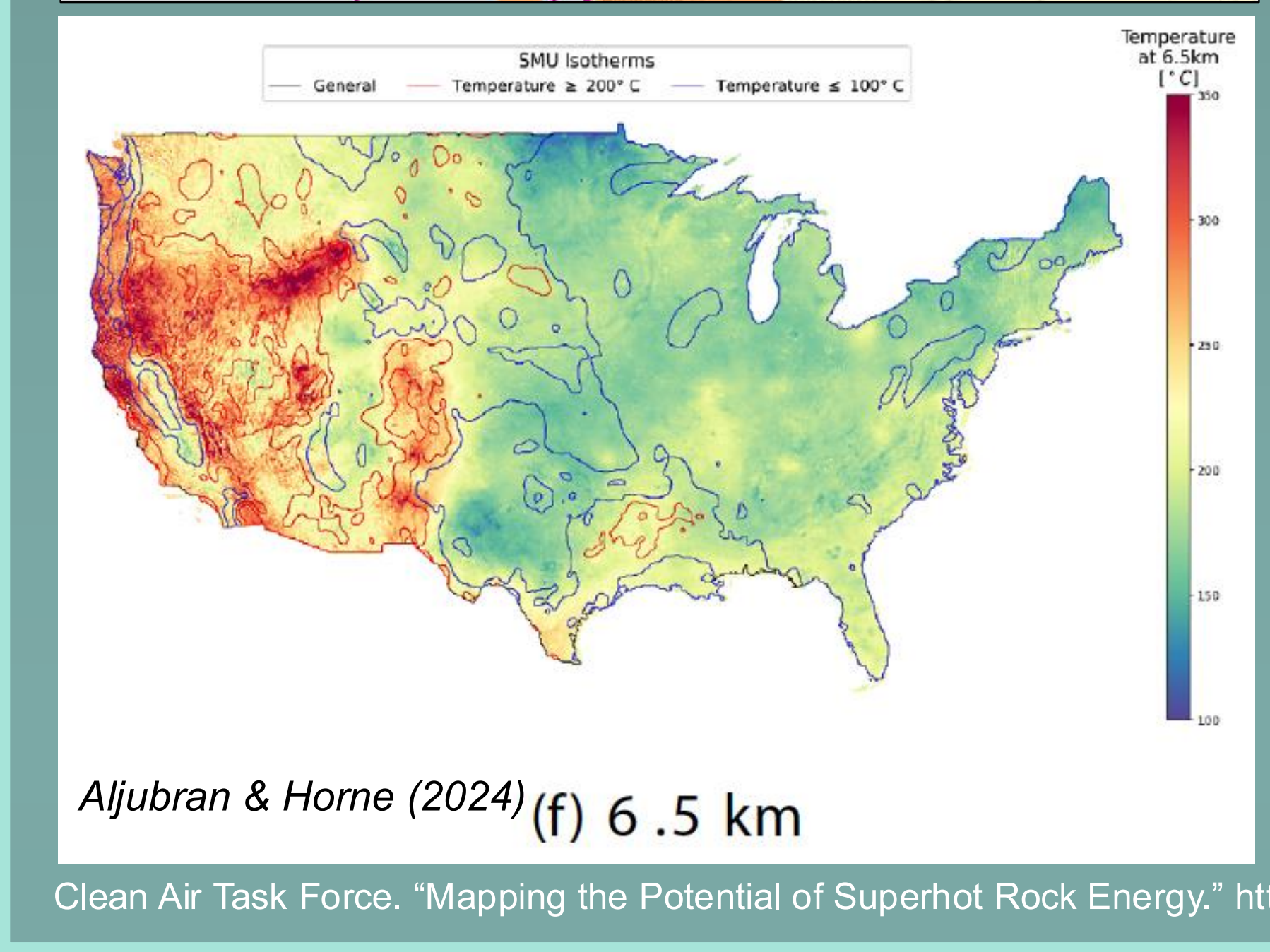
Laura E. Waters[1], Alex J. Rinehart[1]
[1]Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology

Introduction

- The forefront of geothermal energy lies with advancing the science, drilling technologies to superhot rocks (SHR) (>400°C).
- As higher production temperatures are required for providing cost competitive sources of power from enhanced geothermal system, there is some uncertainty about performance of materials used in drilling technologies and the chemical-mechanical response of formation lithologies to supercritical fluids.



Created using Clean Air Task Force The Next Generation of Geothermal Energy Map



Aljubran & Horne (2024)

- In the western US, heat maps show that superhot rocks can be reached by drilling to depths ≤4 km in regions with high geothermal gradients, thus offsetting drilling costs for the well.
- Rates of corrosion of drilling materials and chemical reactions in source rocks are carried out in laboratory setting; challenging for SHR because of materials used in experiments.

Here, we outline:
(1) experimental cold-seal pressure vessels and

(2) how these apparatuses can be used to test a wide variety of materials used in geothermal sectors.

