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Economic Geology, v. 107, pp. 381–384

BOOK REVIEWS

Diversity of Hydrothermal Systems on Slow Spreading Ocean Ridges. P. A. Rona, C. W. Devey, J. Dyment, and B. Murton, editors. Pp. 440. 2010. American Geophysical Union, Geophysical Monograph Series, vol. 188. ISBN 978-0-87590-478-8. Price $129.

This book arrived in my mailbox about one month ago, and I immediately began using it for my own research. I referred to it frequently while preparing several review papers. I was so immersed in the book that I completely forgot how I came to own it. Then I received a gentle reminder from the editor that I was overdue with the review. The fact that I had forgotten how the book ended up on my desk, because I was too busy reading it, is probably a better endorsement than any review I can provide here.

This is a book for specialists in sea-floor hydrothermal systems. It is part of a superb collection of volumes in the AGU Geophysical Monograph Series that track the history of research in this field. The series has its beginnings in the 1995 introductory volume, *Seafloor Hydrothermal Systems* (Monograph 91), which was followed by *Faulting and Magmatism at Mid-Ocean Ridges* (Monograph 106), *The Subseafloor Biosphere at Mid-Ocean Ridges* (Monograph 144), *Mid-Ocean Ridges: Hydrothermal Interactions Between the Lithosphere and Oceans* (Monograph 148), *Back-Arc Spreading Systems* (Monograph 166), and *Magma to Microbe: Modeling Hydrothermal Processes at Ocean Spreading Centers* (Monograph 178). Together with a number of similar volumes published by the Geological Society of London, the Geophysical Monographs represent our most important encyclopedia of submarine hydrothermal systems, covering the development of thought since the discovery of the first black smokers on the East Pacific Rise. With these volumes in your library, you can be assured of having at your fingertips the most complete record of knowledge in the field, written as compelling reviews that provide both the historical context of the research and its relevance for future exploration.

The latest book in this series examines the past decade of research (1998–2008) on slow-spreading mid-ocean ridges, emphasizing the remarkable and unexpected diversity of volcanic and tectonic settings and hydrothermal activity associated with these systems. The architect of the book, Peter Rona, is one of the pioneers of sea-floor exploration on slow-spreading ridges, widely credited with the discovery in 1985 of the first large black smoker system on the Mid-Atlantic Ridge at 26°N. At the time, a general consensus had emerged that hydrothermal activity on the Mid-Atlantic Ridge would be limited, simply because of the lack of magmatic heat associated with slow spreading. However, after the discovery of the TAG hydrothermal field, it became clear that not only were black smokers a common feature of slow-spreading ridges, but the deposits formed there are probably among the largest and most diverse on the sea floor. The reason for this, as documented in the new Monograph 188, is the complex architecture and composition of the slow-spreading crust.

Among the factors involved are the deep-seated magmatic activity and large-scale faulting that characterize slow-spreading ridges. These result in protracted hydrothermal circulation at phenomenal scales. In particular, the large-scale faulting allows a greater volume of hot rock to be accessed by the hydrothermal fluids, and asymmetric spreading provides windows of tectonic stability for the growth of large deposits. Recent seismic data show some of the largest hydrothermal systems are sourced many kilometers from the site of discharge in large-scale detachment structures that can accommodate extension for as long as several millions of years. The most robust hydrothermal systems occur where gabbroic magmatism is contemporaneous with detachment faulting. Tectonic processes associated with the detachment faults also expose a number of different substrates on which sulfide deposits have formed, including ultramafic plutonic rocks of layer 3 (i.e., oceanic core complexes). These rocks are exposed along nearly 25% of the slow-spreading ridges.

