Book Review

Review of German, Lin, Parson (eds), 'Mid-Ocean Ridges: Hydrothermal Interactions between the Lithosphere and Oceans', AGU Geophysical Monograph 148, 2004

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For the last 15+ years, Theoretical Institutes organized by participants in the US RIDGE program have facilitated discussion, debate, and collaboration among researchers involved in studies of magmatic, tectonic, thermal, geochemical, and biological processes at and near seafloor spreading centers. I participated in two of these meetings, in 1993 and 2000, and found the programs to be highly educational, entertaining, and thought-provoking. Participants in the international version of RIDGE, InterRIDGE, organized their first Theoretical Institute, gathering in Pavia and Sestri Levanti, Italy in September 2002, to explore 'The Thermal Structure of the Oceanic Crust and Dynamics of Hydrothermal Circulation.' AGU Geophysical Monograph 148 is a series of papers prepared for and inspired by this InterRIDGE Theoretical Institute (IRTI); based on the papers collected in this volume, which were produced following the conference, field trip, and workshop, it must have been as provocative, timely, and comprehensive as earlier Theoretical Institutes. [Full disclosure: I was on the organizing committee for the first IRTI but was unable to participate because of a schedule conflict, much to my disappointment. My involvement in helping to organize the IRTI ended a few months before the conference, and I was not involved in the preparation of this volume or other conference-related activities after that time.]

AGU Geophysical Monograph 148 is a collection of 13 chapters, written by different authors, focusing on hydrothermal activity at seafloor spreading centers and construction and modification of oceanic lithosphere as a result of magmatic, tectonic, and hydrothermal processes. These are more than review papers, although there is comprehensive coverage of numerous fundamental topics; the papers include reports of updated and new analyses and experiments, including laboratory work, fieldwork, and modeling. The first chapter (by C. German and J. Lin) sets the tone for the volume by summarizing basic knowledge and posing open questions concerning connections between the thermal structure of the crust, seafloor spreading, and hydrothermal circulation. This is fitting because many of the fundamental constraints on hydrothermal fluxes (both on and off the ridge) are based on thermal considerations. The analyses presented are based largely on geometrical and conservation of heat considerations, making the conclusions both robust and accessible to nonexperts. The next chapter (by M. Sinha and R. Evans) summarizes and interprets a number of geophysical approaches for evaluating large-scale, crustal properties, and thus (by proxy) hydrothermal and related processes. The authors note results based on different methods that are in agreement, and others that are inconsistent or nonunique. For example, it is curious that estimates of the global heat flux associated with emplacement and cooling of basaltic melt at seafloor spreading centers is about the same as the lithospheric heat thought to be 'missing' from 0–1 Ma seafloor on the basis of (conductive) heat flow surveys. One interpretation is that essentially all the heat of crustal formation is removed by hydrothermal circulation, but of course convecting fluids are not selective as to where their heat originates; much of the heat mined from young seafloor by hydrothermal circulation is likely to come from the cooling of previously solidified material, and it seems unlikely that convection at the ridge mines large amounts of heat from 10–60 km off axis (full spreading rates of 20–120 mm year^{-1}, respectively, out to 1 Ma).

A chapter on lithospheric and ridge morphology and rheology (by R. Searle and J. Escartín) nicely summarizes conceptual and numerical models and results from selected laboratory studies, and discusses different definitions of the lithosphere, leading to idealized cross-sections through young volcanic seafloor at slow- and fast-spreading ridges. A later chapter explores related topics of magma injection, crustal morphology and deformation, and subseafloor temperature structure (by M. Behn, J. Lin, M. Zuber). Numerical models illustrate the expected geometry of major near-ridge fault systems, with hydrothermal circulation parameterized using a Nusselt-number proxy. The chapter on modeling the thermal state of the crust (by Y. Chen) is brief, focusing mainly on nonhydrothermal processes, except for using plume heat budgets to constrain crustal heat budgets. There is clearly a need for more explicit links between subseafloor hydrothermal, magmatic, and tectonic models.

Studies of rocks recovered from the oceanic crust (*in situ*, ophiolites) provide additional constraints on the heat budget of crustal construction, as discussed in the chapter by M. Cannat, J. Cann, and J. Maclennan, with a focus on slow-spreading systems. The authors lucidly discuss correlations between rock chemistry and magmatic/thermal processes, noting interpretations that are not consistent with other data (often geophysical) or should be constrained by them. As an example of the latter, there is an ongoing debate concerning the dominant mode of emplacement of ocean crustal plutonic rocks. Completing models (gabbro-glacier and sill-intrusion) have different requirements with regard to the depth of hydrothermal cooling, so if researchers ever resolve the latter, it should help to constrain the former.

