American Mineralogist, Volume 84, pages 1209–1211, 1999

BOOK REVIEWS

BORON: MINERALOGY, PETROLOGY AND GEOCHEMISTRY. Edited by E.S. Grew and L.M. Anovitz, Mineralogical Society of America Reviews in Mineralogy, Vol. 33, 862 p.

This very large overview of the role of boron in mineralogy, petrology and geochemistry divides itself with minimal overlap and clutter into three parts: crystal chemistry—including thermochemical, experimental, and geochemical chapters; mineralogy—including descriptive and associative chapters; and analytical methods—including technique assessment chapters.

The chapters are reviewed here in these groups although this does lead, in some cases, to an apparent diminution of attention paid to individual chapters. For any such apparent lack, we apologize and simply state that no specific subject was intentionally slighted. Space and our competence were the deciding factors for the extent of coverage.

The breadth of the material covered in this volume is enormous and of great interest to the petrologist and geochemist as well as the mineralogist. A vast amount of data is presented in impressive fashion, and this book should serve as a major reference for quite some time. More editorial attention could have been paid to reducing redundancy among chapters but the importance of presenting current data has been well served.

Crystal Chemistry (Chapters 2, 3, 4, 5, 8, 12, 13, 14)

The chapters dealing with the crystal chemistry the thermochemical properties, and the experimental and comparative geochemistry of boron minerals reflect the lack of cohesion in the study of boron in general. The introduction of fundamental building blocks (FBB) into the discussion of crystal chemistry is an elegant expression of a unifying concept for expanding the study of boron minerals. Although these non-stereochemists readers found the abbreviations and terminology somewhat daunting, we were primed for the continuation of this theme into the chapters on properties and descriptions that followed. However, as the material soon showed, there was little agreement among the succeeding authors, except to repeat the complexity of the subject and the fact that trigonal and tetrahedral coordinations were possible for boron. Not that the work on the thermochemical properties and behavior was *at all* of poor quality; it was not. It did lack the consistent theme, however, that could have rolled the entire discussion into a more inviting whole, and seemed to emphasize the differences of opinion among authors perhaps more than is warranted. One point of agreement among all authors was the importance of obtaining more and better thermodynamic data for the various mineral species (or their FBBs). All made a strong case for the importance of boron (with its generally incompatible nature in rock-forming processes) as an indicator species for petrogenetic processes. The compilation of thermochemical data for boron minerals, although still incomplete, is a great addition to the literature. It did, though, lead us to wish that more use had been made of this material in the later, more descriptive, chapters.

Mineralogy (Chapters 6, 7, 9, 10, 11)

To some extent, these chapters offer a reprise of the work reviewed in the previous paragraphs but with more recourse to existing mineral systems. The majority of this section deals with boron in metamorphic rock minerals (two chapters) and hydrothermal tourmaline associations. The chapter on metamorphic boron minerals exclusive of tourmaline is a long, detailed (if occasionally inconsistently formatted) compendium of descriptions, compositions, structures, associations, and conditions of formation for the borosilicates. Probably the main criticism of this chapter is that, because of the diversity of sources, it is not always easy to compare parageneses or phase assemblages from mineral family to family. The essential data are generally available in the chapter, however, and Grew's treatment will spur the recognition of and attention to a number of previously overlooked boron-bearing phases in metamorphic terranes. In his section on the origins of the borosilicates, Grew summarizes the important factors bearing on borosilicate stability and generalizes that, "…while tourmaline is more often found as an accessory constituent widely dispersed in common metamorphic rock types, other borosilicates are more commonly found in highly localized concentrations in unusual rock types. …further evidence that special physico-chemical conditions are prerequisites for the formation of borosilicates exclusive of tourmaline." The collection of origins suggested for various occurrences emphasizes the diversity of conditions that may prevail but does little to suggest coherent principles that lead from one boron-bearing mineral family to another.

