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Supporting Information for

Numerical simulation-based clarification of a fluid-flow system in a seafloor hydrothermal vent area in the middle Okinawa Trough

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Introduction

Text S1 describes literature data of rock permeabilities.

Text S2 describes heat balance for the setting of discharge rate of hydrothermal fluid in the simulation.

Text S3 describes the sensitivity analysis for confirming the suitability of the geologic structure model.

Text S1.

The setting of permeability to 10^{-14} m^2 for the volcanic basement was based on several previous studies (e.g., Fehn & Cathles, 1979; Fisher et al., 1994; Coumou et al., 2008), and that of 10^{-17} m^2 for the caprock was based on several references (Bear, 1972; Magri et al., 2010; Raharjo et al., 2016). Because the cracks and fractures in the rocks are mostly vertical, the vertical permeability of the conduit (10^{-12} m^2) (e.g., Yang et al., 1996; Gruen et al., 2014) was set as one order of magnitude larger than the horizontal permeability (10^{-13} m^2). Because the drilling surveys revealed multiple impermeable layers in the sediments (Takai et al., 2011), the horizontal permeability (10^{-14} m^2) of the sediment was set as two orders of magnitude larger than the vertical permeability (5.0×10^{-16} m^2), after Freeze & Cherry (1979).

Text S2.

Because the heat balance is indispensable to include in the simulation, the amount of heat flow associated with convection in the study area was estimated as follows. Heat flow was divided into two components: one caused by high-temperature venting and another caused by lower-temperature diffuse flow (Elderfield & Schultz, 1996). The orifice area of the vent and the flow velocity and temperature of venting fluids are necessary for estimating the former heat flow. The orifice area of the NBC was observed as 12 cm^2 with a radius of about 2 cm according to a seafloor survey (Kawagucci et al., 2011). The flow velocity was estimated as 1 m/s by a seafloor observation, which is equivalent to the reported velocities at other hydrothermal vents (Schultz & Elderfield, 1999; Kawagucci et al., 2011). The temperature of venting fluids was observed as 311°C (Takai & Nakamura, 2010). Using those values, the former heat flow through the NBC vent was calculated as 1 MW, following the method of Converse et al. (1984). Total heat flow of 5 MW was derived by applying the same method and the orifice area of the NBC to the other eight vents identified in the study area. The flow rates of the eight vents were set to be lower, 0.6 m/s, based on the observations that the NBC had the highest flow rate and that the flow velocities at other submarine hydrothermal systems ranged from 0.6 to 3 m/s (Converse et al., 1984; LaFlamme et al., 1989).

The latter heat flow is one order of magnitude greater than the heat flow caused by high-temperature venting (Rona & Trivett, 1992; Elderfield & Schultz, 1996), and may be greater than the former heat flow by a factor of 5 or more, as observed in the Endeavor hydrothermal area at the Juan de Fuca Ridge (Schultz et al., 1992) and its ASHES vent field where the total heat flow associated with high-temperature venting was 4.4 ± 2 MW, versus the diffuse heat flow of 15–75 MW (Rona & Trivett, 1992). Based on those observations and through trial and errors, we set the diffuse heat flow to be eight times larger than the heat flow caused by high-temperature venting.

