Chemical-Mechanical Interactions at Cement-Geomaterial Interfaces in Repository and Borehole Scenarios Monitored with Ultrasonics

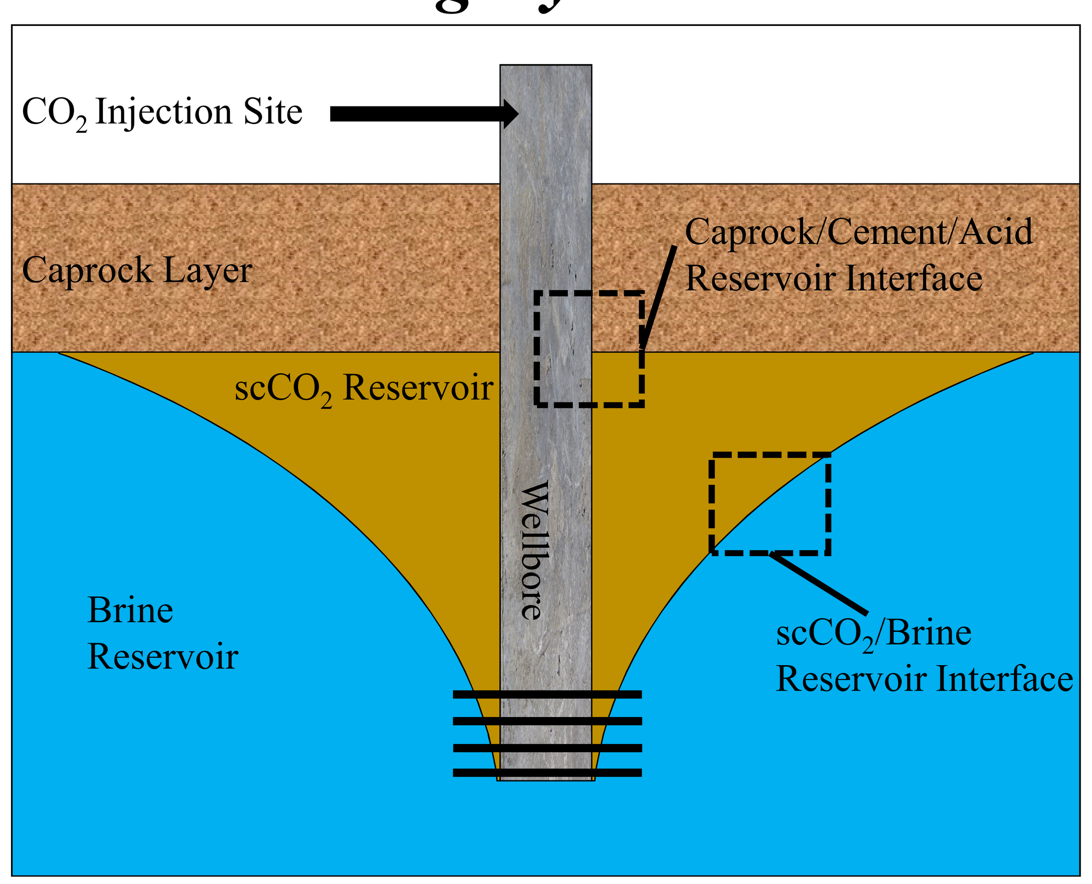
Joseph Mohagheghi[a,b], Thomas Dewers[b], Ed Matteo[b], Jason Heath[b], Carlos Jové-Colón[b]

[a] New Mexico Institute of Mining and Technology, Department of Materials Engineering, 801 Leroy Place, Socorro, NM 87801
[b] Sadia National Laboratories, Center for Energy and Geosciences, 1515 Eubank Blvd SE, Albuquerque, NM 87123

