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Isotopic and element exchange during serpentinization and metasomatism at the Atlantis Massif: Insights from B and Sr isotope data

C. Boschi (1,2), A. Dini (1), G. L. Früh-Green (2) and D. S. Kelley (3)

(1) Istituto di Geoscienze e Georisosorse, CNR, Pisa, Italy (2) Department of Earth Sciences, ETH-Zurich, CH-8092, Zürich, Switzerland (3) University of Washington, Seattle, WA (c.boschi@igg.cnr.it / Phone: +39-050-3152315)

The Atlantis Massif is an inside-corner high at 30˚N on the Mid-Atlantic Ridge and is considered to be a typical example of an oceanic core complex exposed by a major detachment fault system. The southern wall of this relatively young (1.5 My) massif consists of serpentinites with lesser gabbroic and pyroxenitic lenses and hosts the Lost City Hydrothermal field. The low-angle detachment shear zone, localized along the crest of the massif, cuts the serpentinized ultramafic complex and is marked by variably deformed talc and amphibole-rich fault rocks.

Here we present B, O, H, and Sr data that constrain the conditions of fluid/rock interaction and mass transport during a long-lived history of detachment faulting and exhumation of lithospheric sequences within the Atlantis Massif. Our data provide new insights into the integrated history of hydrothermal activity and define the close linkages between tectonic processes, variations in fluid flux, and changes in the chemical-isotopic signatures of fluids in this peridotite-hosted hydrothermal system.

Geochemical and isotopic data (B, O, H, and Sr) of serpentinites indicate that extensive serpentinization was a seawater-dominated process, that occurred predominately at temperature of 150-250˚C. High integrated W/R ratios led to a marked boron enrichment (34-91 ppm). Boron removal from seawater during serpentinization is positively correlated with the δ^{11}B record (11-16 ‰); B concentrations and isotope values are controlled by transient pH-T conditions. In contrast to prior studies, we conclude that low temperature marine weathering processes are insignificant for boron geochemistry of the Atlantis Massif serpentinites.

Talc- and amphibole-rich fault rocks formed within the zone of detachment faulting at temperature around ~300-400˚C and at low W/R ratios. Alteration was controlled by the access of Si-rich fluids derived through seawater-gabbro interactions. Replacement of serpentine by talc produced strong boron depletion and significant lowering of δ^{11}B values (9-10 ‰), which we model as the product of progressive extraction of boron. The interplay between 1) an internal fluid resulting from dehydration of serpentine to talc, and 2) a dominant external Si-rich fluid isotopically equilibrated with gabbroic rocks, resulted in the observed variable isotopic and geochemical signature of the fault rocks. Boron isotope investigations of the Atlantis Massif rocks provide new constraints on the boron geochemical cycle at oceanic spreading ridges and they may have important implications for the behaviour of boron in subduction zone settings.

Finally, our study highlights chemical and physical variations of hydrothermal circulation through time and space at the Atlantis Massif. Serpentinite formation is characterized by pervasive fluid flow under seawater-dominated conditions, while talc-amphibole metasomatic alteration is driven by localized flow of fluids with chemistries affected by interaction with gabbroic intrusions. In concert, these relationships emphasize the complexity of this system and shed new light on past and on-going hydrothermal activity at the Lost City vent field.