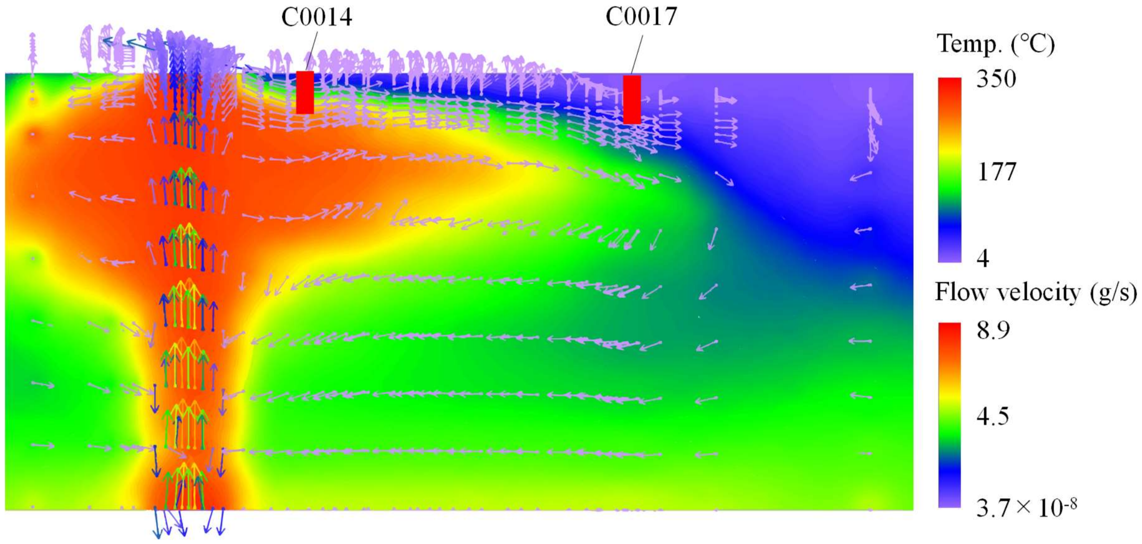
Text S3.

The suitability of the constructed geologic structure model was checked by the following sensitivity analysis. The first check was the importance of the conduit setting. Deleting the conduit from the model greatly decreased the ascending velocity of hydrothermal fluids as well as the supply amount of hydrothermal fluids to the discharge zone. In addition, lateral flows did not occur (Figure S2a). As the result, both the heat flux and temperature became much lower than the measured ones (Figures S2b and c).

The second check was the importance of the caprock setting. Deleting the caprock from the model induced deep infiltration of the seawater (Figure S3a), and consequently caused a significant temperature drop and excessive underestimation of the heat flux and temperature (Figures S3b and c), without an occurrence of boiling. Most hydrothermal fluids flowed out from the discharge zone and the surrounding seafloor, and the occurrence of lateral flow was limited.

These results demonstrate the suitability of the constructed geologic structure model and the essential roles of the conduit and caprock for controlling the fluid flow pattern.

73 **Figure S1.**



74 **Figure S1**. Vertical cross-section of simulation result of the model shown in Figure 3a with the
75 distributions of temperature and fluid flow vectors. The thick red lines denote the seafloor
76 drillings.

Figure S2.