Monograph 188 explores these most recent findings and asks the questions: what is the thermal structure of slow-spreading oceanic crust and how does it control hydrothermal circulation, why are the hydrothermal systems located where they are, what role does detachment faulting play in oceanic spreading and fluid circulation, what is the evidence for deep fluid flow in these structures, how do they compare to continental detachment faults and core complexes, and what are the possible feedbacks between hydrothermal activity and the rheology of the crust in which detachment faults develop? Two papers in the Monograph, one by John and Cheadle and the other by McCaig et al., describe the emergence of detachment faulting as a major feature of slow-spreading ridges, and their role in the development of large-scale subsea-floor hydrothermal systems. Another paper by Lowell examines the range of heat sources at slow ridges, from mantle heat to magmatic heat to the heat generated during serpentinization of exposed ultramafic rocks. Because of the complexity of slow-spreading crust, a wide range of fluid-rock interactions is taking place, many that previously were unknown on fast-and intermediate-spreading ridges. These interactions are reviewed in a series of papers by Edmonds, Cannat et al., Charlou et al., and Seyfried et al. An emphasis is placed on reactions in exposed coarse-grained gabbros and mafic cumulate rocks that produce unusually high H_2 and abiogenic methane in the vent fluids and, in some cases, major fluxes of Fe and Cu. These different reactions may have important implications for understanding metal fluxes and metallogenesis in the dominantly mantle-buffered oceans of the early Earth. The highest-temperature hydrothermal systems on the slow-spreading ridges, particularly in the southern Atlantic, are also among the deepest in the world, down to 4,000 m, with pressures and temperatures that exceed the critical point of seawater.

A wide range of deposit types found on the Mid-Atlantic Ridge are described in a series of papers by Crawford et al., Devey et al., Sauter and Cannat, Fouquet et al., and Kelley and Shank, including black smokers on ultramafic substrates, near- and off-axis deposits, and low-temperature systems driven by cooling of mantle material (Lost City-type). Both the Devey et al. and Sauter and Cannat papers examine the role of melt supply along the south Atlantic and Southwest Indian ridges, and how this influences crustal permeability, which is an important first-order control on the locations and intensity of hydrothermal fluid flow. Their models have important implications for future exploration of slow-spreading ridges. Two papers (Kelley and Shank, Le Bris and Duperron) also examine the parallel diversity of vent fauna on the slow-spreading ridges and explore the possible energy sources for life that present themselves where mantle rocks are exposed on the sea floor. Among the most compelling of the recent discoveries described in the book are the large hydrothermal systems in the Arctic Ocean, along the slow and ultraslow Mohns, Knipovich, and Gakkel ridges (Pedersen et al.). Tivey and Dyment describe important results of deep-towed magnetics, which are illustrated with examples from seven of the main hydrothermal systems along the length of the Mid-Atlantic Ridge. Finally, a paper by Elders and Fridleifsson takes this research back to its roots in Iceland, where the Iceland Deep Drilling Project has been attempting to drill into the supercritical zone of active geothermal systems, shedding new light on magmatic and hydrothermal processes at slow-spreading ridges.

Similar to the other monographs in the AGU series, this book should be considered an important benchmark in the ongoing discovery of sea-floor hydrothermal systems. Because of the pace of these discoveries, the book was necessarily out of date as soon as it left the printer. This is acknowledged by the editors, who point out that the full diversity of hydrothermal systems on the slow-spreading ridges is only just emerging. Since the publication of the monograph, we have already seen new discoveries on the Southwest Indian Ridge (Tao et al., 2011), the discovery of the deepest vents at 5,000 m in the Cayman Trough (German et al., 2010), and ongoing research on supercritical fluids at the deep South Atlantic vents (e.g., Koschinsky et al., 2008) that were only just discovered as many of the papers were being written. At the same time, the first commercial exploration of the slow-spreading ridges has begun. In the last year, Russia has filed for an exploration license covering 10,000 km^2 of the Mid-Atlantic Ridge, and China was granted a similar-sized license for exploration on the Southwest Indian Ridge. Because slow-spreading centers account for ~60% of the total length of the global mid-ocean ridge system and host the largest deposits, they are estimated to contain as much as 85% of the massive sulfide deposit remaining to be discovered at ridges (Hannington et al., 2011). Many of the findings contained in Monograph 188 will be of critical importance in guiding exploration for those deposits.