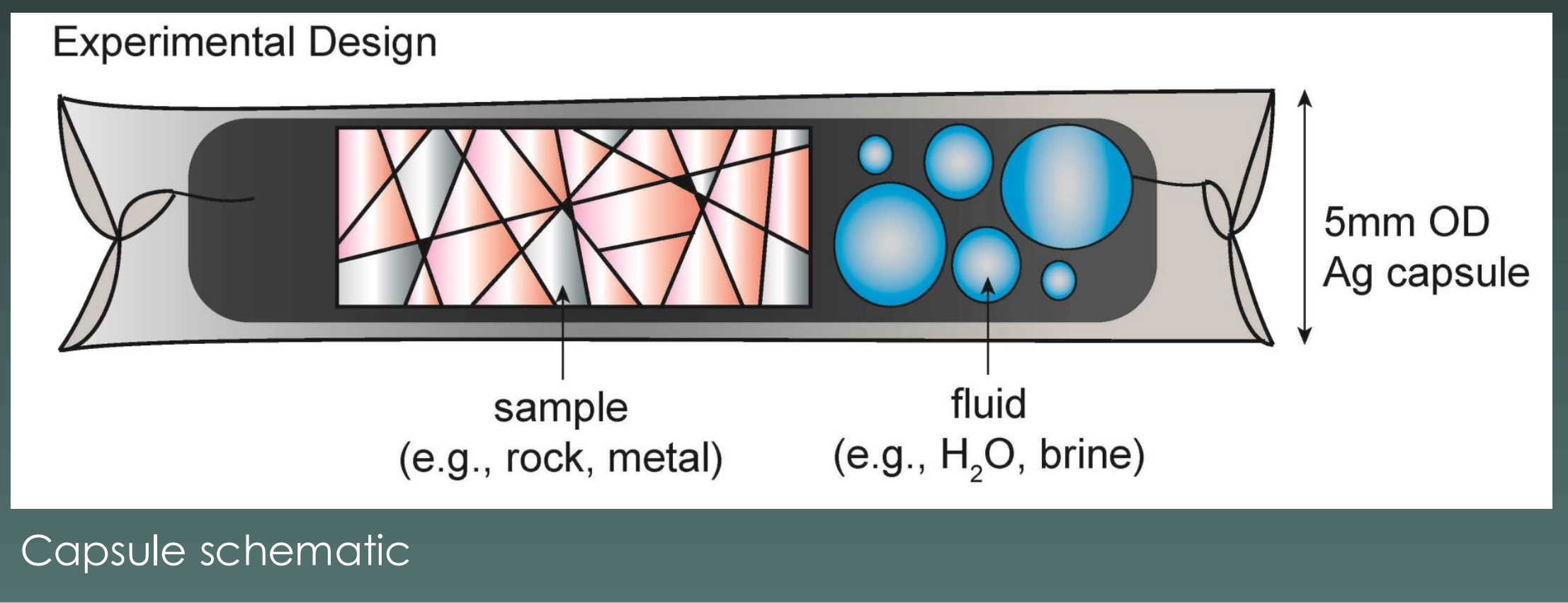
Clean Air Task Force. "Mapping the Potential of Superhot Rock Energy." https://www.catf.us/superhot-rock/heat-mapping/.

Experimental Petrology Techniques: Experiment Design and Apparatus

Experimental Design:

Run products of interest (i.e., cements, drill bits, casing, rock, magmatic compositions) are placed in a precious metal capsule with a fluid of interest (drilling fluid, natural water).