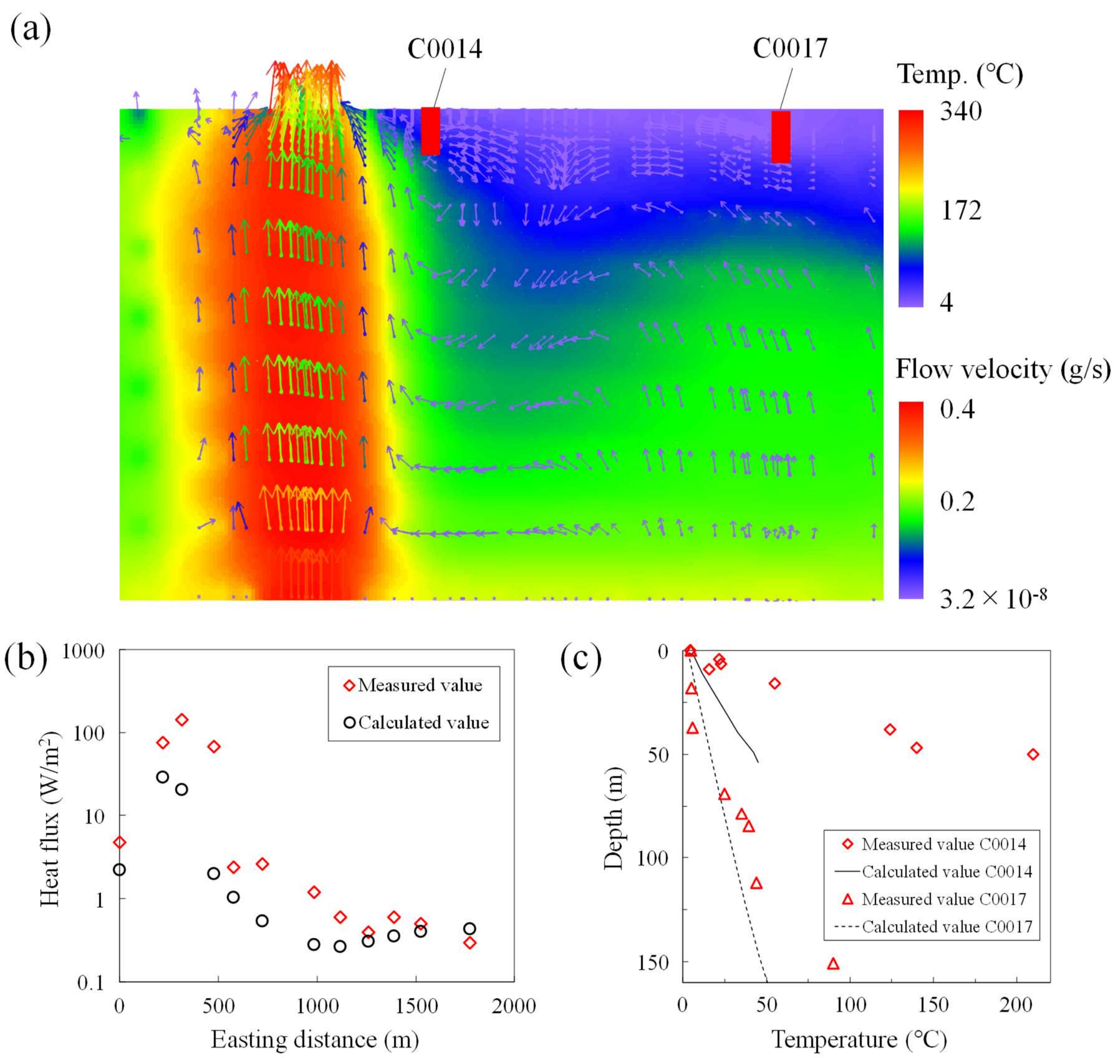


Figure S2. Simulation results of a model without the conduit setting. (a) Distributions of temperature and fluid flow vectors shown in a form of a cross-section same as that in Figure 3a. The thick red lines denote the seafloor drillings. (b) Comparison of calculated heat fluxes with the measured data. The location of the profile in Figure S2b is the same as that in Figure 3b. (c) Comparison of calculated temperatures with the measured data at Sites C0014 and C0017.

Figure S3.