Introduction

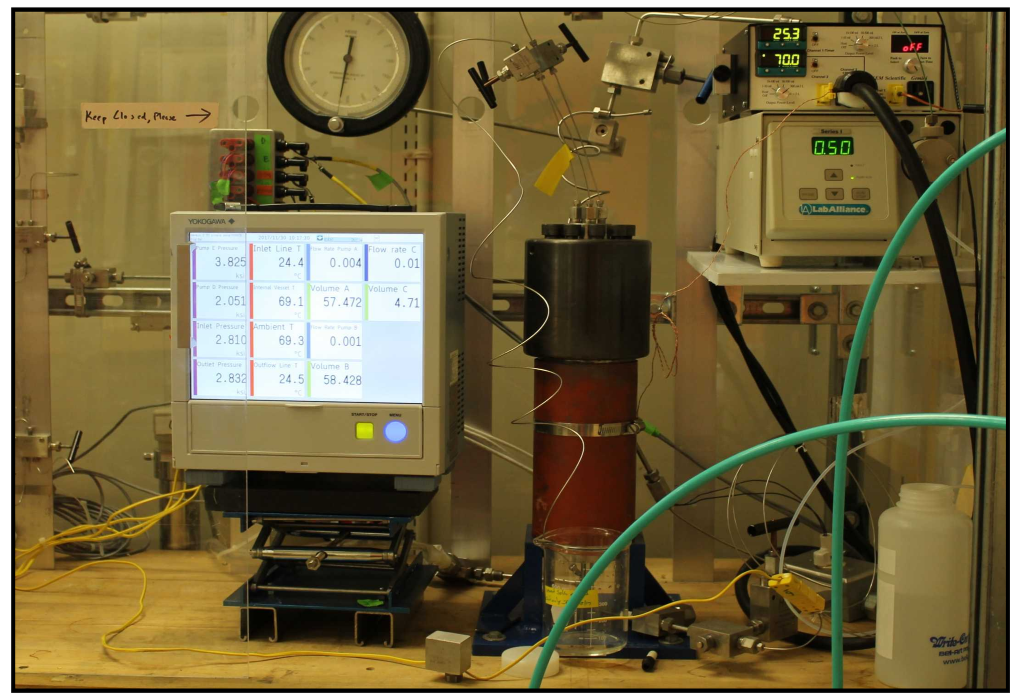
A number of factors negatively affect wellbore integrity including interactions at boundaries between cement and surrounding geomaterial. These include mechanical and chemical mechanisms that can lead to wellbore failure. To examine these interactions, potential coupling, and pathways to failure, we discuss progress on an experimental and modeling study involving cement-clay and cement-salt interfaces. A sample shotcrete-bentonite interface from the FEBEX heater test at the Grimsel Test Site in Switzerland is examined using multi-beam scanning electron microscopy (mSEM) at 4 nm resolution over an area ~10's of square millimeters. We examine changes in alteration as manifested by pore structural changes as a function of distance from the interface. A parallel effort examines time-dependent changes in interface structure in cement cores in a triaxial coreholder. Cores are exposed to conditions of 70^oC, 14 MPa pressure, and small differential loads, with degradation being monitored by effluent pH, pulse-echo ultrasonics, and piston displacement (measuring sample shortening). We will measure the mechanical consequences of interface alteration using nano-indentation. Experimental results are being incorporated as a validation effort in a coupled reactive-transport mechanics model linking the Sandia ALBANY finite element code, the KAYENTA elasto-plastic constitutive model, with the reactive transport code PFLOTRAN. Plans call to apply the model to understanding the evolution of the FEBEX sample, as well as a cement-salt sample from the Waste Isolation Pilot Plant in Carlsbad, New Mexico.

