# 2D simulations of hydrothermal convection at the Lucky Strike vent field, Mid-Atlantic Ridge


N. Bani Hassan and L.H. Rüpke

IFM-GEOMAR, Kiel, Germany (nbanihassan@ifm-geomar.de, +49 (0)431 600-2843)


## 1. Introduction

The genesis of oceanic crust is closely linked to hydrothermal venting. Magmatic intrusions provide the heat that drives hydrothermal convection, while seawater circulation efficiently mines heat from the young ocean floor. At slow spreading ridges, like the Mid-Atlantic Ridge, crust is formed by a combination of magmatic and tectonic processes and an axial magma chamber may not be stable at all times. In addition, major deep-cutting faults may provide high permeability pathways for hydrothermal fluids.

The objective of this study is to constrain the importance of faults for hydrothermal convection at the Lucky Strike vent field at the Mid-Atlantic Ridge.

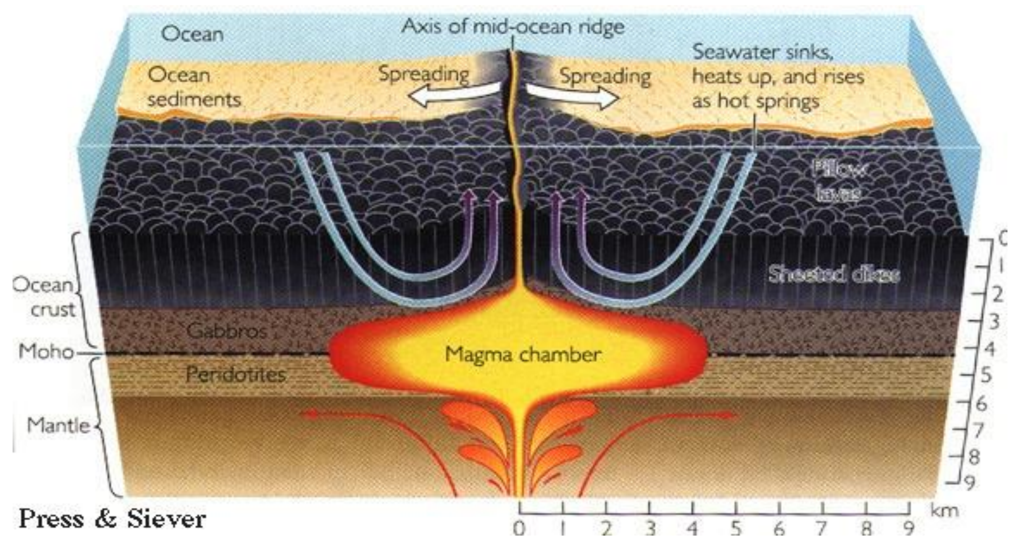


Figure 1: A schematic model of a hydrothermal field at Mid-OceanRidge.

Figure 1 shows a schematic model of hydrothermal convection. In this figure, there is an Axial Magma Chamber (AMC) and some bounding faults leading seawater into the earth. From theoretical point of view, seawater goes down from recharge zones in the sides of ridge and discharge zone would be in the axis of ridge above the AMC and this is potentially the location of vent fields.

## 2. Method

How do faults affect hydrothermal convection? To answer this question, we have developed a 2D hydrothermal convection model (Eq. 1) that is based on Darcy flow (Eq. 2). The equations are solved using a finite-element algorithm that is described in chart 1.

Diffusion term — Advection term

1: $$\rho c_p \frac{\partial T}{\partial t} = \kappa \nabla^2 T - \nabla.(\rho c_p u T)$$

2: $$\begin{cases} u_x = -\frac{k}{\mu} \frac{\partial P}{\partial x} \\ u_y = -\frac{k}{\mu}\left(\frac{\partial P}{\partial y} + \rho g\right) \end{cases}$$

