Numerical Models Generate Transient (Periodic) Hydrothermal Discharge Through a Seamount

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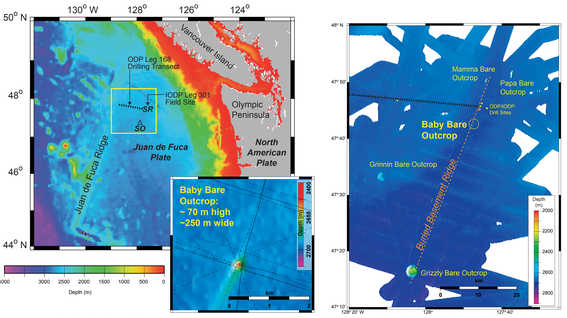
ABSTRACT

We use two-dimensional, finite-element models of coupled heat and fluid flow to investigate heat and fluid transport around and through a small seamount on a young ridge flank (Hutnak et al., 2006). The system geometry and properties are based on observations and measurements on 3.5 Ma seafloor east of the Juan de Fuca Ridge, where hydrothermal discharge exits the oceanic crust through Baby Bare outcrop, an inactive volcanic edifice. We generate radially-symmetric models of Baby Bare outcrop and the surrounding seafloor, and force fluid flow towards the outcrop at rates consistent with observations (5-50 L/s). In many of these models in which the basement permeability is at least 10-13 m2 (consistent with borehole observations and earlier modeling studies), convection within basement is unstable and periodic, resulting in highly variable exit temperatures and fluid and heat fluxes.

Transient flow develops in these simulations although boundary conditions remains constant, as convective rolls migrate towards the basement edifice. The fluid volumetric flux (volume/area/time) through the top of the outcrop varies by tens of meters/year whereas fluid exit temperatures vary by tens of degrees, with frequencies of hundreds to tens of thousands of years. Mixed convection requires sufficient thickness in the basement aquifer (several hundred meters) and a bulk permeability that is neither too high nor too low. When basement permeability is too low, convection is suppressed and models include only lateral circulation and discharge through the outcrop. When basement permeability is too high, local convection is so vigorous that temperatures within the basement aquifer and outcrop become nearly homogeneous, and discharge becomes more steady and isothermal. These results suggest that researchers should look for evidence of transient hydrothermal processes within hydrothermal circulation systems on ridge-tflank seamounts.

1. Introduction & Observations



ydrothermal circulation of seawater through the oceanic crust profoundly influences lithospheric and oceanic olution, and is one of the major modes of transporting solutes and heat between the solid earth and overlying ocean.

ppermost oceanic basement is typically fractured and permeable, and forms a global-scale aquifer for the circulation nutrient-rich fluid, within which fluid circulation continues for tens of millions of years.

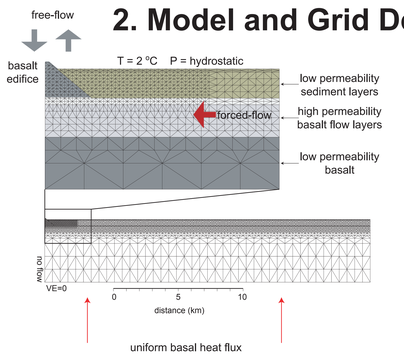
dge flank hydrothermal circulation is driven by heating from below. The driving forces are modest (tens to ndreds of kPa), limited mainly to pressure differences between columns of cold (recharging) and warm ischarging) fluids.

apid exchange of fluids between the permeable crustal aquifer and overlying ocean can only occur where seamounts other basement outcrops penetrate through low-permeability ridge-flank sediments.

bservational data consist of swathmap, seismic, heat flow, coring, and chemical data from the E. Flank of the JFR.

he seafloor is regionally flat (sediment thickness averages 400-600 m), except where it is punctuated by several ssaltic outcrops. Baby, Mama, and Papa Bare outcrops are known sites of hydrothermal discharge. Baby Bare tcrop is the best-studied of the three and discharges fluid at 5-20 L/s. Grizzly Bare outcrop is thought to be a site of drothermal fluid recharge, some of which may transit 52 km NNE to Baby Bare outcrop where it is discharged.

2. Model and Grid Design



The model domain is 21 km wide (radial diameter of 42 km), 6 km tall, and has one edifice. Grid spacing is variable (500-20 m), with the finest spacing in the vicinity of the outcrop.

Boundary conditions consist of no-flow lower and lateral sides, free-flow seafloor held at 2 deg C and hydrostatic pressure, uniform basal heat flux.