Wellbore Integrity

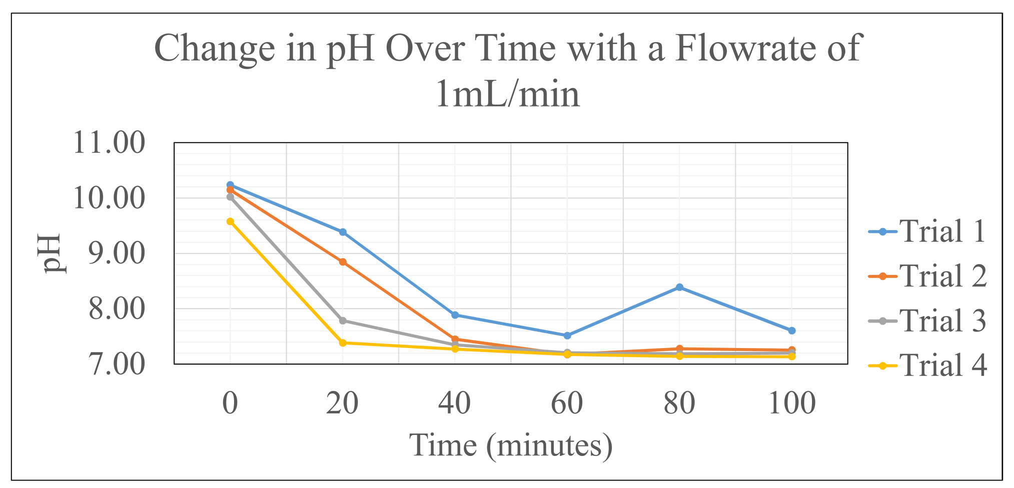


Wellbores are a complex system and there are several human and environmental factors that can affect its overall integrity. A blowout can occur from an uncontrolled flow of liquid or gas from within the wellbore. A kick can break the wellbore due to pore pressure being greater than column pressure. Poor drilling practices, such as using the wrong materials or materials that are not up to standard or using old equipment, can lead to a wellbore failing early. Acidified brine can chemically attack the cement/geomaterial interface of the wellbore and lead to the vertical migration of acidified brine into the region above the caprock. There the acidified brine can possible react with hazardous materials, such as lead or arsenic, and migrate & pollute potential drinking water reservoirs.

