Research Statement

Dr. Jeff R. Havig

Summary: My primary research focus is to improve our understanding of rock-water-microbe interactions, and how those interactions 1) drive geochemical reactions on the Earth's surface, and 2) can be used to interpret the rock record. My work fills a critical need for understanding geochemical cycling and sequestration of elements which is necessary for understanding the evolution of the Earth's surface. I use a wide array of sampling and analytical tools to characterize geochemical environments and trace the influence of life on geochemical reactions across a range of settings. My objective is to build a world-class geochemistry lab that functions independently as a leader in environmental geochemistry using modern systems to understand changes in the environment, to interpret the ancient rock record on Earth, and to develop biosignatures to look for past life on Mars.

Earth sciences are in a golden age of exciting innovations in analytical capabilities and changing paradigms. New techniques, ever decreasing detection limits, and a renaissance in genomics approaches coupled to new geochemical proxies have created a critical need for geochemists that can bridge geology, aqueous geochemistry, and microbiology through field-based approaches. Characterizing geochemical environments in this context allows testing and exploring the limits of systems as they relate to element solubility, cycling, sequestration, and potential for remobilization.

One of the big questions I have applied my work to studying is the geochemical effects on the Earth surface system following the Great Oxidation Event at 2.5 Ga, which impacted redox chemistry of trace elements and saw the greatest precipitation of iron formations and manganese ores in Earth history. To better constrain the effects of the resulting redox-stratified ocean, I spearheaded a project studying Fayetteville Green Lake, NY (a Paleoproterozoic ocean analog). This work resulted in a better understanding of trace element cycling (Havig et al., 2015; Herndon et al., 2018) and impacts of carbon cycling on the carbon isotope signal (Havig et al., 2018) as it relates to redox stratified lakes and oceans. I applied what we learned to focused sampling of the Paleoproterozoic age Nash Formation in Wyoming to help explain some of the most positive carbon isotope values found in carbonate minerals (Havig et al., in prep). My wholistic sampling and analysis techniques coupled to my integrative and collaborative approach is indicative of my approach of integrating rigorous field contextualization with cutting-edge geochemical analyses in the lab.


Figure 1. Preferential weathering of dolomite exposing chert in stromatolites found in the 2.0 Ga Nash Formation, WY.

Hot Springs

1. **Novel biosignatures preserved by silica precipitating hot springs.** In my lab, we are using modern hot springs to interpret hot spring deposits found in ancient hot spring deposits including the 3.5 Ga Dresser Formation of Western Australia and putative hot spring deposits that may contain evidence for past life on Mars. We employ SEM, BIO-SIMS, electron microprobe, and other techniques to detect major and trace elements in siliceous sinter deposits. So far we have learned there may be a characteristic trace element enrichment by life which resulted in a submitted publication (Gangidine et al., expected submission Oct., 2018) and a pending proposal with the NASA Exobiology program. Furthermore, we have learned there are direct correlations between the 3.5 Ga hot spring deposits and those in Yellowstone, and this has resulted in a submitted publication (Djokic et al., submission Oct., 2018) and a planned grant submission to the NASA Habitable Worlds program.

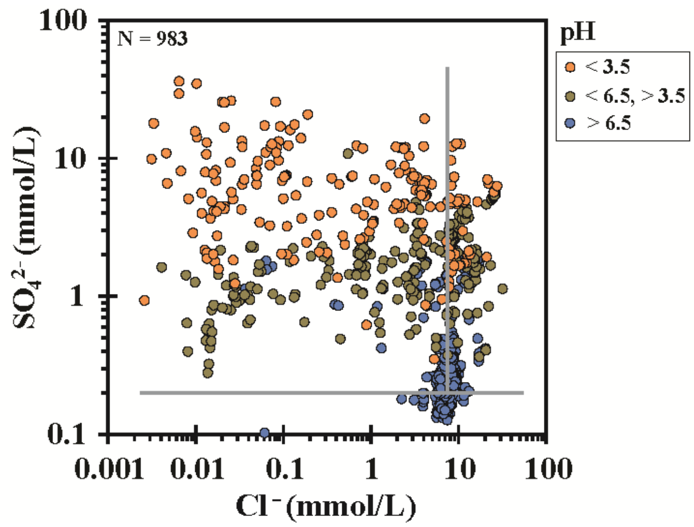

Figure 2. Extensive geochemical variation in Yellowstone hot springs is driven by subsurface processes, influencing elemental composition and pH, and providing a vast natural laboratory to explore.