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December 30, 2011

Granite-Related Ore Deposits. A. N. Sial, J. S. Bettencourt, C. P. de Campos and V. P. Ferreira, editors. Pp. 192. 2011. Geological Society Special Publication 350. London. ISBN 978-1-86239-321-9. Hardcover. Price £90.

This publication comprises papers selected from the symposium, Mineralization Associated with Granitic Magmatism, which was part of the 33rd IGC convened in Oslo, Norway, in August 2008. The symposium session attracted approximately 60 written contributions, many of which focused on ore deposits related to granitic magmatism rather than experimental and theoretical studies on ore fluids and granite-related mineralized systems. As a result of this, the editors selected nine papers for *Granite-Related Ore Deposits*. These have been arranged in groups as follows: granite-pegmatite, skarn and greisen-veins, porphyry, orogenic gold, intrusion-related, epithermal and porphyry-related gold and base metal, iron oxide copper-gold (IOCG), and special case studies.

An introduction by the editors briefly deals with the importance of granite-related mineralization systems, including the diversity of mineralization styles and ore deposits. They then provide a useful overview of magma mixing and unmixing of magmas, and related ore fluid generation. The final section of the introduction discusses the need for better genetic and exploration models based on continuing multidisciplinary investigations. The editors selected the nine papers in an attempt to provide a range of studies distributed broadly in space and time, highlighting granite-related ore deposits from a wide geographical distribution, i.e., Europe, Asia, South America, Turkey, and Iran.

The first main topic in the book is granite pegmatite systems, which comprises three interesting papers. The contribution by A. V. Tkachev is probably the most recent and accurate correlation of global granite pegmatite distribution associated with orogens throughout geological time. The author includes detailed geochronological reconstructions for granitic pegmatite genesis throughout the Earth's history, which illustrate periods of cyclicity of pegmatite generation and associated metallogenic evolution concerned with, in particular, the rare metals. "The eastern Brazilian pegmatite province and related mineral resources," by A. C. Pedrosa et al., presents new geochronological data for granites and pegmatites associated with the Aracuai orogen. Five granitic supersuites have been determined, based on groups of ages and collisional and post-collisional events. The economic ore deposits associated with these supersuites are dimension stone and the famous gem fields. The third paper in this section, by D. Balen and I. Broska, deals with petrological and geochemical research of tourmaline nodule formation in Croatia. The processes they propose for nodule formation, as magmatism evolves with changing physiochemical conditions, are well illustrated in their figure 8.

Two papers in the book deal with skarns, both from Asia. The geochemical characteristics of the Chichibu base metal skarn deposit in central Japan, providing evidence for magmatic fluids coexisting with granitic melt, are discussed by D. Ishiyama et al. Their thesis is based on the presence of halite-bearing and vapor-rich fluid inclusions in igneous quartz, decrease in concentrations of LREE and total REE, according to magmatic differentiation, and cathodoluminescence studies of corroded quartz crystals. They also present chemical data of the Chichibu granites in several figures and a schematic diagram that show the vertical zonation of ore types in the district. The average grade of the Chichibu skarn deposit is reported as 0.3% Cu, 0.2% Pb, 2.4% Zn, 20 g/t Ag, and 1.0 g/t Au. A fractal analysis of ore-forming processes at the Tongling-Shizishan skarn district in Anhui province in China, by Q. Wang et al., was conducted on core from five drill holes from the Shizishan base metal deposits. Using a number of multifractal and self-affine analyses, the authors conclude that although the mineralization intensities for different elements and locations at the Shizishan skarns are not consistent, similar mineralization processes can be correlated to similar fractal exponents.