B. deMartin, G. Hirth, and B. Evans compare numerical and experimental results in a study of thermal cracking within peridotite, the rock type found below the base of the oceanic crust. Work presented in this study suggests that rock properties and thermal conditions should lead to significant cracking at subseafloor depths <4–6 km, in broad agreement with seismic observations. A chapter on observational work at 9°50' north on the East Pacific Rise (EPR; by D. Fornari, M. Tivey, H. Shouten, and colleagues), the best-studied, fast-spreading mid-ocean ridge hydrothermal system in the world, compares seafloor vent distribution and lava emplacement processes, with the two linked (probably) by crustal permeability distribution. The latest photographs, maps, and other images are shown with stunning clarity, and the arguments are compelling, but the lack of quantitative information on subseafloor hydrogeologic conditions and properties remains a vexing problem. R. Lowell and L. Germanovich present scale analyses and results from single-pass (circulation loop) models of coupled fluid-heat flow. Considerable observational complexity can be replicated in models of highly idealized (essentially one-dimensional) hydrothermal systems, particularly when permeability evolution (thermal cracking and precipitation clogging) is included. But the authors highlight the need to push quantitative models to include greater complexity, including multi-phase flow, reactive transport, and links with magmatic and tectonic processes. I would add realistic (heterogeneous) property distributions to that list.

A chapter on the global distribution of hydrothermal vent systems at spreading centers (by E. Baker and C. German), largely on the basis of water column plumes, updates similar studies from the last 10–15 years. This work has been fundamentally important in understanding the heat budget of ridge-crest hydrothermal systems because plumes are natural integrators of advective heat transfer from the crust. Probably the most important result of this work is a strong positive (essentially, linear) correlation between the occurrence of venting (as indicated by plumes) and the magmatic budget of crustal formation. However, slow and ultraslow spreading centers (where seafloor is produced at full-spreading rate $\leqslant 20$ mm year^{-1}) produce disproportionate amounts of heat, an observation that remains to be explained with confidence. One explanation is that slow and ultraslow spreading centers have a greater component of subcrustal cooling, leading to widespread serpentinization of mantle rocks. The latter topic is explored in a chapter on chemical conditions associated with hydrothermal circulation through ultramafic rocks (by W. Seyfried, D. Foustoukos, and D. Allen). This chapter includes an nice overview of geochemical systematics, focusing on processes occurring within and below several newly discovered seafloor vent systems that derive at least a portion of their heat from exothermic water–rock reactions, generating unusual vent fluids (e.g. very high dissolved Fe and CH_4 concentrations).

K. Von Damm presents a 12-year-time series of vent-fluid data from 9°50′N on the EPR, illustrating both complexity and consistency in geochemical trends. Cl and Si concentrations are used to estimate the depth(s) of fluid circulation and reaction, and suggest that this hydrothermal system has moved vertically over the sampling period. As in several other mid-ocean ridge hydrothermal systems, there is a 'Cl mass-balance problem' at 9° 50′ N on the EPR. Most of the vent fluid has a Cl concentration lower than seawater, requiring that salt be stored somewhere at depth. Is this salt being vented elsewhere? Will it remain in the crust until a later venting cycle? Until it is subducted?

The final paper stands out from the rest, focusing on hydrothermal activity within a seamount, an underwater volcano located on the north-eastern boundary of the Easter Microplate in the southern Pacific Ocean (by D. Naar, R. Hekinian, M. Segonzac and colleagues). Much less information is available from this newly discovered feature than from several of the mid-ocean ridge hydrothermal systems discussed earlier in the volume (no fluid samples, limited thermal data), but observations suggest that it may function much like the 'fault-dominated' systems found at several slow-spreading ridges.

The production quality of the volume is high, with a hard binding, good quality paper, and several color plates per chapter. Editing was thorough, as is common for AGU volumes, and I found only a few typos. There are two things missing from this book that might have made it a 'must-have' volume. First, there is no index, so readers looking for multiple views on a topic or experiment must dig through individual chapters without much indication as to what should be found where. Second, there is little cross-referencing of the chapters, which would help with understanding similarities in interpretations or, in some cases, differences. Furthermore, this volume is not as comprehensive as AGU Geophysical Monograph 91, which resulted from the 1993 RIDGE Theoretical Institute, but is similar in the breadth of topical focus to AGU Geophysical Monograph 144, which concentrated on the subseafloor biosphere, a topic covered in passing in a few papers in the current volume.

It is worth asking whether there continues to be a need for volumes such as this one in an age of electronic publishing, when many researchers (at least those in most academic and government institutions) have access to numerous electronic sources from their desktop computers and networks. The answer is yes. First, pulling papers together within a single binding on the basis of topical coverage is helpful, particularly to students and those who are new to the field. Review papers in other journals serve this purpose as well, but coverage of related fields in separate review papers is inconsistent and often contradictory. Other recent volumes of papers from Theoretical Institutes are widely cited, and for many researchers, there is a preference for reading hard copy rather than electronic files. The price for AGU Geophysical Monograph 148 is reasonable ($49 for members), particularly considering the quality of the papers and the number of color figures. I will be rereading and citing the papers in this volume, and passing the book to my students to read, for many years.

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