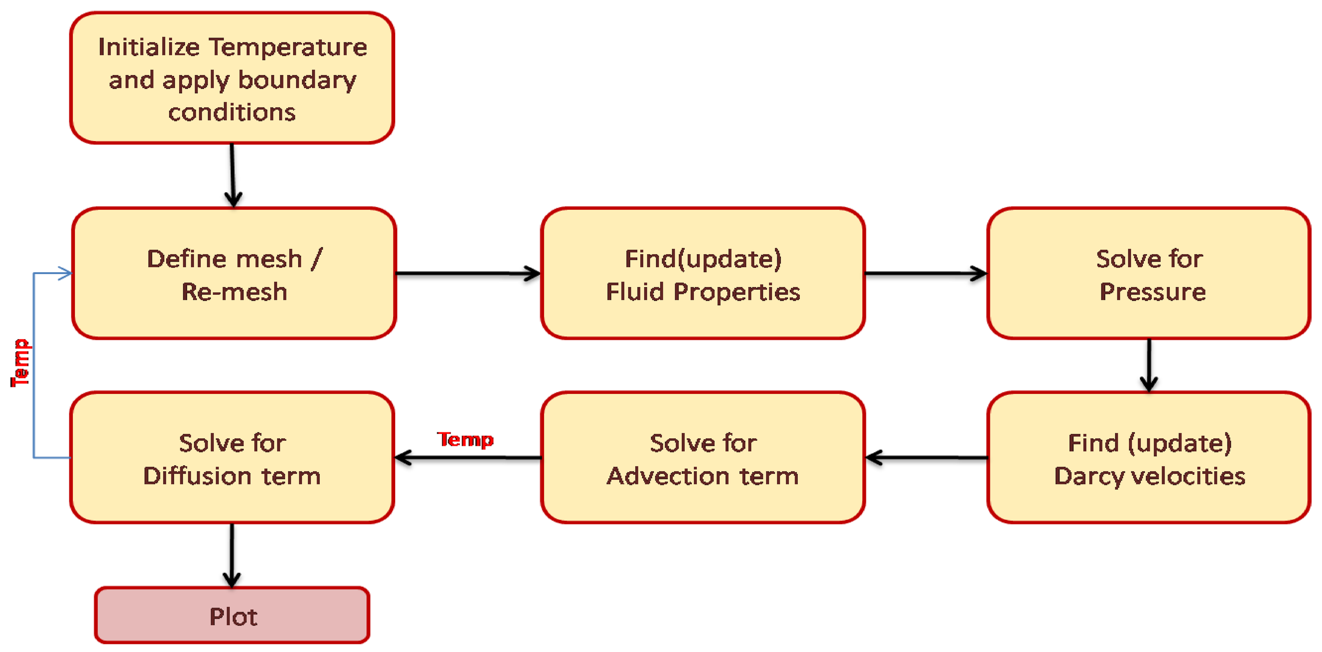


Chart 1: Algorithm for solving the governing equations. This is an iterative algorithm which updates the temperature at each time step.

Fluid properties (viscosity, specific heat, and density) are read-in from thermodynamically computed tables. The volume changes and latent heats of boiling and condensation are accounted for and body-fitting meshes are used to accurately resolve the seismically imaged structures.

## 3. Results and Discussion

To study the effects of faults on fluid pathways at the Lucky Strike vent field, we have digitized and meshed the seismic section shown in Fig. 2. The seismic data is from Singh et al. 2006 and Combier et al. 2009.