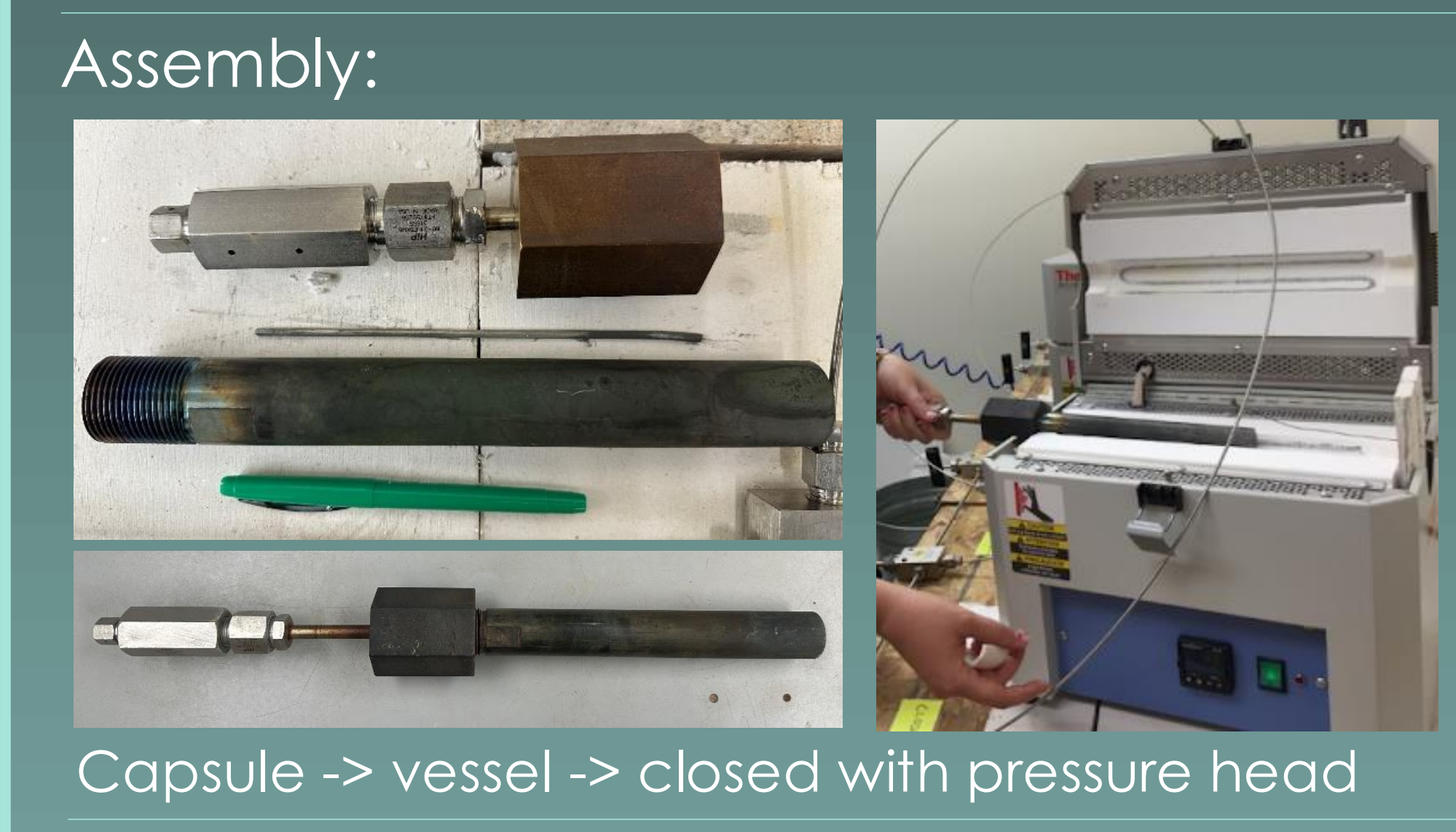
Precious metals can range from silver (melting temperature, MT, = 962°C), silver-palladium (MT >962 to 1555°C), gold (MT = 1052°C), or platinum (MT=1475°C) and can be selected based on melting temperature and chemical reactivity. Capsule OD is ~5mm.



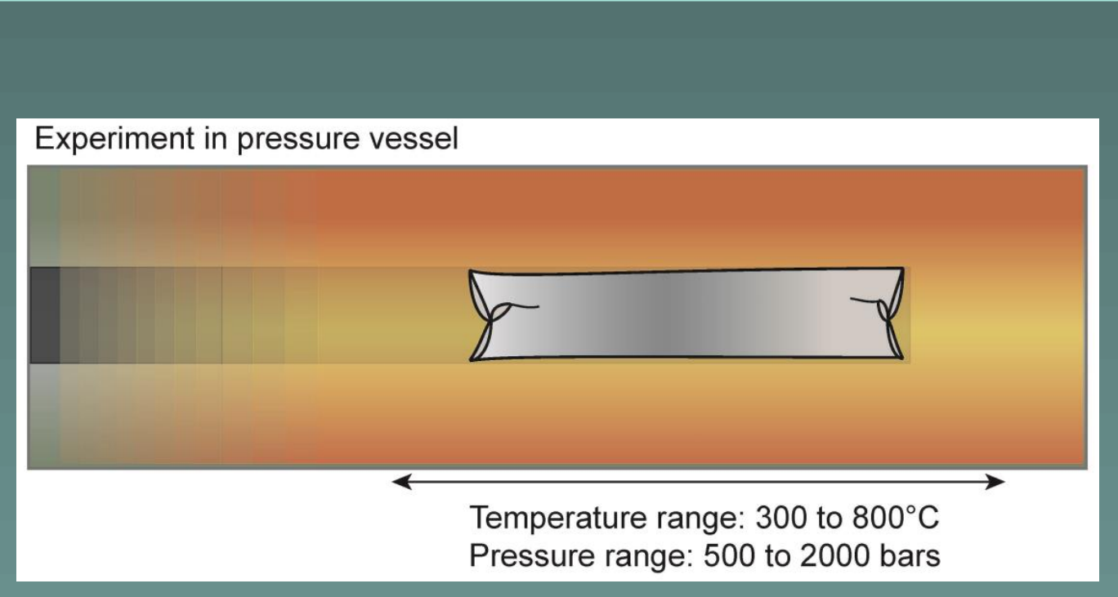
Capsule schematic

Sealed gold capsule

Assembly:

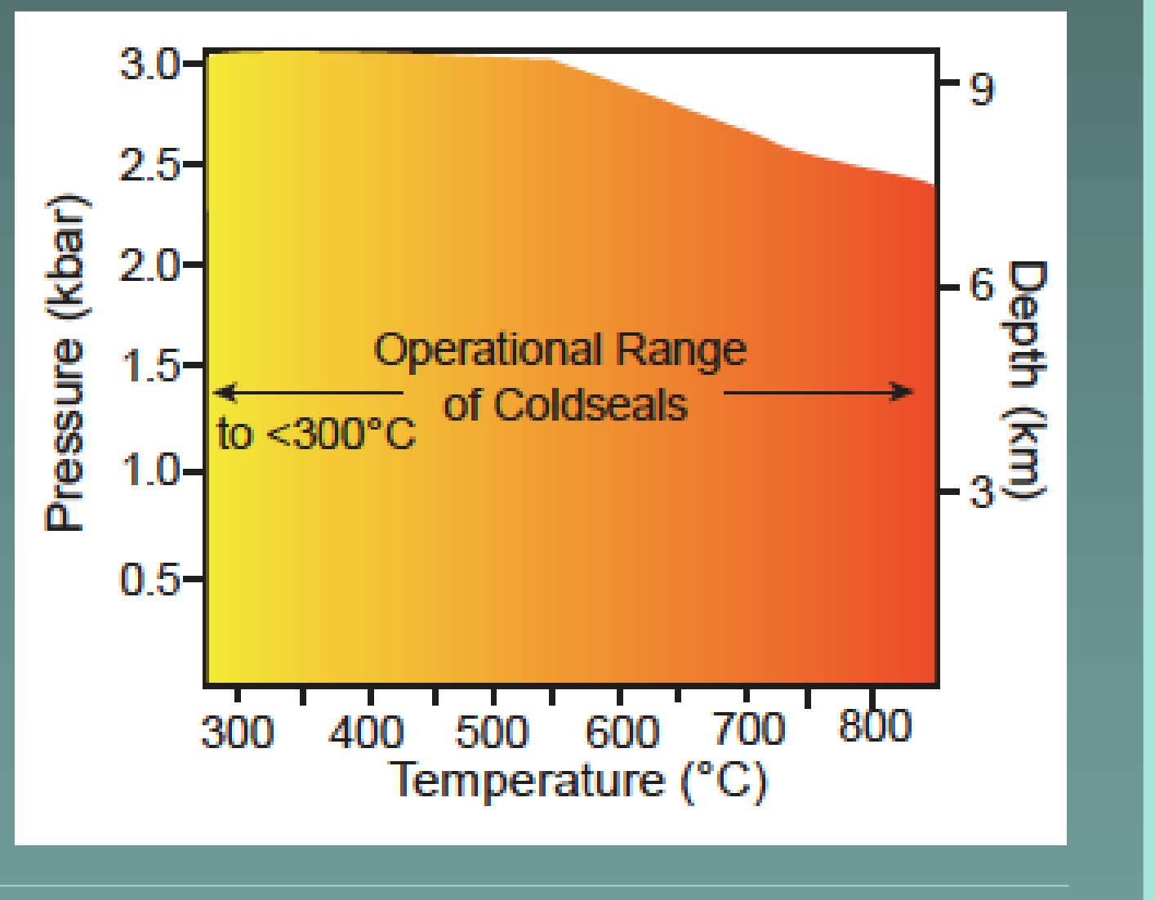


Capsule -> vessel -> closed with pressure head