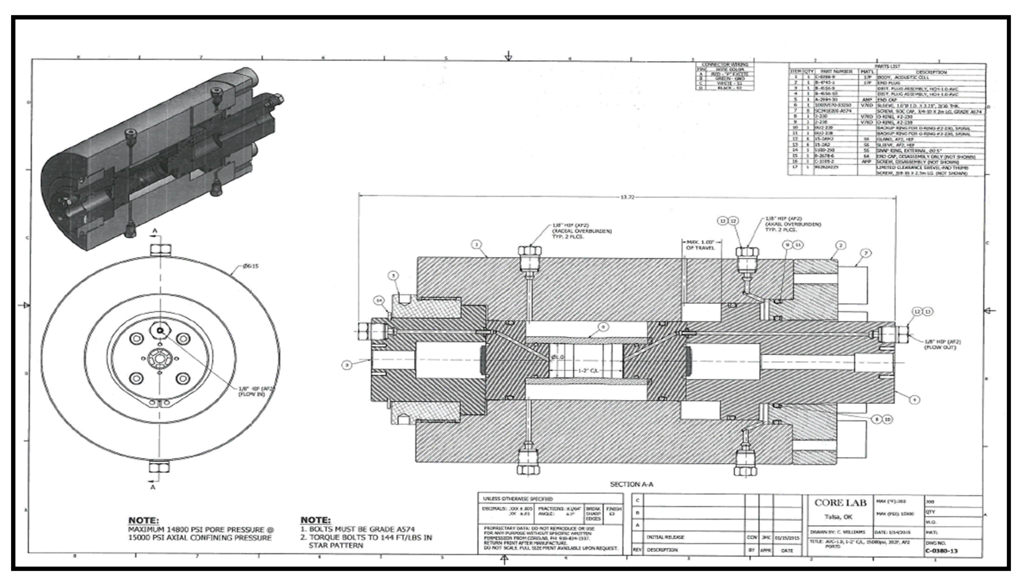
Surface Flow Experiments



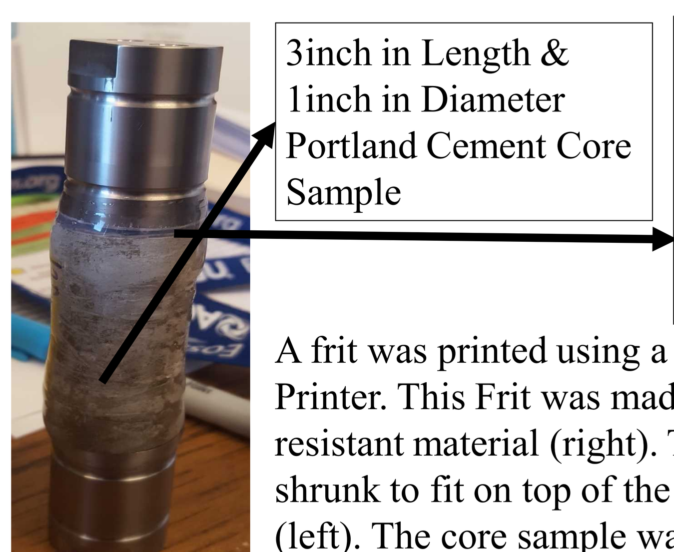
Apparatus set up to study how cement will react with an acid solution over time. The inlet solution is pumped in and over the top of the core. Once the reservoir is filled, the solution is then pushed out and collected for pH measurements.



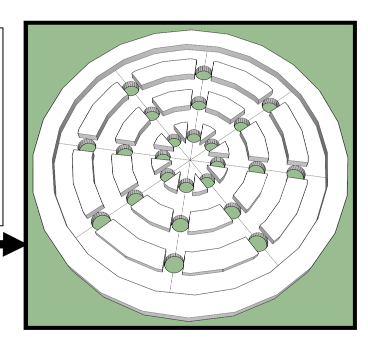
Initial results from running this experiment. The pH decreased after an initial spike, meaning that the inlet stream is making contact and reacting with the cement core sample.



Triaxial-Coreholder Schematic.

