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The influence of isotropic and anisotropic crustal permeability on hydrothermal flow at fast spreading ridges

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We use 3-D numerical models of hydrothermal fluid flow to assess the magnitude and spatial distribution of hydrothermal mass and energy fluxes within the upper and lower oceanic crust. A better understanding of the hydrothermal flow pattern (e.g. predominantly on-axis above the axial melt lens vs. predominantly off-axis and ridge-perpendicular over the entire crustal thickness) is essential for quantifying the volume of oceanic crust exposed to high-temperature fluid flow and the associated leaching and redistribution of economically interesting metals.

The initial setup of all 3-D models is based on our previous 2-D studies (Theissen-Krah et al., 2011), in which we have coupled numerical models for crustal accretion and hydrothermal fluid flow. One result of these 2-D calculations is a crustal permeability field that leads to a thermal structure in the crust that matches seismic tomography data at the East Pacific Rise. Our reference 3-D model for hydrothermal flow at fast-spreading ridges predicts the existence of a hybrid hydrothermal system (Hasenclever et al., 2014) with two interacting flow components that are controlled by different physical mechanisms. Shallow on-axis flow structures develop owing to the thermodynamic properties of water, whereas deeper off-axis flow is strongly shaped by crustal permeability, particularly the brittle–ductile transition. About $\sim$60% of the discharging fluid mass is replenished on-axis by warm (up to 300^{o}C) recharge flow surrounding the hot thermal plumes. The remaining $\sim$40%, however, occurs as colder and broader recharge up to several kilometres away from the ridge axis that feeds hot (500–700^{o}C) deep off-axis flow in the lower crust towards the ridge. Both flow components merge above the melt lens to feed ridge-centred vent sites.

In a suite of 3-D model calculations we vary the isotropic crustal permeability to quantify its influence on on-axis vs. off-axis hydrothermal fluxes as well as on along-axis hydrothermal activity. We also explore the effect of anisotropic permeability that is likely to be a feature of the diking region above the melt lens where the repeated emplacement of meter-size dikes should lead to higher permeability in vertical and along-ridge direction and to lower permeability across the ridge. We further study the effect of along-ridge depth-variations of the axial melt lens on the distribution of hydrothermal vent sites.