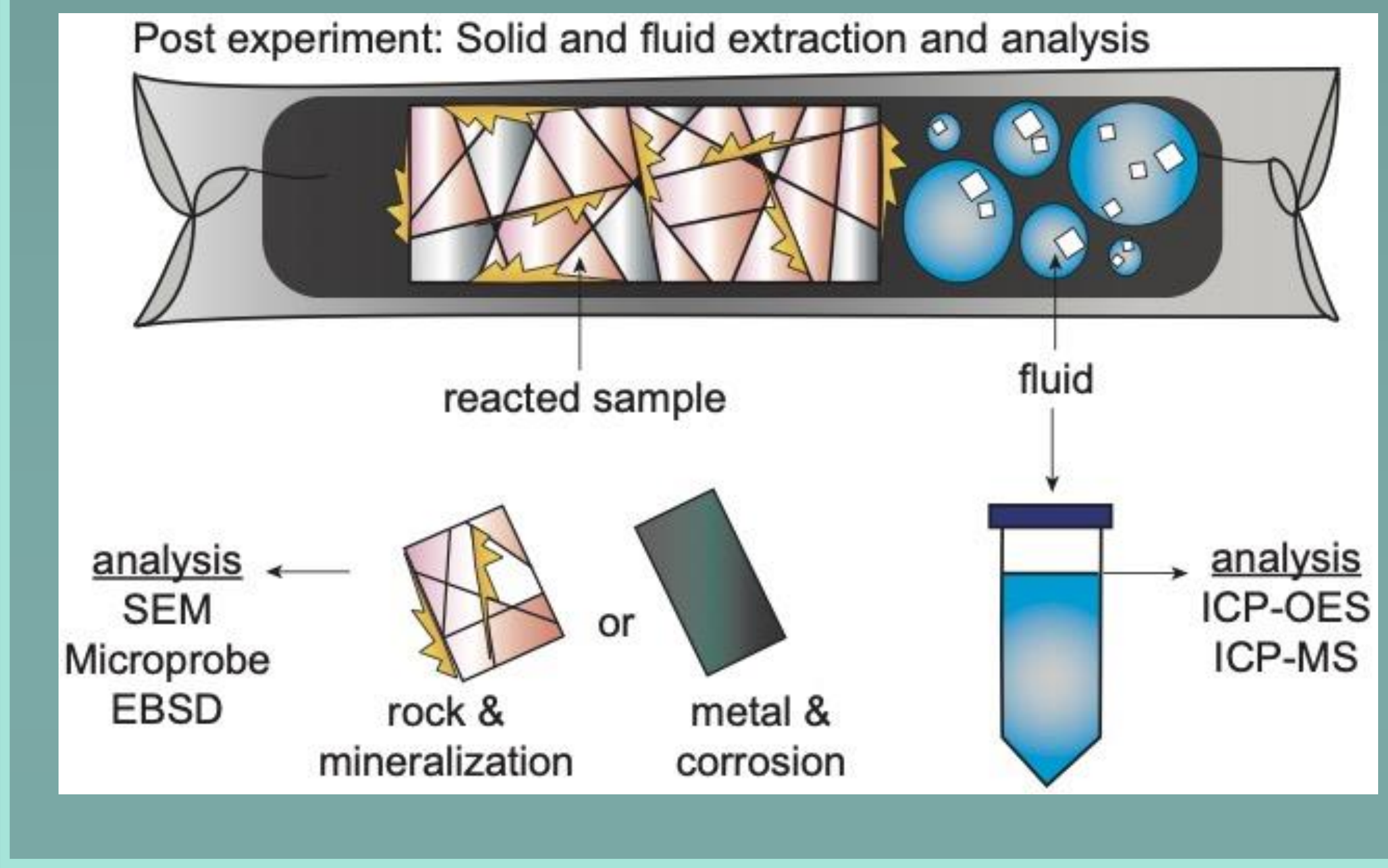


During experiment, capsule is heated in the hot spot.

