American Mineralogist, Volume 80, pages 415–416, 1995

BOOK REVIEWS

GRANULITES AND CRUSTAL EVOLUTION. Edited by D. Vielzeuf and Ph. Vidal. Kluwer Academic Publishers (NATO ASI Series C, vol. 311), 1990, xvi + 585 pages. $197.50.

Granulites and Crustal Evolution is the enduring product of the NATO Advanced Research Workshop on the Petrology and Geochemistry of Granulites held in Clermont-Ferrard, France, in September, 1988. That conference was probably the largest and most comprehensive meeting ever convened to discuss the major problems of the granulite facies and the nature and origin of the lower crust. It is to the credit of the editors, Vielzeuf and Vidal, that the symposium volume is commensurate with the symposium itself. Indeed, this book may be the most influential single volume yet published in the literature of granulites.

A thorough reading of *Granulites and Crustal Evolution* is, I believe, one of the best possible ways to get one's mind around the granulite problem. Description of granulite facies terranes is still the most basic information. This book contains outstanding review papers by active workers on some of the well-studied terranes, such as Finnish Lapland (Barbey and Raith) and the Limpopo Belt of South Africa (Van Reenen et al.). The reviews generally contain new petrologic and geochemical data and new perspectives. Articles summarizing terranes that are just beginning to be explored are particularly valuable. These include the huge high-grade terranes of northeastern Canada (Percival), the Jequié Province of Brazil (Barbosa), the Madagascar (Nicollet) and Sri Lanka (Fiorentini et al.) terranes, the Zambesi Belt of Zimbabwe (Treloar et al.), the Archean province of Montana (Mogk), and the Sino-Korean Craton (Jahn). Each terrane is different, though fascinating similarities exist, all terranes being linked by low H_2O contents of rocks and the widespread presence of pyroxenes. The Sri Lanka and Lapland terranes are composed dominantly of granulite facies supercrustal rocks (metasediments and metavolcanics), whereas the northeast Superior Province terranes feature vast swarms of charnockitic plutons. Some, like the Qianxi region of northeast China, appear to be simply ancient cratonal granite-greenstone terranes overprinted by granulite facies metamorphism. The Ivrea Zone granulites, summarized by Pin, represent post-Precambrian granulite terranes, which, while comparatively few and small, nevertheless provide an important link with the remote past.

Phase equilibrium studies of rock melting figure more and more prominently in the discussion of deep-crust evolution. Useful papers by Clemens, Thompson, Vielzeuf, and others on this subject emphasize that fluid-absent melting of rocks with micas and amphiboles takes place in the upper end of the high-temperature range usually ascribed to granulite metamorphism (850–900 °C). Such dehydration melting is the mechanism most commonly invoked to produce the low H_2O activities associated with granulites. The other contending dehydration mechanism, that of a moving CO_2-rich vapor, could only inhibit melting and thus could not explain granulite facies migmatites, according to Clemens (despite recent experimental evidence to the contrary, which he rejects). In any case, experimental melting studies with and without a participating vapor phase are among the most important lines of research on granulites.

Geochemistry plays a prominent role in the discussion of the origins of granulites. Some granulites are significantly depleted in the large-ion lithophile elements (LILE), particularly Rb and the heat producers K, U, and Th, relative to normal upper-crustal rocks of the same major-element compositions. This factor permits the exposed granite terranes to serve as models of the deeper parts of the crust, explaining the low heat flow of the continental interiors. An alternative lower crustal model is provided by granulite xenoliths, mostly mafic, from alkali basalts, as discussed by several contributors to the symposium volume. The mechanisms suggested for depletion include primary igneous differentiation in the accretion of the crust, subsequent partial melting and extraction of LILE-rich magmas from the deep crust, and metamorphic out-gassing episodes. Trace element partitioning studies do not seem able at present to decide which of these mechanisms is operative in granulite depletion. The paper by Arculus and Ruff endorses granite melt extraction, and Rudnick and Presper argue against this mechanism. Jahn is against melt extraction on the basis of geochemistry and field relations of the Qianxi granulites. These papers, though they do not converge in unanimous conclusions, are important in detailing the many ways in which geochemical analysis and modeling can bear on the granulite problem.

The problem of pressure-temperature-time (P-T-t) paths of granulites is one of the most absorbing current issues. Mineralogic geothermometry and geobarometry (Perkins), coupled with detailed isotopic studies of mineral growth and resetting ages (Mezger, Pin), define two basic kinds of metamorphic cycles. The clockwise cycle is epitomized by the rapid, nearly isothermal excavation of the Limpopo Belt granulites, and the counterclockwise cycle, in which deeply buried terranes underwent slow cooling from peak metamorphism at nearly constant pressure, is shown by the Adirondack Mountains of New York. The granulites of the Zambesi Belt show both characteristics—cooling at depth, punctuated by spurts of uplift associated with periods of thrusting. The mystery of the excavation of granulite terranes deepens as more P-T-t data become available.

