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Geochemical and Geophysical Controls on the Composition of Hydrothermal Vent Fluids at Mid-Ocean Ridges

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Investigations of hydrothermal systems at mid-ocean ridges have confirmed that magmatic and tectonic processes play key roles in vent fluid composition and temperature, as well as in duration and style of venting. At fast-spreading ridges (e.g., EPR 9°N and 21 °S), shallow magma chambers and high thermal gradients enhance phase separation effects and vapor-liquid partitioning of elements, especially in the aftermath of seafloor eruptive events. New and revised thermodynamic data for minerals and aqueous fluids in the two-phase NaCl-H2O system have enabled development and calibration of empirical density models, extending prediction of mineral solubility beyond conventional limits imposed by available theoretical data. These data also enhance the accuracy of quartz geothermobarometry in the near critical region. In contrast, hydrothermal vent fluids at the slow-spreading Mid-Atlantic Ridge suggest very different geochemical and geophysical phenomena. Here, long-lived detachment faults expose lower crustal and upper mantle lithologies. The Rainbow Massif (36.15°N, MAR) provides an excellent, well-studied example. The low pH, moderate silica, and high dissolved Fe and H2 concentrations of the Rainbow vent fluids suggest hydrothermal alteration of olivine gabbro at temperatures in excess of 450°C and pressures sufficient for vapor-liquid phase separation (450–500 bar). Seismic studies at Rainbow reveal the existence of gabbroic intrusions and well-developed crack networks, which can serve as fluid pathways to the seafloor [1]. Temperature and pressure conditions inferred from mineral solubility data generally agree with fluid mass and energy transport for enhanced buoyancy-driven convection in the near critical region. Phase separation of a putative brine phase in the subsurface at a constant temperature and pressure likely accounts for the concentration and temporal stability of dissolved chloride in Rainbow vent fluids. Na-rich vapor might also facilitate pH lowering by Na metasomatism, resulting in enhanced Fe solubility, consistent with density model predictions of magnetite solubility in reducing fluids at temperatures and pressures determined for the subseafloor reaction zone of the Rainbow Massif.

[1] Dunn, Ryuta, Easton, Canales and Sohn (2017), Journal of Geophysical Research: Solid Earth, 122, 9580-9602.