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Numerical investigation of multi-phase flow in saline submarine hydrothermal systems

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Submarine hydrothermal systems sustain unique ecosystems, affect global-scale biogeochemical ocean cycles, and mobilize metals from the oceanic crust to form volcanogenic massive sulfide deposits. Understanding and quantifying the involved processes requires linking seafloor observations to physico-chemical processes at inaccessible depth; here numerical models of hydrothermal circulation within the oceanic crust can be particularly useful.

Numerical modelling of seawater phase transitions and the subsequent multi-phase flow in high-temperature submarine hydrothermal systems is challenging, because of (1) the wide pressure-, temperature-, and composition-ranges, (2) the complexity of the equation-of-state for saltwater with highly non-linear thermodynamic properties, and (3) the strong coupling between the conservation equations describing the multi-phase flow. All existing numerical studies have been restricted to two dimensions.

Here we present novel 2-D and, for the first time, 3-D numerical models for submarine hydrothermal systems, which use the Finite Volume Method on unstructured meshes in combination with the Newton-Raphson Method for solving the strongly coupled equations. We study seawater phase transitions in response to variations in magmatic energy input and find that initially low-salinity venting occurs during periods of high basal heat fluxes. The venting fluid is a mixture of seawater and phase-separated vapor, while the vapor's counterpart accumulates as a dense, high-salinity brine layer at the base of the hydrothermal system. This brine layer limits the heat flow into the overlying convection cell so that phase transitions diminish over time and vent fluid salinity returns to seawater-like values. When the magmatic heat source vanishes, the cooling brine layer is successively entrained into the overlying seawater convection resulting in a higher vent fluid salinity. First 3-D results indicate more complex spatial and temporal variations of vent fluid salinity along the ridge axis.

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