HYDROTHERMAL PROCESSES AT SEAFOOR SPREADING CENTERS:
APPLICATION OF BASALT-SEAWATER EXPERIMENTAL RESULTS

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ABSTRACT

Both the chemistry of seafloor hot springs and the chemical changes exhibited by basalts during alteration to greenschist facies assemblages have been accurately predicted by laboratory experiments reacting seawater with basalt. Although the experiments were run as an isothermal, closed-system, batch process, they largely succeeded in duplicating the products of the natural open-system, continuous flow process. For the solutions, this resulted mainly from rapid reaction rates at high temperature, relative to flow rates in the natural systems, so that equilibrium with the secondary mineral assemblage represented a significant control on solution composition both in the experiments and in nature. For the rocks, it resulted from a similar alteration history in which largely unreacted seawater reached greenschist facies temperatures before reacting with the basalts, and from element exchanges between rock and solution which were coupled via charge balance constraints so that the batch process in the experiments simulated the incremental process in nature.

The key concept in relating the batch process to the incremental process is the seawater/rock ratio, which because of the nature of the chemical exchanges involved can best be estimated from the uptake of seawater Mg by the altered rock. The experiments predict a systematic change in rock chemistry and mineralogy as alteration proceeds to higher seawater/rock
ratios. The prediction is borne out for the fluxes of Mg and Ca, the flux directions of Na, Si, and Mn, and the mineral abundances of chlorite, quartz, and actinolite. It is not borne out for the Fe flux, the magnitude of the Na flux, and the abundances of albite and epidote, because the experiments failed as batch processes to allow for local redistribution of elements via diffusion. This latter process is important in altered rocks from the natural systems for Fe$^{2+}$, which diffuses into zones where chlorite is forming preferentially due to influx of seawater Mg, and for Na$^+$, which accumulates as albite in zones of lesser Mg influx, in exchange for Ca.

INTRODUCTION

Chemical processes in submarine hydrothermal systems at seafloor spreading axes play an important role in alteration of the oceanic crust, in transfer of elements between the crust and the oceans, and in formation of polymetallic sulfide deposits on and within the crust. These processes are inherently difficult to study because they occur in the subsurface beneath the ocean floor and are inaccessible to direct observation and sampling, except by drilling. As no drilling has yet been done into a high-temperature, axial sub-seafloor hydrothermal system, we have only three indirect ways of studying these processes.

The first and most direct is by sampling the effluent from these systems at hydrothermal vents along the mid-ocean ridge axis. This has been accomplished at four sites to date, all in the Pacific: the Galapagos Rift at 86°W, the East Pacific Rise at 21°N and 13°N, and the Guaymas Basin in the Gulf of California (Von Damm et al., this volume). An analogous subaerial hydrothermal system has been sampled on the Reykjanes Peninsula of Iceland, both from vents and by deep drilling (Stefansson, this volume).

The second way is by sampling the solid products of subsurface hydrothermal processes: the altered basalts and gabbros (Thompson, this volume). These are accessible along fault scarps of axial valley walls and transverse fracture zones. As well-developed axial valleys are a unique feature of slow-spreading ridges, our sample collection is heavily biased toward these ridges, particularly the Mid-Atlantic Ridge. An equally significant bias may result from the processes which uplift and expose hydrothermally altered rocks, especially the mettagabbros, along axial valley walls. These walls typically consist of a series of steep fault zones separated by