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Submarine Hydrothermal Systems: Insights from 3D and Multiphase Simulations

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In this talk we present some new insights into black smoker hydrothermal systems using a state-of-the-art finite element-finite volume fluid flow simulator, recently developed in our group at ETH.

First of all, we present fully-transient multi-phase simulations of mid-ocean ridge hydrothermal systems that include the full complexity of the H_2O-NaCl phase diagram. A series of 2D simulations were performed to study the influence of permeability and ocean depth on flow patterns and spatial and transient evolution of venting fluids.

Although geometrically simple, our simulations accurately predict the range of salinities observed in natural systems. In addition, they reveal new dynamical features of the denser brine phase.

In low-pressure systems at
sim1500m water-depth, phase-separation occurs in boiling zones stretching from the bottom of the hydrothermal cell to the seafloor. Low-salinity vapors and high-salinity brines can vent simultaneously, and transient variations in vent-fluid salinities can be rapid. In high-pressure systems at roughly
sim3500m water-depth, phase-separation occurs by brine condensation and is limited to the region close to the underlying magma chamber. Vent fluids consist of a low-salinity vapor mixed with a seawater-like fluid. Therefore, vent salinities from these systems are much more uniform in time and always below seawater salinity as long as phase-separation occurs in the subseafloor. Only by shutting down the heat source can, in the high pressure case, the brine be mined, resulting in larger than seawater salinities. These results are in good agreement with long-term observations from shallow and deep natural systems. Our results show that whether phase-separation occurs by boiling or by condensation is a first-order control on vent-fluid salinity, and especially its variation in space and time.

Next to these 2D simulations, we present results from 3D simulations, which became computationally feasible by parallelizing the code. In 3D, convection self-organizes into pipe-like upflow surrounded by narrow and relatively warm downflow zones. We show that this configuration optimizes the heat output of the system. In this talk, we will present new results from simulations using different geologic structures, including a high-permeability axial plane, a highly permeable basaltic layer and mid-ocean ridge normal faults.