Goldschmidt 2022 Abstract
https://doi.org/10.46427/gold2022.12804

Connecting weathering, entropy and the search for life

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Entropy describes the dissipation of potential energy in a physical system with time. In planetary context, entropy connects microscale and macroscale processes. When a mineral reaches thermodynamic disequilibrium with the surrounding environment, e.g. at terrestrial surface, potential energy is consumed through interactions with water, atmospheric gases, radiation and life. Such interactions provide ecosystems with a steady flow of nutrients and regulate the balance of gases in the atmosphere. Over the Earth's 4.54 billion years history, mineral transformations have been intimately connected with the origin and evolution of life. Life itself has been possible because of the diversity and reactivity of minerals supplied from rocks. The co-evolution of minerals and life is a fundamental phenomenon on Earth that may also be conceivable on other planetary bodies, and identifying its signatures is at the leading edge of planetary sciences and astrobiology.

The search for life and for conditions leading to habitability beyond Earth rely greatly on our capacity to distinguish biotic from abiotic interactions, how they co-evolve on Earth, and whether such knowledge can be applicable to other planetary bodies. Volcanic provinces provide valuable insights into early life-rock interactions and the development of habitability. We conducted laboratory and field studies of terrestrial and planetary analogs to probe the fundamental connections between weathering and life, and establish a geochemical biosignature index that can dissociate abiotic from biotic processes during incipient mineral weathering. Furthermore, I will discuss how early life-rock interactions can result in the formation and preservation of energy-rich microhabitat hotspots in field-collected samples. I will highlight the importance of a broad suite of techniques for addressing the complex research questions associated with this work, specifically the use of clean-room laboratory studies, field experiments and exploratory samples collected from planetary analogs of early Earth and Mars in Iceland. As we expand our civilization beyond Earth's gravitational boundaries, and start to explore extrasolar worlds, it becomes critical to better understand the fundamental processes that shape the evolution of planetary surfaces and their connection to life.

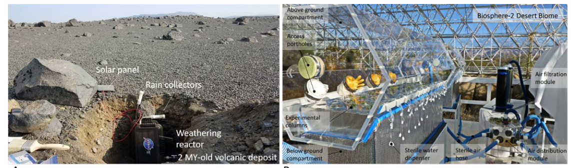

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Fig. 1 Dissociating abiotic and biotic actors of weathering. (A) Field bioreactors deployed during NASA's 2021 Goddard Instrument Field Team (GIFT) expedition at a Mars analog site in Iceland to study abiotic and biotic weathering in field conditions. (B) Rockubators mesocosm setup at Biosphere-2, Arizona, designed to study the effects of abiotic processes, microbes, vascular plants and mycorrhiza on incipient rock weathering.