The controversy about whether a vapor phase was important in granulite facies metamorphism still occupies a prominent place in the discussions. Some of the geochemical studies seem to require open systems for element migration during metamorphism, as, for example, in the Northern Labrador terrane described by Schiøtte and Bridgwater. O isotope studies of the Sri Lanka Highlands, on the other hand, suggest conservative O and hence very little fluid migration (Fiorentini et al.). The evidence of CO_2-rich fluid inclusions, so common in granulite minerals, is not unambiguous and contains some contradictions with calculated f_{CO_2} of some mineral assemblages, especially those containing wollastonite (Lamb) and scapolite (Moecher and Essene). Phase equilibrium calculations for the southern Karnataka granulites of India by Sen and Bhattacharya suggest a pervasive vapor phase (presumably CO_2-rich) during metamorphism. Touret and Hartel patiently point out that some CO_2 inclusions are demonstrably synmetamorphic and that detailed and systematic studies on optimally favorable samples that would allow general conclusions about the fluid-phase history of granulite metamorphism have not been presented for the majority of terranes. About half of the contributors to the Symposium Volume seem to favor active fluids and half to discount them. A major impediment to further progress is the almost total lack of experimental evidence on the partitioning of trace elements between solids and supercritical CO_2-H_2O vapors. The problem of thermal advection by fluids is a difficult one that most modelers are loathe to tackle.

The single aspect of granulites that the volume could be said to underrepresent is geophysical. There are a few thermal modeling studies, but only the paper by Vigneresse brings in the role of gravity and seismic observations in any detail. These techniques are still in the realm of remote sensing: various petrologic models are permissible to account for sound speed and density of the lower crust, and the exposed granulite terranes are still viable as lower-crust models.

Every serious student of granulite facies metamorphism should have ready access to this important volume. It is a must for geology libraries.

Robert C. Newton
University of Chicago

METALLOGENY OF TIN, Lecture Notes in Earth Sciences 32. By Bernd Lehmann. Edited by Somdev Bhattacharji, Gerald M. Friedman, Horst J. Neugebauer, and Adolf Seilacher. Springer-Verlag, Berlin. 1990. 211 pages. $32.00.

The aim of the Lecture Notes in Earth Sciences is to report quickly, informally, and at a high level new developments in research and teaching. In *Metallogeny of Tin,* Lehmann focuses on laying the foundation for a general metallogenic model by identifying the essential and relevant processes in tin ore formation. The material is well organized and presented. Most of the 90 figures (graphs and maps) are large enough to be clearly legible. Six photographs serve to illustrate field and petrographic relationships. Five hundred thirty-one references, some as recent as mid-1990, are cited. The subject and locality indices are useful components of the book.

Metallogeny of Tin is divided into six parts. In the first part, Lehmann discusses metallogenetic concepts, spatial and temporal distribution of deposits, global geochemical evolution of Sn, and the geochemical specialization of tin granites. The next part covers magmatic fractionation, the geochemical heritage of tin provinces, crystal-melt partitioning, the role of oxidation state, solubility of cassiterite in silicic melts, melt-fluid partitioning, and the hydrothermal solubility of cassiterite. In part three, magmatic enrichment of Sn is illustrated with examples from the Erzgebirge, Massif Central, Cornwall, Malaysia, Thailand, Nigeria, Nova Scotia, Cape Granite, and the Snowy Mountains. Examples from Indonesia, Thailand, Burma, Alaska, Malaysia, and Bolivia are used to document the hydrothermal redistribution of Sn in part four. Part five reviews regional distribution patterns and the problem of pregranitic Sn enrichment with reference to the Erzgebirge, Izera Mountains, the Bolivian tin belt, and Kelapa Kampit. The last part presents a concise model for tin ore formation. The model incorporates data available from field studies, petrography, whole-rock geochemistry, stable isotopes, geochronology, fluid inclusions, experimental work on hydrothermal and magmatic systems, and thermodynamic modeling.

Although this book provides a wealth of information on the metallogeny of Sn, some pertinent topics receive little or no mention. For example, only the geochemistry of cassiterite is discussed, leaving the reader with the impression that either no other Sn or Sn-bearing minerals exist or that their conditions of formation have nothing to contribute to an understanding of Sn mineralization. A short section on Sn minerals would add a useful dimension. Sn in skarns and in massive sulfide systems also receives minimal attention, even though some very large and rich deposits exist.

This soft-cover book will be a most useful reference for igneous petrologists and economic geologists, and they should encourage their geology library to purchase a copy.

E. U. Petersen
University of Utah