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Energetics of hydrothermal convection in heterogeneous ocean crust

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Recent advances in hydrothermal flow modeling have revealed the key thermodynamic and fluid-dynamic controls on hydrothermal convection and vent temperatures at oceanic spreading centers. The observed upper limit to black smoker vent temperatures of approx. 400°C can be explained by the thermodynamic properties of water (Jupp and Schultz, 2000). Likewise, 3D models of hydrothermal flow at fast-spreading ridges show cylindrical upwellings with closely interwoven recharge flow (Coumou et al., 2008, Hasenclever et al., 2014). While these studies provide a robust theoretical basis for hydrothermal flow observations at fast-spreading ridges, the situation at slow-spreading ridges is different. The slow-spreading Mid-Atlantic Ridge produces highly heterogeneous crust along its tectonic and magmatic segments with significant permeability contrasts across structural and lithological interfaces. The sub-seafloor permeability structure has a strong control on vent field location such that off-axis hydrothermal systems are apparently consistently located at outcropping fault zones. We have recently shown that preferential flow along high-permeability conduits inevitably leads to the entrainment of cold ambient seawater (Andersen et al., 2014), which causes a temperature drop that is difficult to reconcile with fault-related high-temperature venting. A fundamental question is therefore how hydrothermal fluids can maintain their high temperature while flowing kilometers from a driving heat source through highly heterogeneous crust to a vent site at the seafloor? We address this question by exploring the energetics of hydrothermal convection in heterogeneous ocean crust using 2D and 3D flow simulations. In our analysis we focus on the energy balance of rising hydrothermal plumes and on mixing processes at permeability boundaries, with the aim to establish a more robust theoretical framework for hydrothermal flow through highly heterogeneous seafloor.