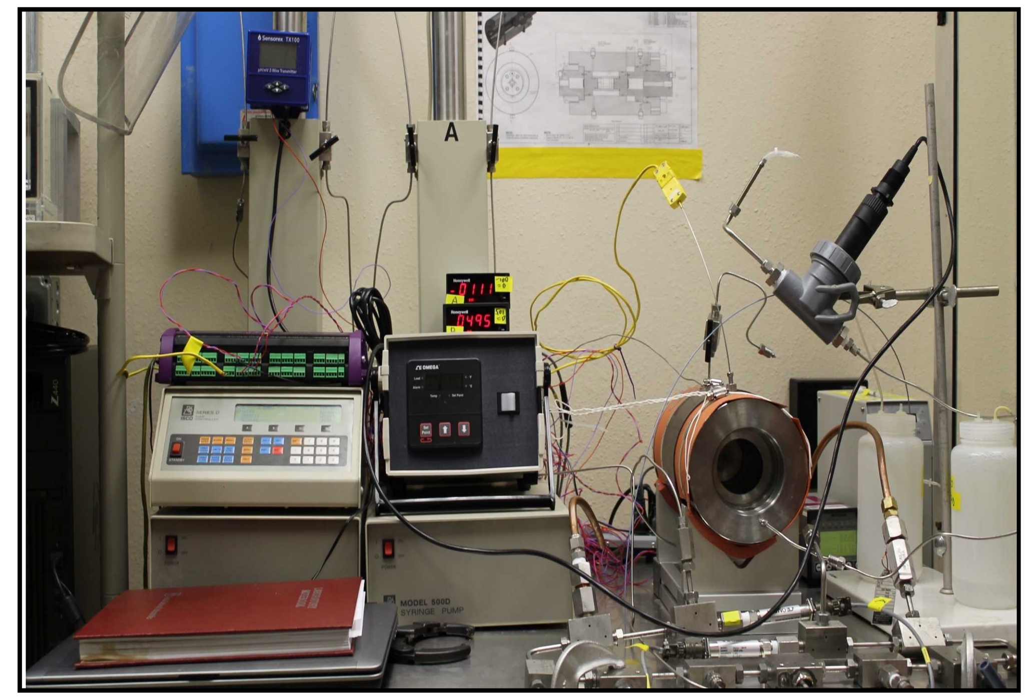


3inch in Length & 1inch in Diameter Portland Cement Core Sample



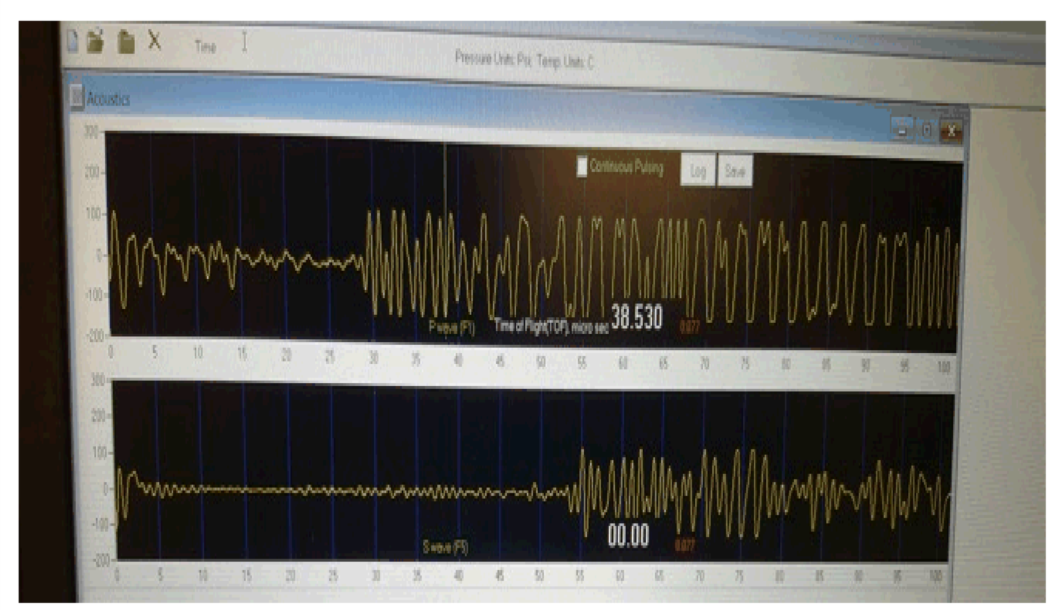
A frit was printed using a Formlabs Resin 3D Printer. This Frit was made from an acid resistant material (right). The frit was heat shrunk to fit on top of the cement core sample (left). The core sample was spun in a lathe to make sure it sat in parallel in the core holder.

Flow Through Experiments



Apparatus for the flow through experiments. This experiment consist of: an inline pH probe to track the effluent out reaction solution's pH at given intervals, an LVDT to monitor any change in the core sample's vertical length, a needle pump to pump the influent solution through the system, a temperature controller, and two iscopumps to add axial & confining pressure to the core sample.

In addition to all the other instruments hooked up to the coreholder, there are also ultrasonics. The ultrasonics are hooked up to shoot P&S waves down the length of the core sample. Above are the results for the initial unreacted cement core.