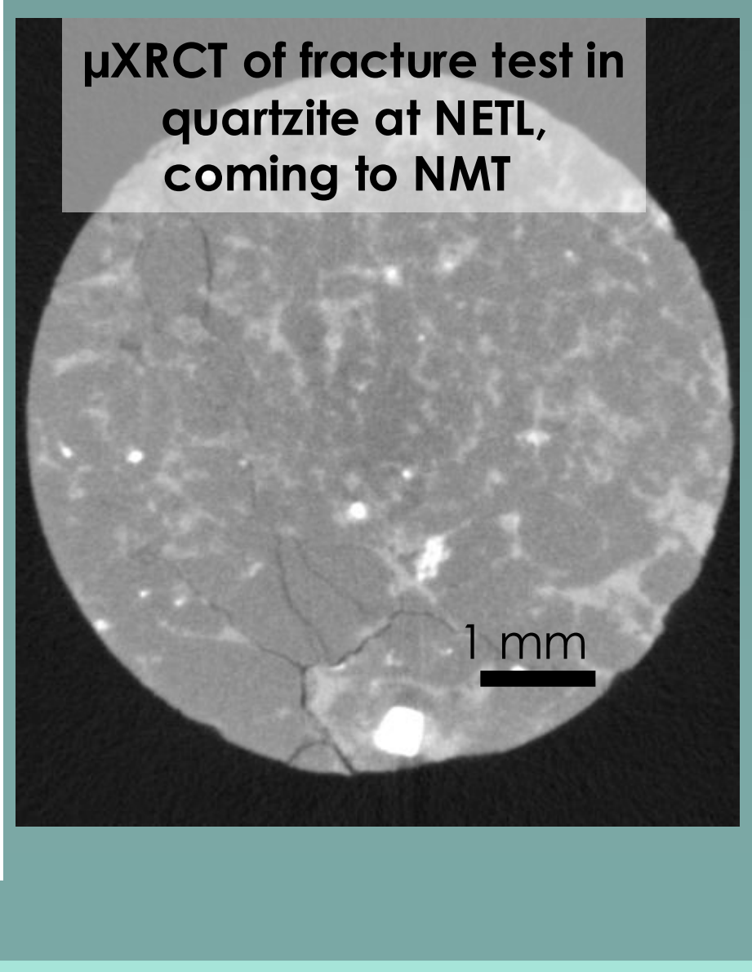
Six furnace assemblies at NMT



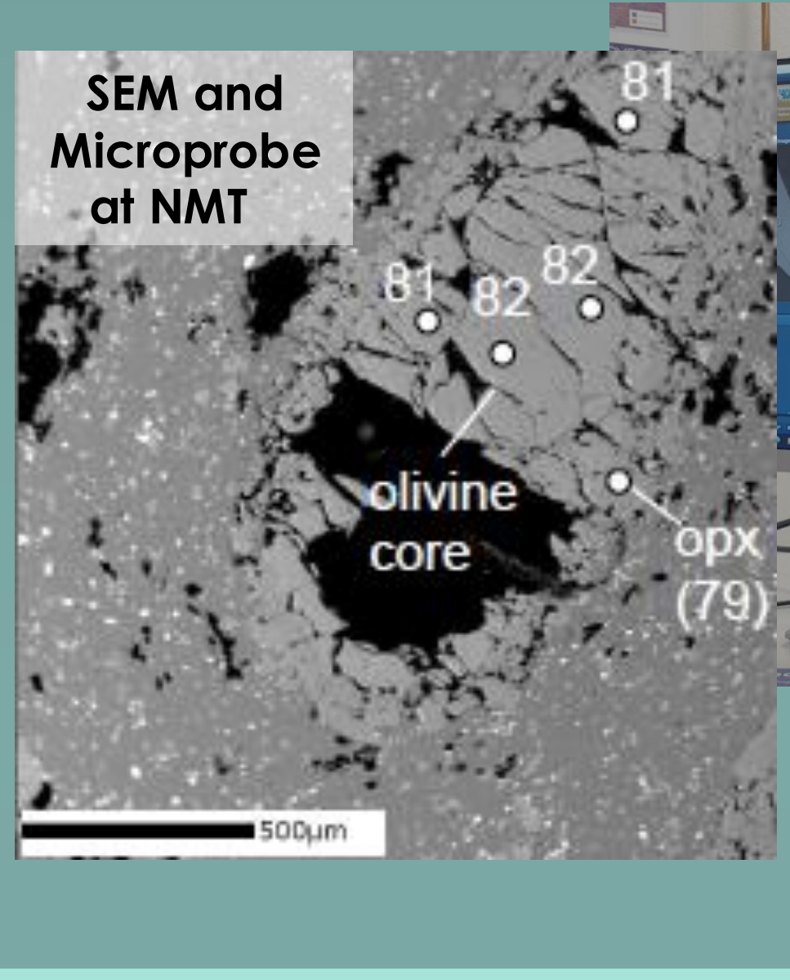
Post-experiment and Analysis:



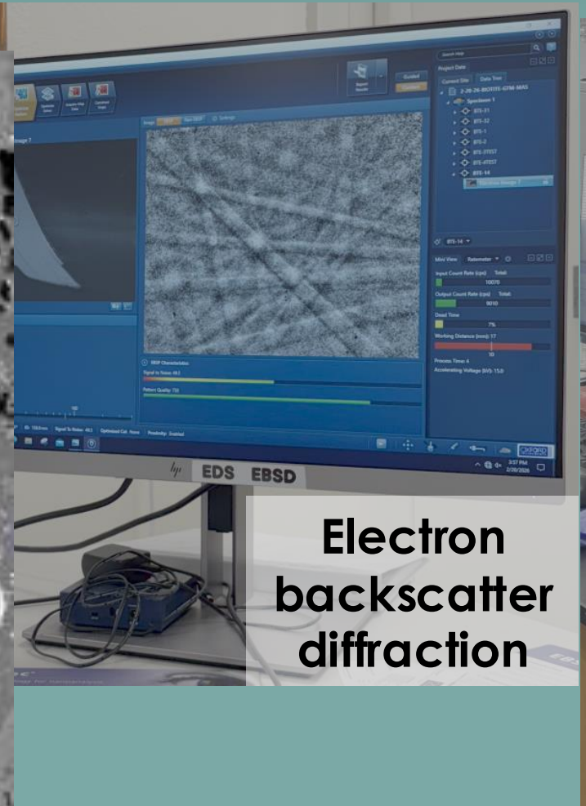
Solid Characterization:
Structural, chemical and mineralogical characterization