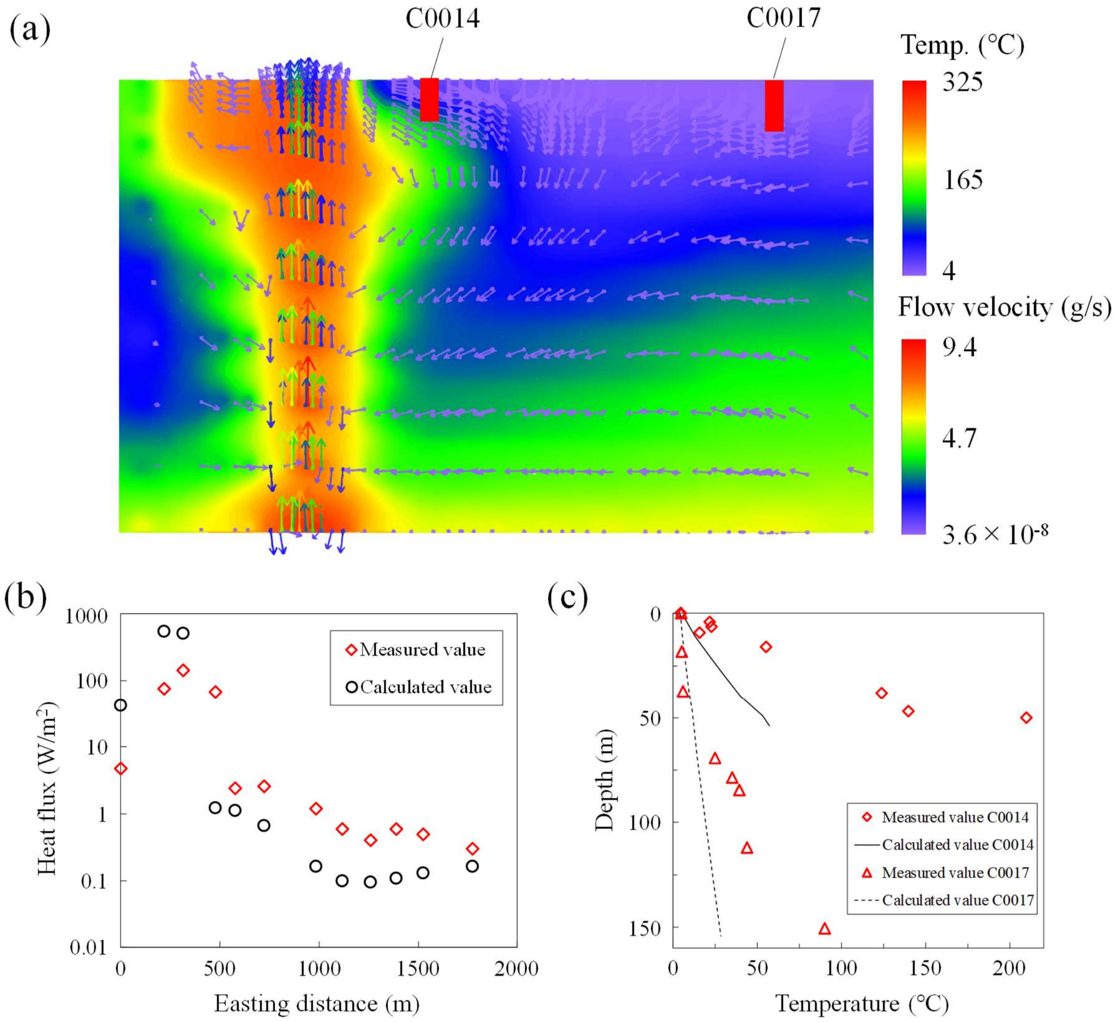


Figure S3. Simulation results of a model without the caprock setting. (a) Distributions of temperature and fluid flow vectors shown in a form of a cross-section same as that in Figure 3a. The thick red lines denote the seafloor drillings. (b) Comparison of calculated heat fluxes with the measured data. The location of the profile in Figure S3b is the same as that in Figure 3b. (c) Comparison of calculated temperatures with the measured data at Sites C0014 and C0017.

Table S1. Physical property values assigned to the four geologic elements for the numerical simulation. *X*, *Y*, and *Z* denote the easting, northing, and vertical directions, respectively.

Parameters	Volcanic basement	Caprock	Conduit	Sediment
Permeability (m^2)	1.0×10^{-14}	1.0×10^{-17}	X, Y: 1.0×10^{-13} Z: 1.0×10^{-12}	X, Y: 1.0×10^{-14} Z: 5.0×10^{-16}
Density (kg/m^3)	2800	2750	2750	2750
Porosity	0.4	0.01	0.6	0.3
Thermal Conductivity (W/(m·K))	2.0	2.0	2.0	2.0
Specific Heat (J/(kg·K))	1000	1000	1000	1000