

Inferences about seafloor hydrothermal alteration mineralogy, temperature, fluid fluxes and Sr isotopes from reactive transport modeling

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High temperature mid-ocean ridge (MOR) hydrothermal systems play a role in Earth's geochemical cycles by facilitating chemical and isotopic exchange between oceanic crust and seawater. This "exchange" is a consequence of hydrothermal reactions that convert primary igneous minerals to the major secondary minerals albite/oligoclase, amphibole, epidote and chlorite. We have developed reactive transport models of this process using the TOUGHREACT code to explore how exchange is affected by shifts in seafloor spreading rate, ocean depth, and basalt and seawater chemistry. Our latest models are done with a two-layer grid representing 750 meters of basalt lava underlain by 750 meters of diabase dikes and heated from below. These models incorporate a water EOS accurate near the critical point, and a thermodynamic database that extends to 600°C and 50 MPa with modifications to represent Sr- and Sr isotope exchange. The models are simplified, 2-dimensional representations and do not explicitly treat spreading, but they reproduce salient features of fluid composition and dike alteration in real systems, and provide constraints on reaction rates, temperature, and Sr-isotope exchange while explicitly relating these effects to heat flux, fluid fluxes, rock permeabilities, fracture spacing, and mineral-fluid reaction kinetics. Work to date that applies to medium spreading rates suggests (1) removal of Mg and SO₄ from fluids is rapid above 150°C but fast-flowing fluid in fractures can retain some Mg, (2) amphibole is the dominant secondary phase at T > 250°C, (3) fluid ⁸⁷Sr/⁸⁶Sr and K+ reflect plagioclase dissolution rates, (4) alteration extent is depth-dependent within the dikes and occurs at T ≈ 250°C to 350°C, (5) large-scale permeability of dikes is ≤ 10⁻¹⁴ m², (5) fluid Sr does not decrease from anhydrite precipitation unless K_{Sr} ≥ 1, (6) Fe/Mg of chlorite is T-dependent between 100°C and 350°C, (7) low-T flow and dissolution kinetics may be sufficient to return anhydrite SO₄ to the ocean. Comparison with observations is a critical step in using models to explore chemical exchange in MOR hydrothermal systems in deep geological time and to understand its role in the evolution of seawater composition, arc magmatism and mantle geochemistry.