Low permeability sediment layers pinch-out along the edge of the edifice and cap high-permeability basalt layers, which host lateral fluid flow. These overlie low permeabilty basalt, through which heat is transported purely by conduction.

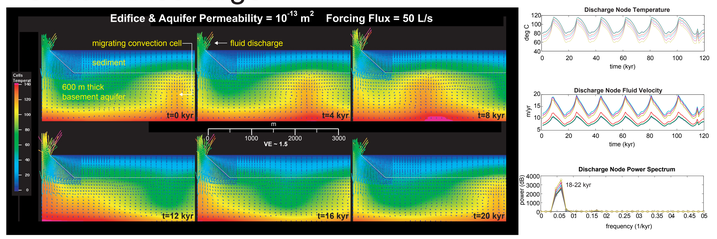
Coupled heat and fluid transport is simulated using a transient, finite-element heat- and mass-transfer code (FEHM) developed at Los Alamos National Laboratory.

Fluid is forced into the far-field model domain at rates consistent with observations (5-50 L/s), and allowed to convect freely in permeable basement.

We vary aquifer permeability, aquifer thickness, and forced flow rate, and examine the influence of these parameters on flow layer temperature, convection cell geometry, and discharge temperature and fluid flow rate.

3. Selected Model Results

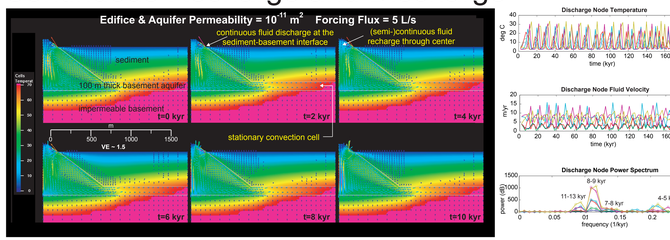
Periodic Discharge



Fluid is forced toward the outcrop at a rate of 50 L/s into the upper 600 m of permeable basement at the far-field domain boundary.

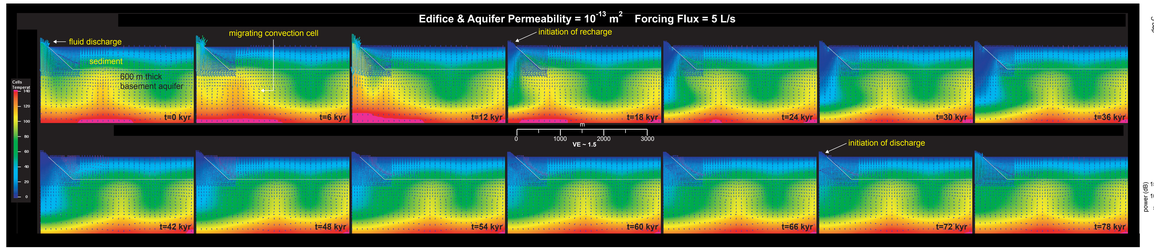
Non-stationary convection cells with a periodicity of 18-22 Ma are formed within the basement aquifer and migrate toward the edifice, resulting in discharge temperature and velocity fluctuations of ~ 50 oC and up to 8 m/yr, respectively.

Continuous Recharge and Discharge



Fluid is forced toward the outcrop at a rate of 5 L/s into the upper 100 m of basement having a permeability of 10-11 m2.
Stationary convection cells are formed within the basement aquifer that redistribute heat locally.
Fluid discharge is highly periodic with frequencies of 4-13 kyr. This rapid recharge and discharge cycle results in short rest times for recharging fluid, resulting in lower discharge temperatures.
Continuous discharge occurrs along the sediment-basement interface, but because model output is only every 2 kyr, it's unc recharge is completely continous or semi-continous.

Periodic Discharge and Recharge



4. Conclusions and Relevance to Seamount Biogeoscience

These numerical results suggest that hydrothermal circulation through seamounts may be highly transient.

Some simulations included variations in volumetric fluid flux of tens of m/yr, and variations in exit fluid temperature of tens of degrees with frequencies of hundreds to tens of thousands of years.

Some simulations also included changes in flow direction, with the basement edifice recharging and discharging fluid at different times, and others included recharge and discharge simultaneously through different parts of the outcrop.

Understanding the processes by which transient flow processes within seamounts may occur is important for interpreting observations of vent fluid chemistry, temperature, and microbial content and activity.

Acknowledgements and references