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Hydrothermal and magmatic couplings at mid-ocean ridges : controls on the locations of high-temperature hydrothermal vent fields

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The heat output and thermal regime of oceanic spreading centers are strongly controlled by boundary layer processes between the hydrothermal system and the underlying crustal magma chamber, which remain to be fully understood. In thermal models, the dynamical interactions between the hydrothermal system and the deeper part of the lithosphere affected by processes such as magma chamber convection, magma crystallization and latent heat release, or simple conduction, is usually not considered and a ad-hoc temperature or heat flux is prescribed at the base of the hydrothermal layer. In this work we develop original two-dimensional numerical models of the interactions between a shallow cellular hydrothermal (porous) system at temperatures <700°C in the upper crust, and a deeper magmatic (viscous) layer at temperatures up to 1200°C representing the lower crust. Our formalism allows for a dynamical interface between the two layers, which is fluctuating according to the dynamics of each layer. We systematically investigate the range of permeability and viscosity that characterized the dynamics of the porous and magmatic systems, respectively. An intriguing and highly debated question that we investigate is about the genesis of focused (i.e. kilometer-wide), hundreds-of-mega-watt (MW) powerfull, high-temperature (300-400°C) hydrothermal fields such as those discovered along the East Pacific Rise at 9°50'N or along the Juan de Fuca ridge/Endeavour segment for example. One hypothesis is that these fields require the formation of "elongated" hydrothermal convection cells that cool the crust on 5-10 kms, but the processes controlling the formation of such large aspect ratio (length/height) are poorly constrain. Our models show that such cells naturally arise from the dynamical coupling between a « low-viscosity », convecting lower-crust and a low-permeability upper hydrothermal layer. They also predict along-axis variations in the depth of the axial magma lens (AMC) seismic reflector of fast- and intermediate-spreading axes, and constrain lower oceanic crust cooling rates. They also suggest a dynamic link between upper oceanic crust along-axis permeability variations and stresses due to lower crust magmatic flow. We discuss the likelihood of this range of viscosity and permeability using available oceanic and ophiolites constraints and suggest that our work can motivate and help design future deep-sea experiments (e.g., drilling…).