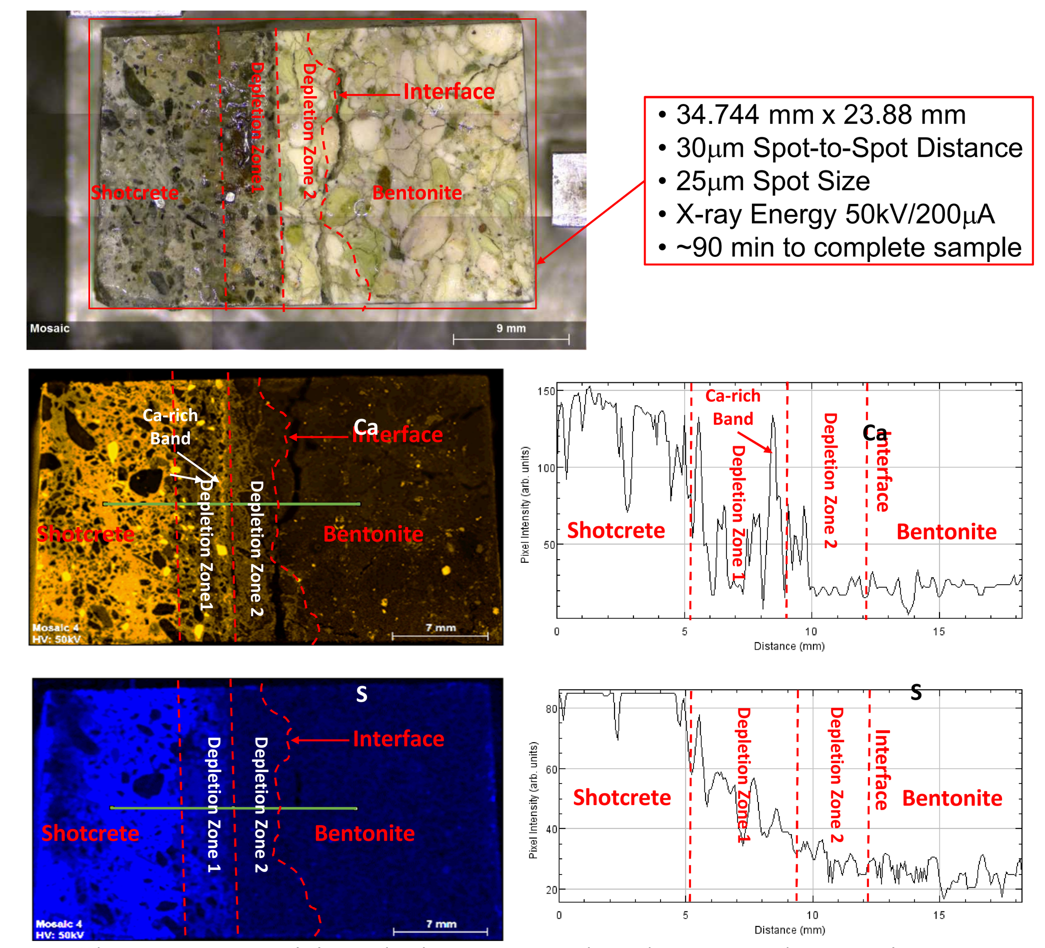


Above are the P&S waves of the same cement core sample, but after 30 days of reacting with acid solution. Notice how the waves have shifted. It is suspected that the P&S waves of the Portland Cement/Westerly Granite core sample will also change after reacting with acidic solution If this proves to be correct, ultrasonics can be used to monitor wellbore integrity.

