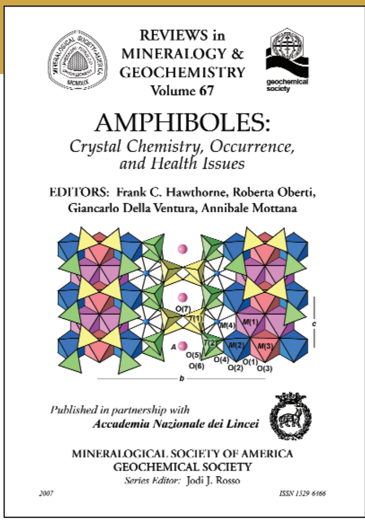
AMPHIBOLES: Crystal Chemistry, Occurrence, and Health Issues[1]



As noted in the preface, volume 9 of the Reviews in Mineralogy series, *Amphiboles and Other Hydrous Pyriboles*, published 25 years ago, seemed to contain all that was possible to know about this group of fascinating minerals. As this new RIMG volume (67) shows, that assessment was clearly wrong. The present volume incorporates advances in knowledge resulting from new instrumental techniques, the investigation of hitherto neglected rock types, and the development of new ideas.

The volume is published jointly by the Mineralogical Society of America (MSA) and the Accademia Nazionale dei Lincei (ANL). The 13 chapters provide an extensive review of materials presented by invited speakers at a three-day short course on amphiboles held at the Accademia Nazionale dei Lincei in Rome, Italy, October 29–31, 2007. The short course was organized by Frank C. Hawthorne, Roberta Oberti, Giancarlo Della Ventura, and Annibale Mottana.

In chapter 1, Hawthorne and Oberti present a concise overview of the subject, with several excellent color illustrations of amphibole structure types. This chapter discusses the wide range of chemical compositions in the amphibole group, which now includes Li-containing and exotic oxygenian amphiboles. It incorporates new aspects regarding concentrations of light lithophile elements, particularly Li and H, as well as unexpected solid solution between Na and Li in the M_4 site in monoclinic amphiboles, among other more standard aspects of amphibole crystal chemistry.

In chapter 2, Hawthorne and Oberti review earlier classification schemes and discuss their shortcomings in light of new data. They do not propose a new classification scheme, as this is the responsibility of the International Mineralogical Association (IMA). Instead, they outline problems associated with the earlier schemes. They suggest that a revised classification be based on the dominant cation (or groups of cations) instead of on a specific number of cations and that any future classification be based on chemical variations among the A, B, and C cations (in the schematic formula $AB_2C_3T_8O_{22}W_2$) instead of the A, B, and T cations.

In chapter 3, Oberti and others deal with amphibole compositions found over the last 25 years in nature and also dwell on the compositions of synthetic amphiboles used in studies to clarify the crystal chemistry of exotic cations.

Chapters 4 and 5 deal, respectively, with long-range order and short-range order. Oberti and others describe the experimental methods for determining site populations and then document in detail the site preferences of the most common cations and anions. Hawthorne and Della Ventura examine the short-range order (SRO) of cations and anions in monoclinic amphiboles and show that detailed information on SRO can be obtained from a combination of infrared spectroscopy and local bond-valency theory, augmented by results from Rietveld and single-crystal diffraction.

In chapter 6, Welch and others describe temperature- and pressure-induced structural transitions in amphiboles and focus on orthorhombic–monoclinic transitions in natural cummingtonite and synthetic, sodium-rich, lithium-containing Mg amphiboles. They also deal with in situ studies of temperature-induced non-convergent cation disorder in cummingtonite and Mg analogues of richterite.

Chapter 7, by B. Evans, is a comprehensive review of all the attempts that have been made to synthesize the end-member amphiboles. It focuses on the common rock-forming amphiboles in the system $Na_2O–CaO–MgO–FeO–Al_2O_3–SiO_2–H_2O$, in which consideration of metamorphic phase relationships provides some enlightenment regarding the possible attainment (or otherwise) of end-member compositions.

Following up on Evans' treatment of the intrinsic stability of some common amphibole end-members, Maresch and Czank review in chapter 8 the important published results on experimental reaction paths and discuss the many complications that can beset the experimentalist in the quest to synthesize single-phase amphibole of a specific composition.

Amphibole-group minerals are widespread in igneous rocks formed in extensional and subduction zone settings. Such amphiboles, as well as those in kimberlites, lamproites, carbonatites, and calc-alkaline granitic rocks, are discussed in detail by Martin in chapter 9.

