Multiphysics: Fluid Mixing and Brine Pool Formation for Economic Geology Applications

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Abstract

Significant submarine mineral deposits form when hot, metal-laden, saline fluids emerge onto the seafloor and mix with ambient seawater. Resulting density changes of fluid mixtures can trigger fluid buoyancy reversals, brine pool formation, and metal accumulation (Figure 1). While some of these processes are known from experiments, the inception, development, and physical-chemical processes operating within brine pools are poorly understood. These processes are crucial for our understanding of submarine fluid dynamics, mineral deposit formation, and exploration. Recent porous media fluid flow modeling yielded realistic submarine fluid discharge properties of such systems, i.e. temperature, discharge velocity, and salinity (Schardt, 2014). COMSOL Multiphysics® is used to integrate these results as well as field observations and theoretical studies to investigate the free mixing of ingression hot, saline hydrothermal fluids with cold seawater in a submarine depression and assess the conditions necessary to form and develop a brine pool. A 200 x 100 m solution domain, representing a seafloor depression filled with seawater (T=2C, Salinity=4.06 %, P=219 atm) is used with a narrow fluid injection site at the bottom (T=250C, V=0.1 m/s, Salinity=21 %) and a weir on the top of the right boundary to enable fluid exit. The goal is to track resulting fluid temperatures, salinity/density changes and associated fluid buoyancy reversal, and determine the conditions for brine pool formation under realistic conditions (concurrent changes in temperature, salinity/density, fluid convection patterns). Results will be compared with field data from an active brine pool (Atlantis II Deep) to gain insight into the processes controlling internal processes and trace the mineralization history of such ore-forming systems.

The initial model setup employed a physics-defined mesh, convective heat transport, solute transport of a single species (NaCl), and a turbulence (SST) fluid flow physics. Individual stationary solvers were used for heat flow and solute transport, and a time-dependent solver for fluid mixing. Initial calculations did not converge, indicating that the large scale differences of this model (cm scale fluid injection and xx m scale fluid mixing/buoyancy reversal) cannot be resolved using a turbulent flow modeling approach. Instead, a laminar fluid flow model was used and a stationary solver for both heat and solute transport; fluid flow was computed with a time-dependent solver. Initial results predict the formation of a central plume (Figure 2). At this early stage (4.8 h) the plume is still buoyant and continues to rise until it reaches neutral buoyancy; this is anticipated to occur at around 100 m.

It is expected that fluids will begin to reverse buoyancy, pond at the bottom of the depression,

and a brine pool will form with increasing salinity. The weir will eventually regulate fluid influx and further model modifications will examine internal brine layer formation, driven by convection and double diffusion.

Reference

Schardt, C. (2014) Hydrothermal fluid migration and brine pool formation in the Red Sea: The Atlantis II Deep, Mineralium Deposita (in review).

Bäcker, H. (1973) Rezente hydrothermal-sedimentäre Lagerstättenbildung, Erzmetall 26: 544-555.

Figures used in the abstract

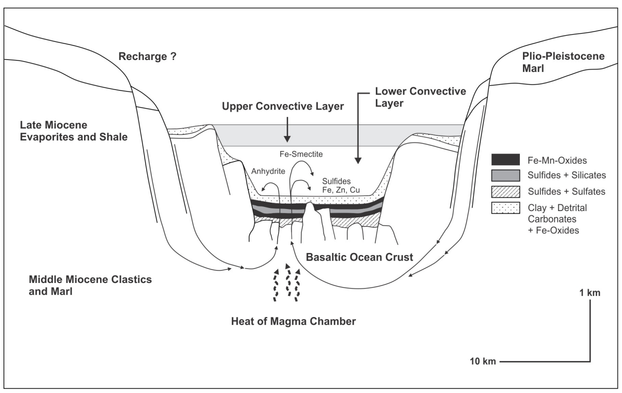

Figure 1: Schematic profile of a brine pool showing internal layers and metal accumulation (modified from Bäcker, 1973).

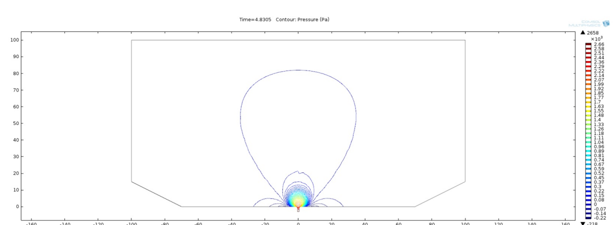

Figure 2: Initial hydrothermal plume development for laminar flow simulations. The early time step (4.8 h) shows that the plume is still rising and has yet to reach neutral buoyancy.