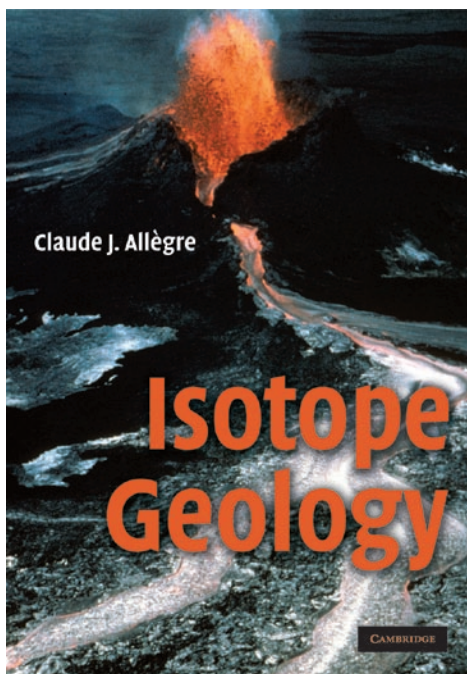


ISOTOPE GEOLOGY¹

Unlike physics or chemistry, teaching isotope geochemistry is difficult because it is such an interdisciplinary and experiential field. Learning isotope geochemistry is also difficult, not because it is technically difficult, but because geochemistry requires the synthesis of many concepts and applications. Writing an effective book on geochemistry is thus even more difficult. Claude Allègre's *Isotope Geology* is a welcome addition to the collection of Earth science textbooks, joining the two classic isotope geochemistry books by Gunter Faure and Alan Dickin.

You might ask whether there's a need for a new isotope geochemistry book, given how effective the texts by Faure and Dickin are. However, Allègre's *Isotope Geology* is presented using a fundamentally different approach. While Faure's and Dickin's texts are presented in encyclopedic format, that is, each chapter is dedicated to a given isotope system and its applications, *Isotope Geology* has distinctly avoided this format. Instead, each of Allègre's chapters deals with an over-arching concept, wherein case studies of isotope systems illustrate the meaning or importance of the concept. For example, chapters 2 and 3 are titled "The Principles of Radioactive Dating" and "Radioactive Dating Methods," respectively. In these two chapters, Allègre lays out all the radioactive decay equations that one will ever need, providing simple examples from different isotope systems to illustrate their application. He even explains the concept of "fossil" isochrons (not explicitly treated in Faure and Dickin); while the fossil isochron concept is almost mathematically trivial, I have noticed that it is a difficult concept for students to grasp. In any case, if a student can master chapters 2 and 3, he/she should be poised to examine any radioactive system. Allègre is clearly of the philosophy that one's fundamentals must be sound.

I can rave about many other aspects of this book. The most striking is Allègre's amazing ability to articulate concepts through simple and elegant figures and prose. All figures have been redrafted and distilled down to their bare essentials. The text is succinct and to the point, and the layout avoids unnecessary clutter and confusion. Whether this was intentional or not, the end product is like a clear whistle in a thick fog. A testament to the elegant simplicity of the book is that I can even make sense of my copy of the original French version, even though my French reading abilities are horrible. Another highlight is that we get



to see a little bit of Allègre's own perspective. The text is punctuated by anecdotes that liven up the discussion and provide a personal connection with the reader. In some cases, Allègre relates the history of certain ideas or controversies, thus implying that science is a human endeavor marked by fits of brilliance as well as mistakes. Allègre lays out what is now known and what still has not been resolved, inspiring the inquisitive student to explore further.

A few other highlights are worth mentioning. Chapter 7 provides an up-to-date overview of the principles of stable isotope geochemistry, focusing first on fundamentals and then touching on specific examples in low- and high-temperature geochemistry. I was pleased to see discussions on the use of mass-independent fractionation as paleoenvironment records and of "clumped" isotopes in estimating temperature. Chapter 6, "Radiogenic Isotope Geochemistry," summarizes the application of radiogenic isotope tracers in understanding planetary differentiation, clearly one of Allègre's favorite topics. In the last chapter, "Isotope Geology and Dynamic Systems," Allègre provides a much-needed overview of box modeling and mass transport modeling. A student will come away with a sound understanding of residence and response times in geochemical systems. While such concepts are also considered in Albarède's *Introduction to Geochemical Modeling and Introduction to Geochemistry*, this is the first time that such a treatment is explicitly presented in an isotope geochemistry book. This is just another example of Allègre's process-based approach.