Schumaker addresses the topic of metamorphic amphiboles in chapter 10. The metamorphic amphibole compositions presented here (approximately 3000) are based on analyses from the literature published (mostly) after 1980, that is, since Reviews in Mineralogy volumes 9A and 9B. The author examines the compositions and ranges of compositions of several thousand analyses and plots these in well-chosen compositional spaces. He also reviews coexisting amphiboles, particularly in light of TEM work done in the last 15 years. This section is very well illustrated with miscibility-gap diagrams based on the compositions of coexisting amphibole pairs.

In chapter 11, Tiepolo and others address the partitioning of trace elements between solid and liquid. Most of the mathematical models simulating melt generation, migration, and evolution within the mantle and/or crust require the availability of reliable solid–liquid partition coefficients for the mineral phases involved in the process. At constant pressure and temperature, trace-element solid–liquid partition coefficients depend on both melt and crystal structure. In both cases, bond-strength requirements and ionic radii govern the substitution of a trace element for a major constituent in a given polyhedron and thus determine the value of the partition coefficient. Extensive data tables and graphical illustrations document the partitioning of light lithophile elements, rare-earth elements, high-field-strength elements, actinides and Pb, and transition metals.

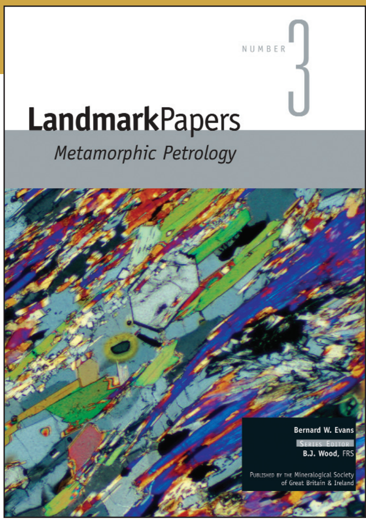
Chapter 12 (Gunter et al.) relates to amphibole asbestos issues. It describes the nomenclature used in the asbestos group minerals, the analytical methods used to differentiate and define the phases, and regulatory and legal issues. It illustrates the natural occurrence of asbestos minerals in various rock types and discusses the well-known asbestos problems in Libby, Montana (USA), El Dorado Hills, California (USA), and Biancaville, Sicily (Italy). A final section deals with the incorporation of amphiboles in biological materials. The chapter concludes as follows: (1) the health impact of inhalation of amphibole asbestos is worse than that of chrysotile asbestos; (2) the occupational exposure to amphibole asbestos is much more harmful than non-occupational exposure to amphibole asbestos; (3) it is not clear whether low-level environmental exposure to amphibole is a significant health risk; and (4) considerable research is still needed to understand how minerals behave in the lung.

In the final chapter, Cipriani gives a very interesting, historical account of the use of the names hornblende and amphibole, and of other species names from antiquity and the 18^{th}, 19^{th} and 20^{th} centuries. Most of the amphibole unknowns were resolved by the determination of the crystalline structure of amphiboles and pyroxenes by the father-and-son team of William Henry Bragg and William Lawrence Bragg, as well as by B.E. Warren in the period 1925–1930.

Cont'd on page 213

1 Hawthorne FC, Oberti R, Della Ventura G, Mottana A (2007) Amphiboles: Crystal Chemistry, Occurrence, and Health Issues. Reviews in Mineralogy & Geochemistry 67, Mineralogical Society of America, 570 pp, ISBN 978-0-939950-79-9, US$45 (25% discount for MSA and GS members)

LANDMARK PAPERS: *Metamorphic Petrology*[2]



Published by the Mineralogical Society of Great Britain and Ireland, the Landmark Papers series is intended to provide historical context, particularly for students, for the development of a particular branch of mineralogy. This volume (#3) contains Bernard Evans' selection of seminal articles in metamorphic petrology, and his delightful and invaluable commentary on each topic. Evans is absolutely the perfect scientist to have taken on this daunting task. He played an integral role in the flowering of metamorphic petrology after the 1950s, yet was directly linked to those who earlier laid its foundations—after all, how many of us actually spent time in the field discussing metamorphism with Pentti Eskola?! As Bruce Yardley notes in his gracious foreword, it is really Evans' commentary that compels the reading of this book. If pressed, any one of us could probably list a dozen or two articles that we view as integral to our science. But how many of us could explain as eloquently as Evans the context under which each article was written, how it was received at the time, and how it fostered further research? Few of us, indeed, and we are fortunate for his efforts.