µXRCT of fracture test in quartzite at NETL, coming to NMT



SEM and Microprobe at NMT



Electron backscatter diffraction

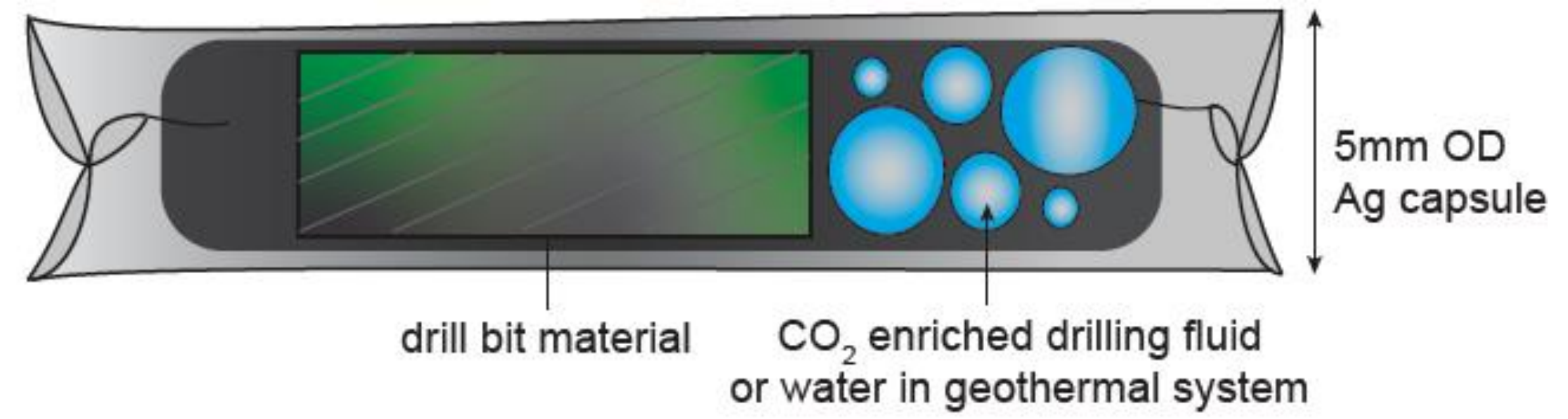
Fluid Characterization:
ICP-OES, ICP-MS

ICP-MS

Superhot Rock Technology Gaps (Clean Air Task Force Report) & Solutions from Experimental Petrology

Gap: Drilling

- The Clean Air Task Force Report finds that drilling technologies represent an area of the geothermal industry that requires the most effort and improvement on research for these technologies:
  "The primary challenge is the lack of end-to-end testing in [super hot reservoir] conditions (in labs or the field)"
- The report highlights a need for the development of ultra-high-temperature downhole tools and temperature management equipment to access geothermal gradients sufficient for power generation (374°C to >450°C)
- Conventional downhole drilling tools run at 175°C. Few operate in the range of 200-225°C. Some drill fluids can reach to 353°C.
- Experimental petrology techniques can address one of the three overarching challenges: Lack of access to SHR in controlled, laboratory settings.

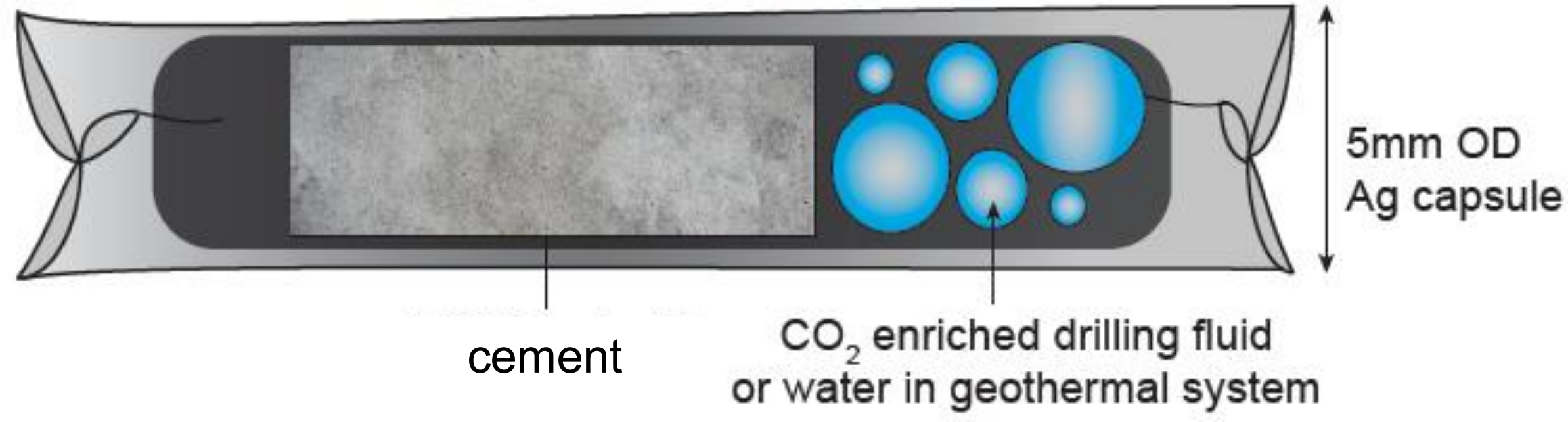


Solids -> extracted analyzed with EMPA, SEM and/or EBSD
Time series experiments yield corrosion rates