2. **Interpreting Martian hydrothermal deposits.** I am leading collaborative project to combine geochemical analyses of hydrothermal areas with remote sensing to aid in the interpretation of hydrothermal deposits on Mars. So far we have learned there is an apparent distinguishing spectral difference between siliceous sinters deposited in acid vs. alkaline-deposition environments which will tell us where our best locations for finding evidence for life on Mars. This preliminary data will serve as the foundation for a planned grant to NASA Solar System Workings.
3. **Hypolithic microbial communities as analogs for the first terrestrial oxygenic phototrophs.** Whiffs of oxygen before the Great Oxidation Event indicate terrestrial weathering but few models exist for quantifying Archean terrestrial oxygen production. I am examining hypoliths (microbial communities living under siliceous sinter) in YNP as analogs for microbial communities living on continental surfaces during the Archean. Initial characterization showed these environments provide unique environments that would protect microbial communities from UV radiation and desiccation (Havig and Hamilton, in revision). These data are the legs of a pending proposal with the NASA Exobiology program.

Freshwater Carbon Cycling in Response to Eutrophication

Recent work has suggested that lakes and reservoirs sequester more carbon per year than the worlds oceans, making them crucial bioreactors for element cycling. I have lead research designed to start to disentangle the effects of invasive mussel species and harmful cyanobacterial blooms on carbon sequestration in lakes using carbon isotopes (Havig and Hamilton, submitted). My continuing work characterizing element cycling and sequestration in lakes fills a vital need, and I plan to submit proposals to the NSF Geobiology/Low Temp. Geochem. program as well as local sources (e.g., state Sea Grant programs) to fund this work.

Approach

Most of my sampling and analytical expertise is in aqueous environments, built on a foundation starting from my first experiences as an undergraduate studying environmental chemistry and culminating with my dissertation work on Yellowstone hot springs. From this I have applied what I have learned to lakes, glaciers, acid mine drainage, and geologic samples. Techniques include analysis for major elements (e.g., electron microprobe, ion chromatography, ICP-OES, SEM-EDX), trace elements (e.g., ICP-MS, SIMS), carbon and nitrogen isotopes (e.g., Gas Bench and EA-IR-MS, BIO-SIMS) as well as *in situ*/real-time (e.g., pH, conductivity, temperature, dissolved oxygen, field spectrophotometry). It is of utmost importance to my research and my program to train students and postdocs in sampling and using analytical techniques available.

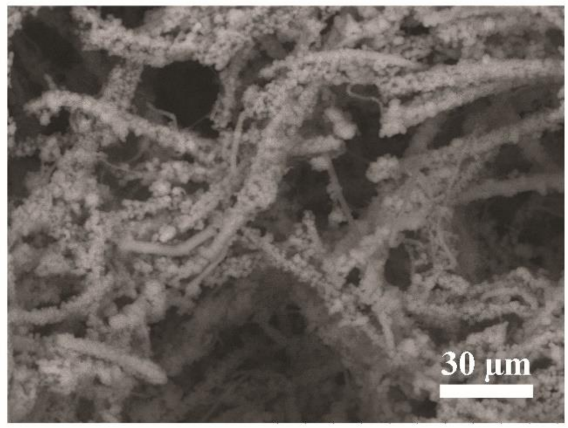

Figure 3. Silica precipitates around bacterial filaments from the outflow channel of an alkaline hot spring in Yellowstone.

Through characterizing geochemical environments and constraining how they influence element cycling and sequestration, my research will improve our ability to interpret the ancient rock record. Furthermore, it will contribute to interpreting remote sensing and geochemical analyses of the surface of Mars, and in understanding element cycling and sequestration in lakes and reservoirs. My work will help answer questions such as: When did life first arise on Earth? How did element cycling change across the Great Oxidation Event? Is there evidence for past life on Mars? How are anthropogenic effects influencing the ability of lakes to sequester carbon from the atmosphere? I will mentor students and postdoctoral researchers as they assist in executing this work, helping to train early career scientists in asking big picture questions they can answer through focused, field-based research using a range of analytical techniques and in building collaborations that will strengthen their work.