

Numerical simulation of submarine hydrothermal ore-deposits due to a coupled process of fluid migration and reactive geochemical transport

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Submarine hydrothermal ore-deposits are known to be rich in metal resources and are to be found abundant around the Japanese islands. In recent years, several studies (mostly field surveys) had been carried out and a lot of data on chemical, physical and biological properties of compounds have been gathered especially for hydrothermal fields in the Okinawa Trough. However, the mechanism of formation (hydrothermal fluid flow in combination with geochemical reaction) of these deposits is not yet clearly understood.

Hydrothermal ore-deposits are formed by precipitation of metal elements from hydrothermal fluid due to rapid cooling around the seafloor where the fluid discharges. Contrary to the hydrothermal systems in the mid-ocean ridges, hydrothermal systems in the Okinawa Trough has a fluid discharge region at the seafloor in sediment-rich environment. The sediment is often composed of two components; one is hemipelagic sediment possibly transported from the continental margin and the other is volcanoclastic sediment derived from felsic volcanism in the vicinity. Because these two components have quite different permeability, it is expected complicated fluid migration within the discharge region.

In this study, we investigated the above process using a numerical code TOUGHREACT V3.0 –OMP, which is for coupled non-isothermal multiphase fluid flow and geochemical reactive transport. A 2-dimensional radial model with the radius of 5 km and a depth of 1 km below the seafloor was chosen to represent a sufficient area of the discharge region around the hydrothermal vent. The center of the radial model represented a fluid conduit (10 cm diameter) where the venting hydrothermal fluid of 300 °C ascends from basal to the seafloor, with a flow rate of ~1000 t/day. Almost all model parameters are chosen based on available results of geophysical survey of the Iheya hydrothermal fields in the Okinawa Trough¹⁾. The geological structures were set as having diverse permeability from $1 \times 10^{-10} \text{ m}^2$ to $1 \times 10^{-16} \text{ m}^2$, which reflects alternating pumiceous volcanoclastics layer and hemipelagic sediment layer. The initial thermal gradient was set to 4.8 °C/100 m. The top boundary (seafloor) was set to constant pressure condition (20 MPa) and a basal heat flux was also imposed at the bottom ($5.6 \times 10^6 \text{ W/m}^2$), assuming a pumice thermal conductivity of 0.96 W-m/°C.

The geochemical setting included initial concentrations of primary species, as, for instance, Na^+ , SO_4^{-2} , H_4SiO_4 , Ca^{+2} , S^{-2} , Zn^{+2} , HCO_3^- or NH_3 for seawater and hydrothermal fluid separately. Chemical reaction including precipitation of minerals) caused by mixing of the both fluids and cooling was considered in this setting. In order to simulate accumulation of mineral precipitations to form hydrothermal deposits over a long-time duration (an order of thousands of years), the numerical simulation was conducted for 10000 years.

As a result, the following features were clarified: First, high velocity venting hydrothermal fluid ascends to the seafloor through the fluid conduit at the center of the model, whereas nearby cold water percolates downward from the seafloor and convection occurs. Second, among the alternating layer structure, preferential horizontal flow is obvious for layers with high permeability, which resulted in primary sulfide precipitation with a lateral extend.

These results are likely to be consistent to recent field studies during scientific drilling into the submarine

hydrothermal fields in the Okinawa Trough, Japan.

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1)Tsuji, T., Takai, K., Oiwane, H., Nakamura, Y., Masaki, Y., Kumagai, H., ... Kuramoto, S. (2012).

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