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Investigating the nano- and micro-scale features of continental fractured-rock deep biosphere

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Microbial communities in the deep continental biosphere are isolated from Earth surface inputs. Within rock fractures, microbial life must derive energy and other essential substrates from rock and groundwater sources. Fracture-scale mineral precipitation and dissolution reactions can control habitability of fractures by liberating substrates and creating habitat or filling fractures and preventing exchange with fracture networks. We are investigating these processes in legacy boreholes and archived cores from the Canadian Shield. We access the deep continental biosphere at 700 m below ground surface through the Soudan Mine Underground State Park. Two types of samples are investigated: (1) suspended particles collected from boreholes by filtering anoxic brine; and (2) thin sections created from rock cores within depth increments corresponding to fractures. We are using a multimodal approach that employs soft (C, N), tender (P, S), and hard (Mn, Fe) X-ray imaging and absorption spectroscopy, as well as X-ray diffraction, to describe the solid-state chemistry of host rock, fracture surfaces, and suspended particles. With this approach, we describe the crystalline host minerals, any poorly crystalline secondary minerals precipitating within fractures, as well as the oxidation-reduction potential of key elements that can contribute to microbial metabolism (S, Mn, Fe). Equally important for our study is the ability to measure the speciation of biologically relevant elements (C, N, P) and map the distribution of those elements relative to minerals. These data streams are used together to determine the possible reactants and products of biological activity in fractures. They are also used to interpret the interactions among brine, rock, and microbial life that create positive or negative feedbacks on habitability of fractures in the continental deep biosphere.