The chapter dealing with metamorphic tourmaline offers a discussion of tourmaline crystallography, crystal chemistry, species, and solid solutions that is well worthwhile for the beginning tourmaline student, giving a coherent look at the web of names, compositions, substitutions, and geometries that abound with respect to this mineral. A small quibble is the visual omission of some Z- and Y-site species in the c-normal projection. The potential for boron deficiency in the mineral is summarily dismissed by the authors on the basis of spectroscopic and structural refinement studies, but we are familiar with several studies that cast doubt on such an arbitrary dismissal. The polar properties of tourmaline are well known as curiosities. Henry and Dutrow advocate the further examination of such properties for use in mineralogical and petrological studies. This section is an excellent basis for such examination and an eloquent appeal for more detailed work. In particular, the potential for developing intracrystalline partition coefficients that might be useful in low-temperature geothermometry for some diagenetic to low-grade metamorphic environments is exciting. Compositional variation in metamorphic tourmaline has received only sporadic attention since the publication of Henry and Guidotti's seminal paper (1985). This work is reviewed here and additional contributions from several authors incorporated into a comprehensive discussion of such variation for different protoliths and different metamorphic environments. The authors use exchange-vector terminology to clarify their discussion but are not always consistent in the format of the terminology. Nonetheless, this is an excellent addition to the research on metamorphic petrology and the role of tourmaline in deciphering petrologic complexities.

The section of this chapter on tourmaline as a reservoir and monitor of boron in rock systems reflects the conflicting interpretations and theories about the origins of tourmalines in disparate rock systems. A vast amount of work needs to be done on distribution of tourmaline, boron-mineral compositional types, boron isotopes, etc., among different petrogenetic environments. This section is a good window on the potential of such research. Detrital tourmaline has had a checkered career as a provenance indicator (as evidenced by the author's remarks concerning some early provenance studies) and yet still holds much promise in that position. The author's diagram (reproduced in this section from Henry and Dutrow, 1992) illustrates both the utility and uncertainty of tourmaline composition as such an indicator. One of us (J.T.O.) has used a combination of Henry and Guidotti's (1985) classification and a multivariate statistical approach to obtain consistent natural groupings of detrital tourmalines (unpublished data).

Slack's extensive discussion of hydrothermal ore deposits of many types associated with tourmaline outlines the diverse relationships that the mineral may have with ore deposition. This discussion is largely descriptive for many types of deposits but for two, veins in metamorphic rocks and stratabound deposits, the author essays to provide a unifying framework for relating the tourmaline to the ore mineralization. Many of these deposits show such diverse and apparently conflicting evidence for the relation of tourmaline and ore formation that the main result of the author's discussion is to broaden the world of possibilities, a conclusion reiterated by the author in his summary. In a separate section on tourmalinites Slack presents abundant evidence and reasoning to show that the formation of these exotic rocks may be due to several related syngenetic processes, or to metasomatic processes associated with granitic intrusion or regional metamorphism. A section on tourmaline chemistry is presented with respect to different types of ore deposits and the author demonstrates a tendency for tourmaline compositional projections to cluster into groups representative of the associated ore deposit. We would have liked a multivariate analysis of these compositional parameters to remove the closed system bias and lack of discrimination inherent in a two-dimensional system. The brief section on isotope work in tourmalines again emphasizes the manifold nature of tourmaline formation but offers several potentially rewarding avenues of applying tourmaline isotope studies to more general geologic problems.

The premise of the chapter *Boron in Granitic Rocks and their Contact Aureoles* is that tourmaline, as a detrital mineral in sedimentary (or metamorphic) protoliths, provides the source and the buffer for boron retention in boron-enriched granitic rocks formed by anatexis. The authors make a complex case for the development of relatively B-rich magmas (2–10% B_2O_3) from the complete or partial melting of low-(Fe + Mg) tourmaline-bearing pelitic rocks, disagreeing with other investigators who peg the upper limits for B_2O_3 in magmas at about 1%. They point out many possible mineralogic expressions of crystallization of such magmas depending upon temperature and extensive variables in the magma-wall rock system. The possibilities are well explained and backed up with examples. A short but interesting section of the chapter is devoted to a discussion of the development of metasomatic wall-rock reactions around B-rich magmas. The authors conclude that the development of tourmaline in metasomatic haloes around plutons is an almost singular indicator of the boron content of the intrusion. This is an important part of the investigation of magmatic crystallization and suggests a need for further development of the analysis put forward here and the collection and incorporation of detailed thermodynamic data into this study, as well as into the metamorphic and hydrothermal studies of the preceding chapters.