Since this is supposed to be a critical review, I should mention how *Isotope Geology* can be improved. Given the importance of concepts and fundamentals in this book, it would have been better to delve even deeper into certain themes. For example, there is only limited discussion about nuclear chemistry and physics. What controls the mass of nuclei? What are mass defects? Why are some nuclei unstable? How would one calculate the amount of energy released by radioactive decay? One homework problem asks for the total heat released by decay of a certain amount of a radioactive element. The reader is given the heat-production rate, but it would be nice to know how this number is determined. Another example concerns the chapter on stable isotope geochemistry. Although the equations for equilibrium and kinetic isotope fractionation are presented, Allègre could have elaborated on the physics of equilibrium isotope fractionation as they relate to bond strengths and energy wells, perhaps including some key concept figures. Finally, given the recent rush to study stable isotope fractionation of the heavy metals, I would have enjoyed more than just two pages of discussion on this topic.

I can't help pointing out one egregious error. This involves the story of Lord Kelvin and why he was wrong about the age of the Earth. The almost universally accepted story, the one presented by Allègre, is that Lord Kelvin did not take radioactivity into account in his heat-conduction equations. In fact, a simple calculation shows that accounting for radioactivity doesn't improve Kelvin's situation much. The real reason why Kelvin's estimate was wrong was because of a fundamental flaw in his model, that is, the Earth loses interior heat to the surface by convection, not by conduction. For a review of the correct version of the story, see a piece by England, Molnar, and Richter in *GSA Today* (2007).

In conclusion, Allègre's book represents a long-awaited contribution, which complements those by Faure and Dickin. Read Allègre's book first, then turn to Faure or Dickin for detailed examples of applications for a specific isotope system. Not only is this trio of books on my bookshelf, but I recommend the entire set to my students. This book is accessible to all, not just geochemists, but also geophysicists. Last, I much prefer the purple-laced Kandinsky cover of the original French edition, as it looks much prettier on my bookshelf.

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¹ Allègre CJ (2008) *Isotope Geology*; translated by Christopher Sutcliffe. Cambridge University Press, Cambridge, ISBN 978-52186-228-8, 512 pages, \$80

WORKING WITH MIGMATITES²

The Mineralogical Association of Canada is well known for the short course volumes it has published over the past forty years on various geological topics. One of the most recent volumes, *Working with Migmatites*, edited by Edward W. Sawyer and Michael Brown, appeared shortly after the release of *Atlas of Migmatites*, by E. W. Sawyer, a special publication by the same association that beautifully illustrates migmatites from the outcrop to the grain scale. The nearly synchronous publication of these two volumes is not accidental, but simply demonstrates that it was an opportunity moment to summarize current knowledge after a period of sustained and fruitful research on crustal melting. Numerous studies have improved our knowledge of melting reactions, melt segregation and transfer, and the role of partially melted rocks in the evolution of orogens. Nonetheless, no synthesis of the current research on migmatites has been published since the outstanding work by K. R. Mehnert in 1968, the volume edited by M. P. Atherton and C. D. Gribble in 1983, and the publication by J. R. Ashworth in 1985.

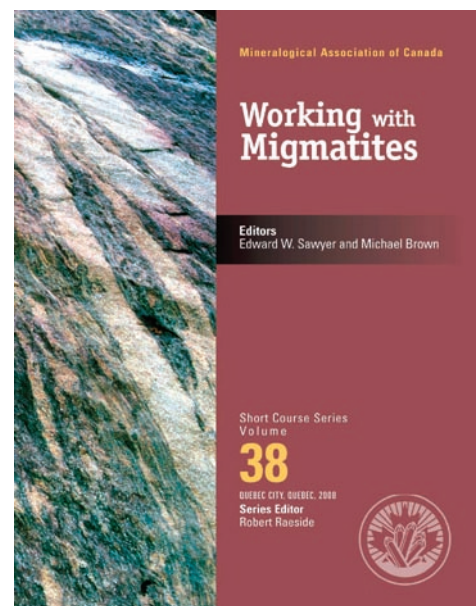
Working with Migmatites fills the gap, paying special attention to those who “don’t know where to start” with these fascinating or confusing rocks (depending on one’s viewpoint). The book is easily accessible to anyone having a minimum familiarity with metamorphic and igneous petrology. It addresses three main topics covering different scales of observation: (1) how to study migmatites in the field, (2) what textures tell us about the process of anatexis, and (3) how migmatites are linked to granites and to the evolution of the continental crust.