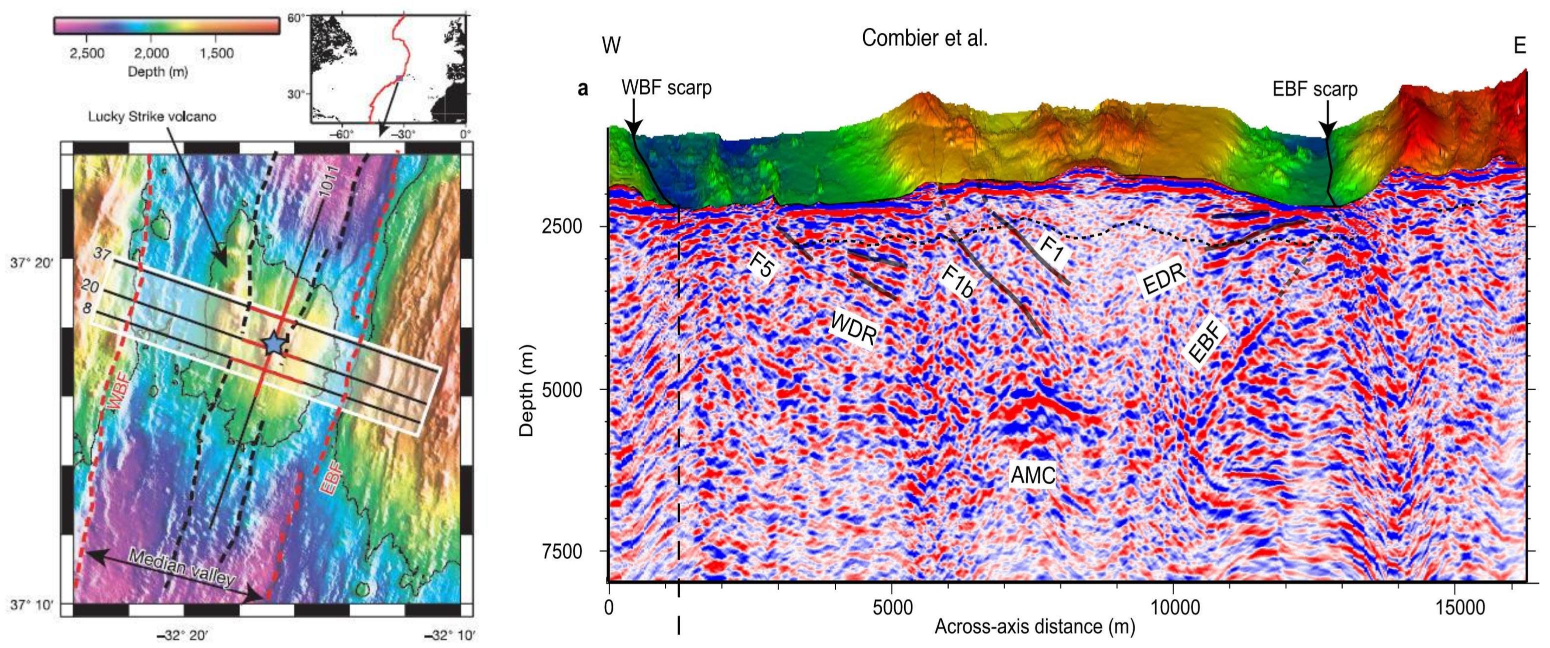


Figure 2: A 2D migrated and depth converted seismic section from Lucky Strike vent field. The vent field is located above the AMC (images from Singh et al. and Combier et al. 2009).

