Numerical simulations of hydrothermal circulation: the effect of the bottom slope on upwelling water salinity

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1. Introduction

The seafloor hydrothermal system is the hot spring associated with ocean ridge volcanism. In mid-ocean ridge hydrothermal circulation, seawater enters the oceanic crust through cracks and cools magma chambers under ridges. Hydrothermal systems contribute considerably to heat transport at ridge areas.

The NaCl concentrations of hydrothermal fluids are diverse, and can be both higher and lower than that of seawater (e.g. von Damm, 1995). The diversity is considered to be produced by the phase separation of seawater. The aim of this study is to explain the longevity of low-salinity vents. It cannot be explained by Kawada et al. (2004)'s model.

In this study, we numerically simulate hydrothermal circulation in a two-dimensional permeable medium, including the effect of the bottom slope of the circulation region as well as the phase separation of seawater. We expect that the inclination of the bottom will make the brine flow down along the slope, thereby contributing to diluting the upwelling fluid.

2. Model

We model the circulation beneath the ridge axis as two-dimensional permeable flow. We assume that the heat source extends horizontally continuously underneath the circulation region. We use NaCl-H_2O two-component fluid. We employ the phase diagram for 45 MPa for calculating the condition of phase separation. The shape of the calculation area is a rectangle longer in the horizontal direction with an aspect ratio of 1:2. The upper boundary of the calculation area is the seafloor, and the bottom boundary is the bottom of the permeable region. The pressure of the upper boundary is held constant, allowing the circulation fluid to recharge and discharge. The bottom of the permeable region is set to be isothermal with 800 degrees Celsius, which is within the range of the brittle-ductile transition temperature, between 600 and 800 degrees Celsius. The bottom of the permeable region slopes down in the direction from right to left. We use 8 values for the inclination of the bottom: 0 (horizontal), 1.6, 2.4, 4.8, 7.1, 9.5, 14.0, and 18.5 degrees. The side boundaries are impermeable without mass, heat, and composition fluxes.

3. Results and Discussion

The flow and salinity structures are categorized into three types, corresponding to horizontal, gentle (1-5 deg.), and steep (7-20 deg.) slopes.

For the horizontal bottom, four cells appear in the steady state. The brine accumulates to the bottom of circulation region and form a stagnant layer. The NaCl concentration of upwelling fluids is about the same as that of seawater.

For gentle slopes, a two-cell state and a three-cell state alternate periodically. The concentrated brine layer also forms at the bottom, but is not stagnant because of the bottom slope. The brine slides down the slope, and accumulate to the left, leaving a dilute fluid around the right side of the circulation region. Therefore, the salinity of the discharging fluid near right side becomes lower than that of seawater, and that near the left side becomes higher than that of seawater.

For steep slopes, a one-cell state and a two-cell state alternate periodically. Upwelling flow forms only at the right side (above the top of the slope) for the one-cell state. The NaCl concentration of the fluid is lower than that of seawater because concentrated fluids slip along bottom slope, leaving a dilute fluid above of the slope.

To summarize, we show that the NaCl concentrations of hydrothermal fluids are influenced significantly by the inclination of the bottom plane of the circulation region.