The petrology and alteration geochemistry of Paleoproterozoic intrusions hosting Au mineralization at Algtrask in northern Sweden are the main theme of the contribution by T. Bejgarn et al. This well-illustrated paper has detailed descriptions of the hydrothermal alteration assemblages, geochemical and geochronological data, and gold paragenesis. The authors report that the REE signatures and petrography of porphyry dikes at Algtrask are similar to those at the nearby Tallberg porphyry-style Cu deposit. Structural evidence, however, indicates that Au mineralization at Algtrask is hosted in earlier D_2 to D_3 events and thus is younger than the copper mineralization at Tallberg. The indicated and inferred Au resource at Algtrask is approximately 4.2 Mt at a grade of 2.3 g/t Au. The Cenozoic Zaglic and Safikhanloo low-sulfidation gold prospects in northwestern Iran are described in detail by S. Ebrahimi et al. Their contribution outlines the geological setting and geochemistry of the host volcanic rocks and alteration and paragenesis of the gold mineralization, in addition to fluid inclusion and S isotope studies, all of which support a low-sulfidation epithermal deposit classification. The Zaglic and Safikhanloo deposits are reported to contain two tonnes of gold.

Research by O. Delibas et al. on the magnetite-rich Fe-Cu-Mo mineralization associated with the Cretaceous calc-alkaline Karacaali Magmatic Complex (KMC), central Anatolia in Turkey, proposes that intrusion of an oxidized, Fe- and Cu-rich basic magma into a partially crystallized acid magma resulted in partial mixing, triggering the abrupt separation of an iron oxide-rich melt. The authors present new geochronological, whole-rock geochemistry, and geochemical analyses for plutonic rocks from the KMC, in addition to chemical analyses for magnetites associated with the various mineralization styles (veins, breccia matrix, and vesicle fillings). Primary Cu and Mo mineralization is reported to be present in both granitic and monzonitic rocks. A model for the metal enrichment processes in the KMC is illustrated in figure 11. The authors stress the importance of magma mixing and metal unmixing, possibly associated with stress relaxation during postcollisional evolution. The final contribution in the book is that of J. Rossi et al., who examine the metal fertility of the Carboniferous San Blas pluton in western Argentina. The geology, petrography, and geochemistry of the granites are discussed, as well as isotope studies. The granite shows graphic intergrowth textures and miarolitic cavities. The authors conclude that these data, together with Sr/Eu ratios, indicate the San Blas pluton is a fertile evolved granite. Adjacent alluvial deposits containing Sn and W suggest a degree of erosion of a metalliferous cupola.

This special publication has many interesting topics and papers mostly related to granite magmatism. With the title *Granite-Related Ore Deposits*, I was expecting to read about significant economic ore deposits associated with granites, current metallogenic models, and research relating to the origin of ore fluids and their chemistry. In this regard, I felt the publication title doesn't exactly reflect the theme of the contributions therein. All of the contributors have presented quality papers; however, none of these relate to economically significant orebodies in a global perspective. I suspect this is mainly due to the available papers presented at the IGC from which those for publication had to be selected. Perhaps with the exception of the Brazilian dimension stone and gem deposits referred to by Pedrosa-Sores et al., the granite-related mineralization occurrences described in the book do not constitute significant ore deposits in an economic sense. The contribution by Ebrahimi et al., about epithermal Au in Iran, is an excellent research compilation. However, I felt it was not specifically relevant in a granite context. I had the same impression about the high standard of papers by Balen and Broska (tourmaline nodules) and Rossi et al. (the San Blas pluton). Overall, the papers are well written and easy to read. The editing of the publication is thorough, particularly considering the diverse international backgrounds of the contributors.

It is difficult to recommend who should buy this publication. It would not be appropriate as a teaching text, nor would it appeal to most exploration geologists, despite the title. I do feel the publication would seriously interest those involved with granite research. Another appealing aspect of the book is the detailed description of lesser known mineral deposits in Turkey, Iran, China, and Sweden.

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VANCOUVER, CANADA
July 20, 2011