The first two chapters (by Ed Sawyer), which are echoed in the last chapter, serve essentially as a guide to studying migmatites from sample to map scale. The chapters have two main focuses: how to describe migmatites, and how to collect pertinent geological information in complex-looking rocks. E.W. Sawyer revisits the constituent parts of migmatites and proposes a simplified terminology based on the current view that migmatites are formed by partial melting. This choice offers the definite advantages of giving the terminology overall consistency—thus making it more accessible to a non-specialist—and of proposing divisions that reflect the amount and distribution of the anatectic melts and related residual rocks at the outcrop scale. Gary S. Solar, in the final

chapter, underscores the opportunity offered by the study of migmatite geometries to understand segregation and flow histories and their relationships with plutons. The main point here is that, even though migmatites look like “swirled-up soup,” they are basically structurally coherent rocks, which can provide us with information on the relationships between deformation, migmatite morphology and map-scale melt distribution. An essential point is that, due to the heterogeneity of migmatites, the scale of observation is critically linked to the object of the study: each scale provides its own specific type of information.

The next three chapters deal with phase assemblages and microstructures as indicators, from sample to grain scale, of the presence and distribution of former melt—key points for understanding rock rheology and melt segregation. However, the use of thin sections to reconstruct the anatectic event, and especially the melt distribution pattern at the grain scale in migmatites, is hampered by the fact that most microstructures result from superposition of solidification and subsolidus transformations. This difficulty may be circumvented by studying quenched, natural, melt-bearing enclaves and pyrometamorphic rocks and by modeling partial melting reactions. Bernardo Cesare (chapter 3) shows that partially melted enclaves from “erupted migmatites” allow direct insight into melting reactions, melt composition and melt distribution. An original and interesting section dealing with melt inclusions is worth noting. Marian B. Holness (chapter 4) reviews the microstructural criteria for establishing the distribution of former melt at the grain scale and discusses the effect of textural maturation, melt extraction and cooling rates on the preservation of initial melt geometries. The improvement of our understanding of microstructures in two-phase rocks (melt + solid) from field and experimental studies probably constitutes one of the main advances in the knowledge of melt-bearing rocks over the past twenty years. Of particular importance are the relationships between mineral reactions, nucleation and growth, which exert a first-order control on the production and distribution of melt. Richard W. White (chapter 5) illustrates how petrological modeling of high-variance assemblages offers, notwithstanding some difficulties, many new possibilities. These include providing a predictive framework for localizing melt production pulses in P–T space, showing how melt loss can influence melt production and back reactions, and evaluating the effect of the diffusive process on spatial focusing of reactions and melt production.

The last topic dealt with in this volume (chapter 6) concerns the migmatite–granulite–granite connection, in other words, the differentiation of the continental crust related to the transfer



of magma from the zone of production to the zone of emplacement. Michael Brown introduces the subject with a short presentation of several key issues, such as the fertility of crustal rocks, the source of heat for melting, the volume of melt generated, and the spacing of intrusions. He then reviews the processes involved in the production of magmas in the mid-crust and their transfer to the upper crust, from melting and melt extraction to magma ascent and emplacement. Emphasis is placed on the role of mantle input in crustal melting and on the effect of accessory minerals on melt chemistry, factors that complicate the quest for the source of granites. However, most of the chapter is concerned with the mechanics of melt extraction and emplacement and with the relationship between melt extraction and mesoscale structures in migmatites and granulites, starting with veins as the first drainage pathway focusing magma flow. An interesting comparison is made between numerical and experimental models, with a review of the different modes of flow leading to the development of a dynamic self-organized system. The chapter ends with an illustration of a 3-D interpretation of migmatite–granite relations in orogenic crust.

Overall, reading the seven chapters of this volume may give the impression that migmatites are relatively simple rocks to tackle. However, more than the reality, this reflects the teaching skills of the authors and the illuminating effect of integrating various approaches. I don’t know whether this landmark contribution will encourage a new generation of petrologists to take an interest in migmatites, but I have no doubt that it will be, for some time, the reference for all those interested in crustal melting, for either research or teaching purposes.

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² Sawyer EW, Brown M (eds) (2008) *Working with Migmatites*. Mineralogical Association of Canada Short Course Volume 38, ISBN 978-0-92129-446-7, 158 pp, \$40