Developments in Seafloor Mineralization of Intraoceanic Arcs

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The application of geophysical techniques used during near-seafloor surveys conducted by autonomous underwater vehicles (AUVs) or remotely operated vehicles (ROVs) has added greatly to our understanding of seafloor hydrothermal systems. For example, magnetic surveys of the seafloor have delineated zones of magnetic “lows” that are interpreted as fluid “upflow” zones, which are typically coincident with seafloor manifestations of hydrothermal activity. In addition, these surveys have demarcated zones of magnetic lows where there is no present-day discharge of hydrothermal fluids, indicative of extinct upflow zones. Three-dimensional modeling of the magnetic lows shows they are typically cylindrical in geometry and commonly coalesce several hundred meters below the seafloor. One unexpected outcome of this geophysical technique is the ability to delineate older, buried caldera structures within volcanoes that have been masked by the growth of a resurgent cone, such as Clark volcano of the Kermadec arc, signifying the potential for older (and richer) mineralization at depth.

Recent studies of submarine arc hydrothermal systems have included hydrodynamic modeling that tackles these very complex systems in a systematic way. For example, numerical simulations for Brothers volcano (Kermadec arc) of multiphase hydrosaline fluid flow for both the northwest Caldera and the Cone sites were done to explore the flow paths of saline magmatic fluids released from a crystallizing magma body at depth, and to map their interaction with seawater circulating through the crust. Results show that when a saline, magmatic fluid was temporarily injected from the top of the cooling magma chamber into the overlying convection system, a number of hydrological phenomena in the subsurface of Brothers occurred, including phase separation, explaining some of the present-day seafloor hydrothermal manifestations and their vent temperatures. This type of modeling has important implications for the metal enrichment of seafloor systems and the origin of distinct ore types known from exposed volcanogenic massive sulfide systems on land.

Future studies will include a detailed heat flow survey of Brothers volcano to ascertain the scale and distribution of heat flux. This information is important when planning instrumentation in shallow drill holes, or even the siting of deeper drill holes via the International Ocean Discovery Program. Deep drilling would provide the missing link (i.e., the third dimension) in our understanding of mineral deposit formation along arcs and the subseafloor architecture of these volcanoes and their related permeability. Drilling would also enable characterization of the subvolcano, magma chamber-derived volatile phase to test model-based predictions that this is either a single-phase gas or two-phase brine-vapor. Penetrating the subseafloor would also allow us to investigate the distribution of base and precious metals and metalloids, as well as the reactions that have taken place along pathways to the seafloor, so that we can quantify the mechanisms and extent of fluid-rock interaction, and consequences for mass transfer of sulfur and carbon metals and metalloid species. All of the above will ensure that we can continue to refine models on the formation of seafloor massive sulfide deposits associated with arc volcanoes, thereby enabling easier prospecting for and potential exploitation of these deposits.