The book consists of 15 chapters and 17 papers reproduced in the original form (one in translation). Yardley comments that several papers would not figure in the Science Citation Index, and I'll admit I had not read all of them previously, let alone referenced them. But make no mistake—the average number of citations per paper is well over 400, and 3 or 4 rate 1000+ citations each. Each represents a *major* contribution to our science, and scholars of metamorphic petrology are advised to read them and consider Evans' commentary closely. The chapters are organized chronologically and cover fairly specific topics, but rather than listing them individually, I think of their authors as focusing on three main questions:

1. How do we make sense of the minerals we observe in the field? (Barrow 1912; Eskola 1920; Ernst 1971; Ferry 1983; Chopin 1984; Austrheim 1987)
2. What are the chemographic and thermodynamic foundations for interpreting metamorphic mineral assemblages? (Goldschmidt 1912; Bowen 1940; Thompson 1957; Greenwood 1962; Hensen 1971)
3. How do we quantify the conditions or processes of metamorphism? (England and Richardson 1977; Ferry and Spear 1978; Helgeson et al. 1978; Wood and Walther 1983; Berman 1988; Holland and Powell 1990)

These articles and Evans' commentary illustrate not only the longevity of these questions, but also the importance of synthesis: many studies, as far back as Goldschmidt's and Eskola's, could be readily included in two or even all three categories. Seeing all these articles together helps us understand not only why we use the approaches we do, but also how multiple methods interconnect to illuminate larger questions of mass transport, mineral growth, plate tectonic processes, etc.

Evans notes that some readers may reasonably question his choice of articles. In part this reflects a planned Landmark Papers volume on experimental petrology that subsumed some articles he would otherwise have included. But we each have our biases. Were I to suggest landmark papers, I might include the importance of chemical zoning in metamorphic minerals and its quantitative interpretation (e.g. Hollister 1966), a bit more on the direct links between metamorphism and tectonics via P–T–t paths (i.e. not just England and Richardson's geodynamic modeling, but also Spear and Selverstone's field and theoretical analyses), and Carlson's work on mineral growth and textures. Others no doubt have their favorites as well. In that regard, I should stress that, first, not all research areas can be linked to a single landmark paper; for example, the origins of metamorphic geochronology are so diverse, they might be better discussed in other contexts. Many will notice that Frank Spear's monograph is repeatedly referenced and provides a good additional resource for students. Second, it is important that Evans' commentary does cover most alternative "landmark" articles and also some recent reviews. He fully acknowledges that ideas were developed in multiple ways with further major (arguably "landmark") contributions, and also that one researcher commonly produced multiple articles of similar import. For example, how do we choose *one* article from the numerous contributions of, say, Gary Ernst in high-pressure metamorphism or Philip England in geodynamics? Most of these "also ran" papers are referenced in Evans' commentary. So, if I have one quibble, it is really about how the Landmark Papers series is laid out. The historical context leading into a landmark paper is well defined, but the diversity and sheer number of subsequent articles make it difficult to know which were really important: in the forest of papers seeded by a "landmark" contribution, it is all too easy to lose the larger trees for all the smaller ones. It would help in future volumes to provide a mechanism for designating more clearly which half-dozen or so other articles represent major contributions associated with a landmark.

To return to this book's emphasis on interdisciplinary integration in metamorphic petrology, I remember once telling a fellow graduate student that I was studying metamorphic petrology, to which he replied, "Metamorphic petrology? I could never do that—you have to know too much about too many things." *Landmark Papers: Metamorphic Petrology* illustrates beautifully why metamorphic petrologists actually do routinely integrate thermodynamics, phase equilibria, kinetics, geodynamics, field methods, petrography, structural and regional geology, quantitative chemical analysis, mineral structure, and crystal chemistry. Perhaps most importantly, Evans' commentary captures the beauty and magic of metamorphism and metamorphic minerals, as well as the excitement that drove the curiosity of so many of geology's intellectual giants. We can only hope that these articles and commentary will further excite new generations of geology's finest.

Matthew J. Kohn
Boise State University

[2] Evans B (2007) Landmark Papers: Metamorphic Petrology. Mineralogical Society of Great Britain and Ireland Landmark Paper Series 3 295 pages, ISBN 978-0-903056-24-3, £32

AMPHIBOLES: CRYSTAL CHEMISTRY, OCCURRENCE, AND HEALTH ISSUES (Cont'd from page 212)

This book is well written, rich in high-quality illustrations, and carefully edited. It is a present-day synopsis of what is known in amphibole mineralogy, just as volume 9 of Reviews in Mineralogy was the most up-to-date compendium of amphibole knowledge 25 years ago. It is an essential volume for anyone who does research in the amphibole group; it is also a very necessary reference for anyone who teaches aspects of silicate mineralogy. It is a great reference volume, and I highly recommend it.

Cornelis (Kase) Klein
University of New Mexico