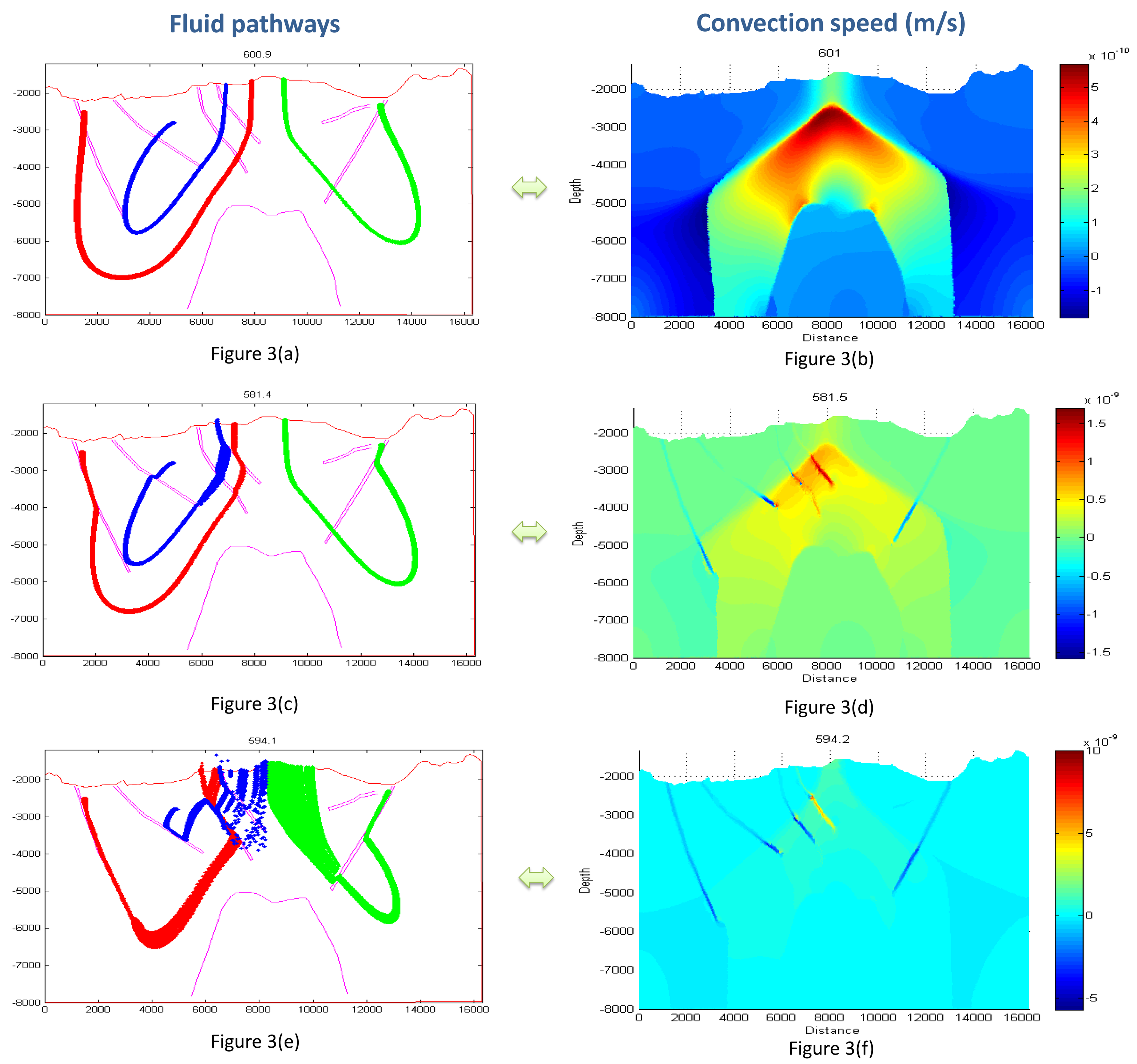


Figure 3: Effects of fault permeability on fluid pathways and convection speed. In a) and b) fault and matrix permeabilities are the same, while in c,d and e,f the fault permeabilities are 10 and 100 times the matrix permeability, respectively.

To explore characteristic p-T loops and cycle times, we used a tracer advection scheme that tracks individual parcels of fluid. Three groups of tracers are used to indicate the pathways. Each group contains 50 tracers with 2 meters interval. Green and Red groups have been located in the beginning of east and west bounding faults respectively and Blue group locates arbitrary inside the rocks. Figures 3 (a, c & d) demonstrate the pathways of tracers and (b, d & f) show convection speed. It is clear from Figure 3 that flow becomes progressively focused in the faults for increasing fault permeabilities.

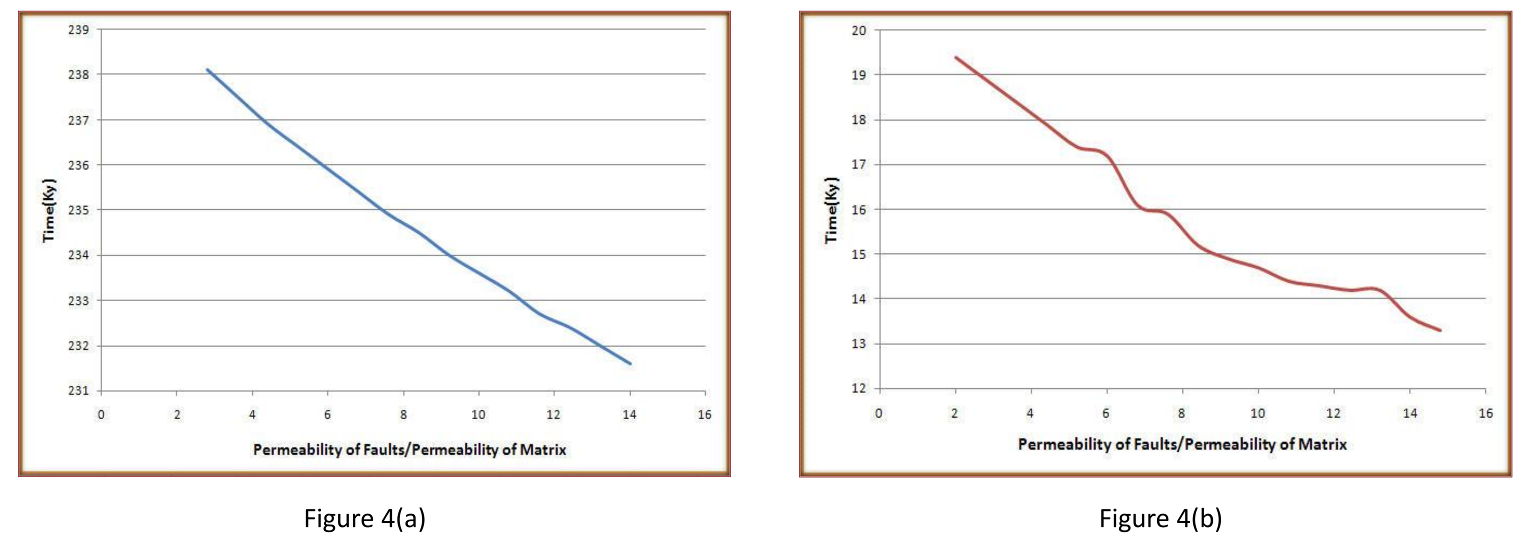


Figure 4: a) Cycle time of a group of tracers. b) Cooling time of magma chamber to 1/e intial temperature.