The brief chapter on the phase chemistry of borate deposits presents a very clear explanation of the geology and geochemistry of borates and relates the compositions and variables quite succinctly to natural processes. However, we would have liked a more complete thermodynamic analysis of trace element associations with borates; the relation of borates to other evaporite mineral suites; metamorphic variations in borate suites; and expansion of the activity diagrams.

Analytical methods (Chapters 15, 16, 17, 18, 19)

With the current-day burgeoning of EMPA analysis in examination of light-element-bearing geologic materials, McGee and Anovitz's survey of advances and problems in such analyses of boron minerals is a significant and needed contribution to the research literature. The authors' comments on instrumental and analytical developments dwell primarily on the properties of layered synthetic micro structure crystals (LSM), the development that, more than any other, has allowed EMPA to become a primary tool in light-element analysis. They point out the peak-shape(?)/peak-shift(?) problems that complicate the analyses of uvite or danburite when the other mineral is used as a standard and suggest that peak areal measurements might be an appropriate solution although such measurements involve significant extra calculations. The separate discussion of standards and sample preparation promotes the use of tourmalines as primary and secondary standards for the analysis of tourmalines. The discussion of specific boron analysis problems in kornerupine, vesuvianite, and tourmaline gives the reader a very specific look at obstacles and methods of overcoming them. McGee and Anovitz's make a strong case for further development of a suite of mineralogic standards and a complete list of criteria for accurate EMPA boron analysis. A significant omission in this chapter is a lack of discussion of the orientation effect in EMPA boron analysis. This effect, which may cause an error of as much as 10% of the amount present, is arguably caused by polarization properties of the analyzed mineral and is an important consideration for both the unknown and the boron standard.

The survey chapter on secondary ion mass spectrometry (SIMS) of geological materials for boron gives the reader a good overview of the mechanics of the analytic technique, the pitfalls to be avoided, and some of the applications to which it has been put. To the future-work section, we would add data collection on partition coefficients and thermochemical measurements called for in other chapters of this work and distribution data for boron in coals and coal-fired byproducts of interest to air-pollution researchers.

Robertson and Dyar provide a stimulating survey of the use of different nuclear methods to determine the boron contents of geologic materials. The PIGE spectrum provided in the article certainly does have narrow and generally isolated boron peaks, although some potential interference with Na seems to appear for one peak and the general boron intensity level is much less than that for the other elements shown. Perhaps more disappointing, however, is the table of results (Table 2) offered to demonstrate the applicability of nuclear methods. The averaged values presented seem to be between 5% and 30% of the amount present, a large error if one is trying to generate partition functions or structural formulae for boron-bearing minerals. These values are similar to or greater than the EMPA uncertainties even with uncorrected orientation (polarization) effects.

The chapter devoted to parallel electron energy-loss spectroscopy (PEELS) of boron in minerals is an excellent introduction to a seldom-used spectroscopic technique that apparently holds great promise for the examination of boron in minerals. Along with an explanation of the technique that is advanced enough to pique the interest of an initiate but not so detailed as to discourage it, the authors offer cogent examples and enough general theory to excite the reader to utilize PEELS. The information on coordination of boron in minerals potentially obtainable with the PEELS (and other mentioned) techniques helps satisfy the calculation of detailed thermochemical properties called for in other chapters of this volume.

A true nuts-and-bolts review of the analytical complexities of boron isotope analysis, the *Instrumental Techniques for Boron Isotope Analysis* chapter gives the reader a good quick look at the practicalities and imperfections of such analyses. It is left for the reader to refer back to Chapter 13 to realize what the sample preparation, analytical accuracy, and technique limitations mean to the application of boron isotope data to geochemical problems. Cross-referencing between the three major sections of this book is, in part, left to the reader but the data are there and the effort is worth it.

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