Clean Air Task Force (2024). "Bridging the Gaps: A Survey of Methods, Challenges, and Pathways Forward for Superhot Rock Drilling." https://cdn.catf.us/wp-content/uploads/2024/05/23145003/shr-bridging-gaps-drilling.pdf

Gap: Casing and Tubular Materials

- The Clean Air Task Force Report finds that casing materials in SHR wells face long-term degradation due to high temperatures (350°C to 500°C), causing microstructural changes that reduce tensile strength, ductility, and toughness.
- Common carbon steels and low alloy steel (K55; L80, and T95) fail in superhot conditions. Low-carbon steels may exhibit creep (slow deformation) at temperatures from 435°C to 700°C. The extent of these changes remains insufficiently characterized across different alloy types, and there is limited understanding of how steels and corrosion-resistant alloys respond to prolonged exposure to extreme temperatures.
- Common cements (e.g., Portland cement; effective up to 390°C) and calcium aluminate blends (tested up to 540°C), have not been adequately tested under superhot conditions.

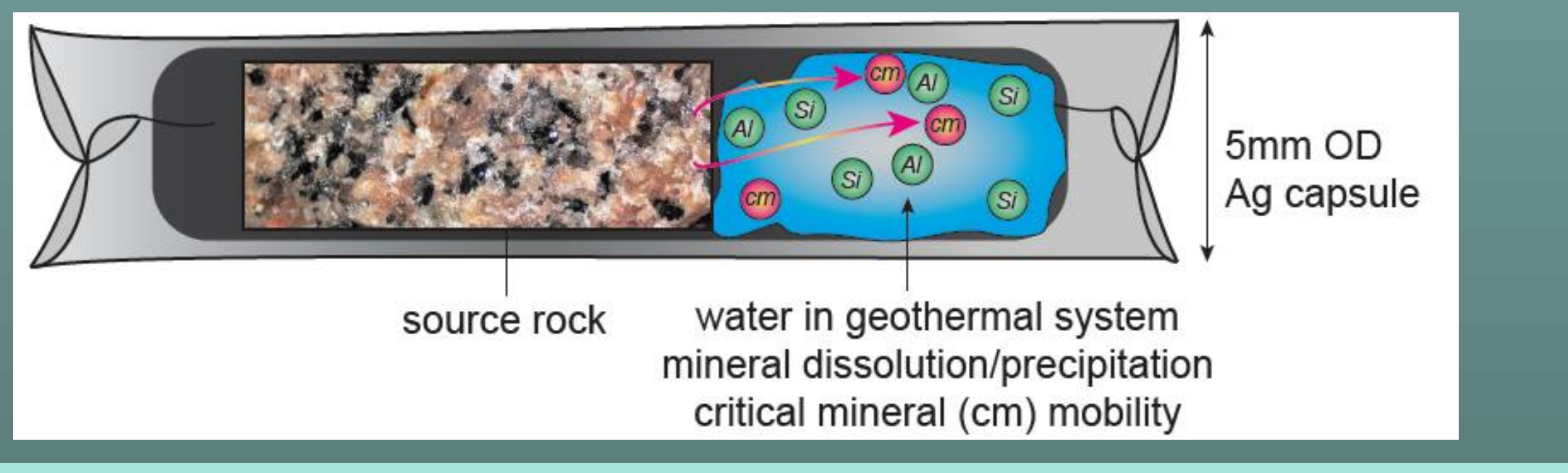


Solids -> extracted analyzed with EMPA, SEM and/or EBSD
XRCT analyses can provide information about crack development
Time series experiments yield reaction rates, which can be compared to commercial models

Clean Air Task Force (2024). "Bridging the Gaps: A Survey of Methods, Challenges, and Pathways Forward for Superhot Rock Drilling." https://cdn.catf.us/wp-content/uploads/2024/05/23145003/shr-bridging-gaps-drilling.pdf

Gap: Borehole Logging

- Few studies with samples of supercritical fluids, and the chemical reactions that control fluid compositions are still poorly understood.
- A better understanding of fluid geochemistry is needed for SHR development, because geochemistry effects drill string fatigue and corrosion issues (can add rock and drill bit in experiment).



Gap: R&D New Laboratory Vessel Design to Replicate SHR Flow Through Experiments

- Materials used in experimental petrology to reproduce magmatic temperatures may be a useful point of comparison for engineering strategies in the superhot rock regime (e.g., Zr enriched cements).
- Cross field collaboration (petrology + rock mechanics) for new vessels