Interface Microscopy Experiment

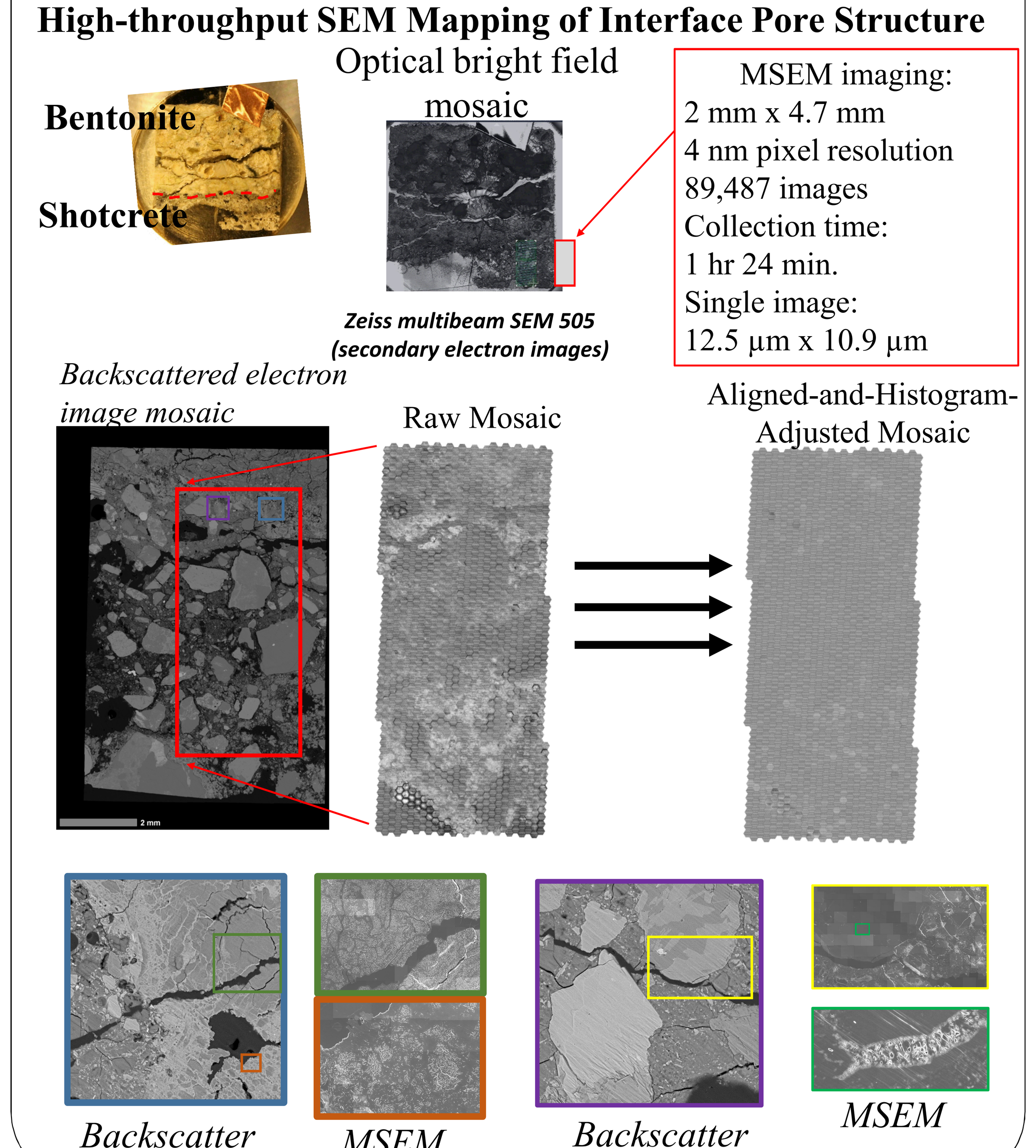
Goal: examine compositional and pore structural changes at shotcrete-bentonite interface for sample from the FEBEX heater test at the Grimsel Test Site in Switzerland

Micro-XRF mapping of shotcrete-bentonite interface



- Sharp compositional changes at the shotcrete-bentonite interface
- Consistent spatial correlation of various elements at interface
- Depletion on shotcrete side of interface – leaching?
- Spatially-limited reaction front?

