

Advances in Biogeochemical Thermodynamics of Seafloor Hydrothermal Systems

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The biosphere of the Earth is supported from below by dynamic energy fluxes that move among a fabric of water and rock. And while the water is more often prized as *essential for life*, it is the various rocks that set the table for life by drawing the fluids at Earth's surface towards extreme relative compositions. This is especially true throughout the vast oceanic basement, where photosynthesis is impossible. Seawater moving through cracks, faults, and pore-spaces in mafic and ultramafic rocks drives mass and energy exchange, establishing hydrothermal fluids that feed expansive and diverse ecosystems. However, the overwhelming majority of the oceanic subsurface is physically inaccessible, requiring substantial contributions from modeling and laboratory studies to aid the interpretation of drill cores when reconstructing the alteration history at specific sites.

Our recent advances in high-throughput parallel computing has facilitated an expansion in oceanic crust alteration modeling. These advances allow us to draw large numbers of model water-rock systems stochastically from distributions of all relevant variables, view alteration fluids and mineralogy with respect to such dimensions, and evaluate energy supplies during mixing. For example, basalt alteration generates significant quantities of H₂ primarily via Fe(III)-sequestration in epidote, regardless of all realistic variations in basalt composition. In other words, the epidote stability field is large and does not imply specific reaction conditions.

Conversely, specific combinations of alteration minerals leave small footprints in the collective variable space, allowing them to be employed as indicators of specific conditions when recovered in altered samples. As an example, the coexistence of carbonate and anhydrite indicates alteration between 100 and 200°C, and a water-to-rock ratio of between 10 and 30, independent of basalt composition, while pyrite and pyrrhotite indicate an even narrower range of water-to-rock ratio between 1.5 and 2 for a specific subset of basalt compositions. Therefore, our approach allows recovered alteration mineralogy to be correlated with (1) ranges of initial rock compositions that may have guided their formation, (2) the range of hydrothermal fluids coeval with their emplacement, and (3) the amount of energy available to metabolic processes within these fluids as they mix with seawater.