To further study this effect we have explored characteristic cycle times and cooling times of a magmatic intrusion. Figure 4 a) shows that the characteristic residence time of fluid parcels decreases with increasing fault permeability. Figure 4b) explores a scenario where the AMC is cooled by hydrothermal convection. Here we find that the cooling time decreases with increasing fault permeability.

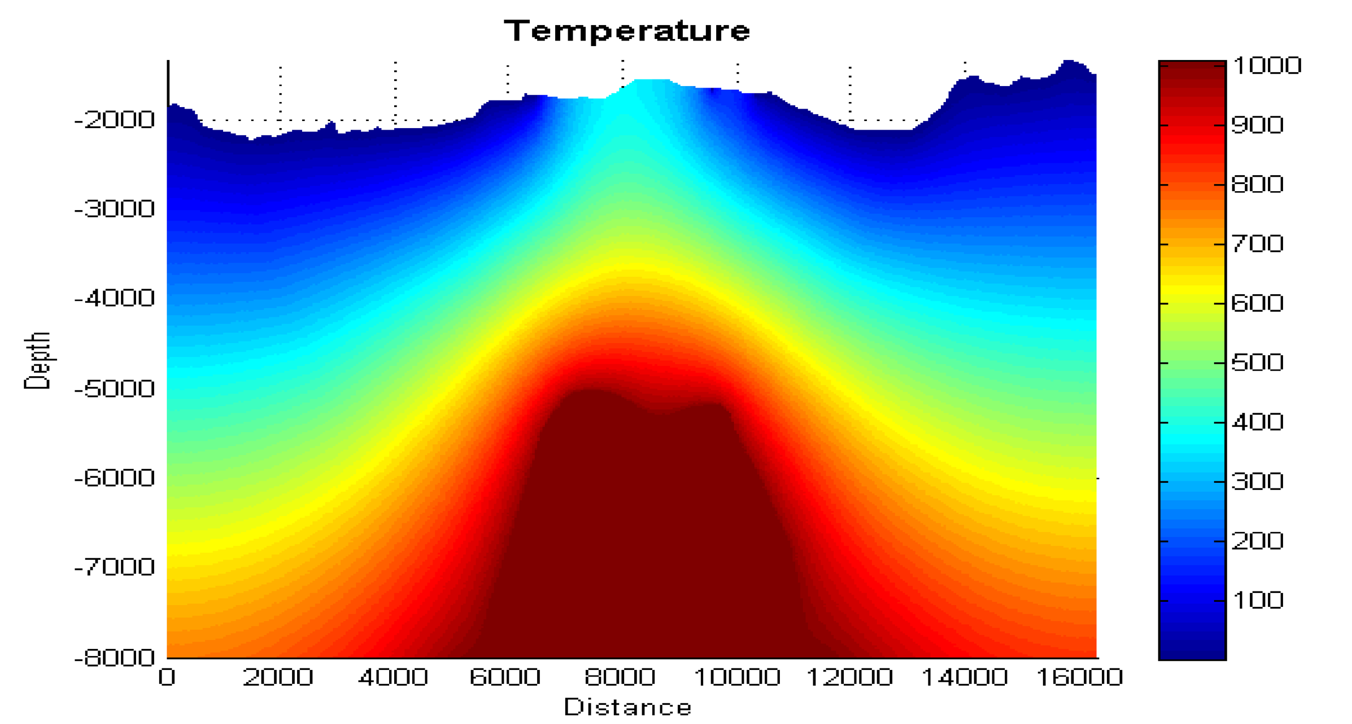


Figure 5: The distribution pattern of temperature after 594 Ky in the configuration of figure 3.

Figure 5 illustrates the steady state temperature field for a permanent AMC. Note that the high temperature vent field is directly located above the AMC.

## 4. Conclusions

- Hydrothermal convection at the Lucky Strike vent field was studied with FEM simulations.
- Deep cutting faults, imaged by reflection seismic, have the ability to focus flow.
- Residence and cooling times are both affected by variations in fault permeability.
- Faults can have strong control on flow patterns.

## 5. References


[1] Singh, S.C. et al. Discovery of magma chamber and faults beneath a Mid-Atlantic Ridge hydrothermal field. Nature, vol.442, 1029-1032 (2006)

[2] Press & Siever, Plate Tectonics. W.H. Freeman & Company (2001)