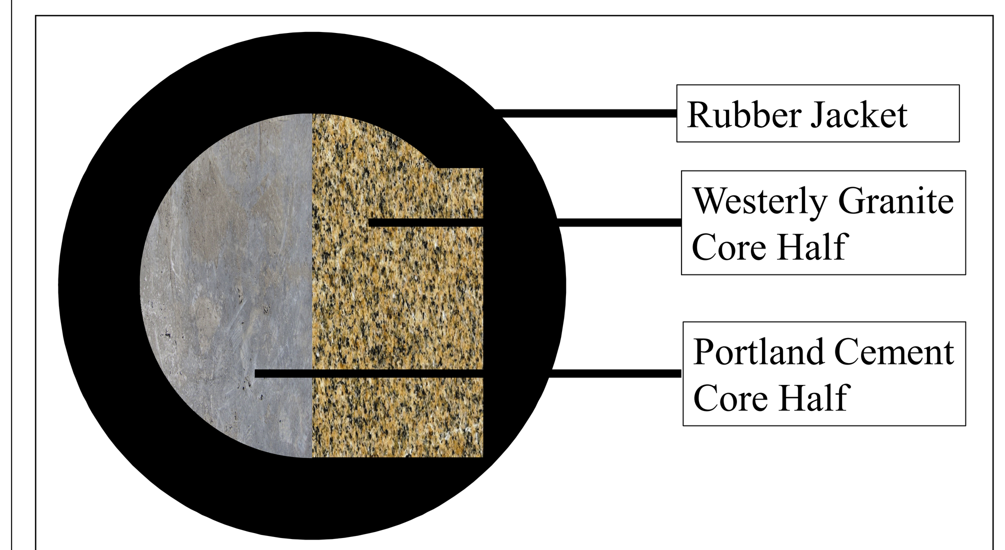
High-throughput SEM Mapping of Interface Pore Structure



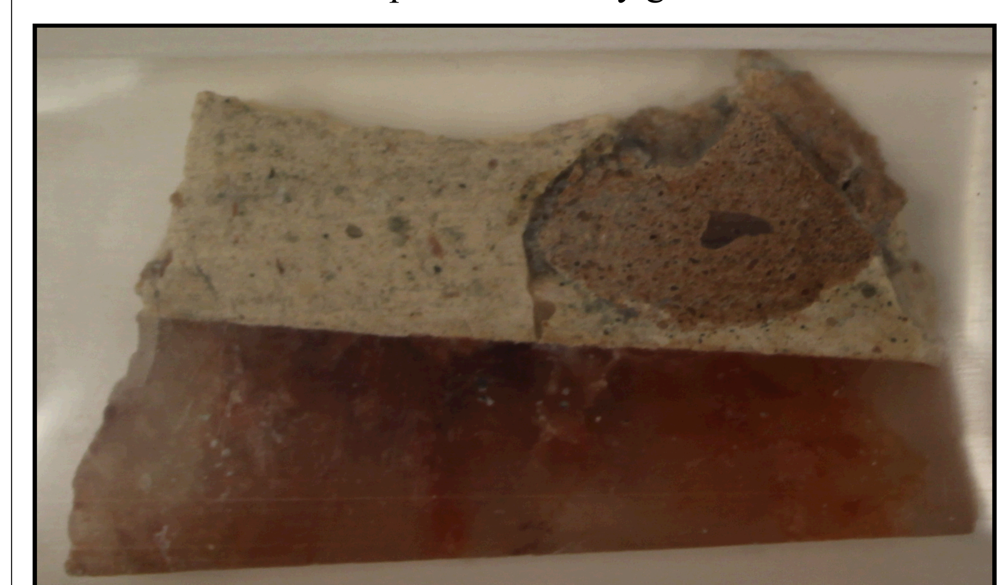
Conclusion

The research goal of this research is to find a novel way to screen wellbores for preliminary signs of loss of integrity. The surface flow experiments are being used to understand the one dimensional acid/cement reactions. The mSEM analysis shows how cement changes in composition and porosity at the boundary with another geomaterial. Lastly and most importantly, the flow through experiments are imitating wellbore conditions to understand how the acidic solutions will affect the cement at the cement-geomaterial interface. Preliminary results from the cement core sample show that there is a change in the P&S waves after the cement reacts with the acid, so it is not a stretch to expect something similar with the cement/geomaterial core.

Planned Work



Shown above is a cross section of the core sample that is to be tested in the flow through experiments. One half of the 1in diameter by 3in in length core will be cement and the other half will be non porous westerly granite.



A cement/salt sample that was recently made and will be scanned in the mSEM in order to extract porosity data.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.