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Numerical 3D models support two distinct hydrothermal circulation systems at fast spreading ridges

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We present 3D numerical calculations of hydrothermal fluid flow at fast spreading ridges. The setup of the 3D models is based our previous 2D studies, in which we have coupled numerical models for crustal accretion and hydrothermal fluid flow. One result of these calculations is a crustal permeability field that leads to a thermal structure in the crust that matches seismic tomography data of the East Pacific Rise (EPR). The 1000°C isotherm obtained from the 2D results is now used as the lower boundary of the 3D model domain, while the upper boundary is a smoothed bathymetry of the EPR. The same permeability field as in the 2D models is used, with the highest permeability at the ridge axis and a decrease with both depth and distance to the ridge. Permeability is also reduced linearly between 600 and 1000°C. Using a newly developed parallel finite element code written in Matlab that solves for thermal evolution, fluid pressure and Darcy flow, we simulate the flow patterns of hydrothermal circulation in a segment of 5000m along-axis, 10000m across-axis and up to 5000m depth.

We observe two distinct hydrothermal circulation systems: An on-axis system forming a series of vents with a spacing ranging from 100 to 500m that is recharged by nearby (100-200m) downflows on both sides of the ridge axis. Simultaneously a second system with much broader extensions both laterally and vertically exists off-axis. It is recharged by fluids intruding between 1500m to 5000m off-axis and sampling both upper and lower crust. These fluids are channeled in the deepest and hottest regions with high permeability and migrate up-slope following the 600°C isotherm until reaching the edge of the melt lens. Depending on the width of the melt lens these off-axis fluids either merge with the on-axis hydrothermal system or form separate vents. We observe separate off-axis vent fields if the magma lens half-width exceeds 1000m and confluence of both systems for half-widths smaller than 500m. For half-widths in-between these numbers both systems interact periodically with each other.

The potential coexistence of two hydrothermal circulations at fast spreading ridges is of importance for the interpretation of chemical signatures of hydrothermal vents and the quantification of the mass and energy exchange between ocean and solid Earth: (1) An extended off-axis system will expose a much larger volume of the crust to high-temperature hydrothermal alteration. Especially the lower crust (below the level of the melt lens) would also be exposed to hydrothermal fluid flow. (2) The off-axis vents may therefore have a different chemical signature as they sample the lower crust whereas their on-axis counterparts only sample the upper crust. This distinct signature may, however, be lost when both systems merge and mix before discharging. (3) The residence time of the off-axis fluids in the crust is much longer compared to that of the on-axis fluids. (4) The off-axis hydrothermal system may lead to additional ore deposits at some distance (1-2km) to the ridge axis, where one may not expect them to be.