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2D simulations of hydrothermal convection at the Lucky Strike vent field, Mid-Atlantic Ridge

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The genesis of oceanic crust is closely linked to hydrothermal venting. Magmatic intrusions provide the heat that drives hydrothermal convection, while seawater circulation efficiently mines heat from the young ocean floor. At slow spreading ridges, like the Mid-Atlantic Ridge, crust is formed by a combination of magmatic and tectonic processes and an axial magma chamber may not be stable at all times. In addition, major deep-cutting faults may provide high permeability pathways for hydrothermal fluids. The Lucky Strike hydrothermal is well suited for studying these feedbacks between hydrothermal flow, magmatism, and faulting. A recent high resolution reflection seismic study has imaged an axial magma chamber and major faults (Singh et al. 2006). We have used these geophysical constraints as input for two-dimensional hydrothermal flow models. The key objectives of these simulations are to explore fluid circulation pathways, constrain the importance of faults for hydrothermal flow, and predict vent locations and temperatures.
To achieve these goals, we have developed a high performance hydrothermal convection model based on the Finite Element Method (FEM). The model accounts for Darcy-type flow and heat transfer. Fluid properties (viscosity, specific heat, and density) are read-in from thermodynamically computed tables. The volume changes and latent heats of boiling and condensation are accounted for and body-fitting meshes are used to accurately resolve the seismically imaged structures. To explore characteristic p-T loops and cycle times, we use a tracer advection scheme that tracks individual parcels of fluid. We find that faults have first order control on convection speeds and pathways. Faults close to the magma chamber appear to be preferential re- and discharge pathways for hydrothermal fluids, while more distant faults appear to not have a major influence on the flow pattern. Furthermore, we have explored a wide variety of scenarios with permanent and transient intrusions, differing permeabilities of the matrix and fault zones, and initial temperature fields.