

ISOTOPE GEOLOGY

Radiogenic and stable isotopes are used widely in the Earth sciences to determine the ages of rocks, meteorites, and archeological objects, and as tracers to understand geological and environmental processes. Isotope methods determine the age of the Earth, help reconstruct the climate of the past, and explain the formation of the chemical elements in the Universe. This textbook provides a comprehensive introduction to both radiogenic and stable isotope techniques. An understanding of the basic principles of isotope geology is important in a wide range of the sciences: geology, astronomy, paleontology, geophysics, climatology, archeology, and others.

Claude Allègre is one of the world's most respected and best-known geochemists, and this textbook has been developed from his many years of teaching and research experience.

Isotope Geology is tailored for all undergraduate and graduate courses on the topic, and is also an excellent reference text for all Earth scientists.

CLAUDE ALLÈGRE is extremely well known globally in the Earth science research and teaching community. He is currently an Emeritus Professor at the Institut Universitaire de France, Université Denis Diderot, and the Institut de Physique du Globe de Paris, and has had a long and illustrious career in science. He is a former Director of the Department of Earth Sciences, Université Paris VII, former Director of the Institut de Physique du Globe de Paris, past President of the French Bureau of Geological and Mining Research (BRGM), and former National Education Minister for Research and Technology for the French government. In his career he has won most of the available honours and awards in the geosciences, including the Crafoord Prize from the Swedish Royal Academy of Sciences, the Goldschmidt Medal from the Geochemical Society of America, the Wollaston Medal from the Geological Society of London, the Arthur Day Gold Medal from the Geological Society of America, the Médaille d'Or du CNRS, the Holmes Medal from the European Union Geosciences, and the Bowie Medal from the American Geophysical Union. He is member of several academics: Foreign Associate of the National Academy of Sciences (USA), Foreign Member of the Academy of Art and Science, Foreign Member of the Philosophical Society, Foreign Member of the Royal Society, Foreign Member of the National Academy of India, and Membre de l'Académie des Sciences de Paris. He is also a Commandeur de la Légion d'Honneur, a past President of the European Union of Geosciences, past President of the NATO Earth Sciences Committee, and former editor of the journals *Physics of the Earth and Planetary Interiors* and *Chemical Geology*. He has written hundreds of research articles, and 25 books in French.

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Dedication

I dedicate this book to all those who have helped me to take part in the extraordinary adventure of developing isotope geology.

To my family, who have probably suffered from my scientific hyperactivity.

To those who were paragons for me and have become very dear friends: Jerry Wasserburg, Paul Gast, George Wetherill, Al Nier, John Reynolds, Mitsunobu Tatsumoto, Clair Patterson, George Tilton, Harmon Craig, Samuel Epstein, Karl Turekian, Paul Damon, Pat Hurley, Edgar Picciotto, Wally Broecker, and Devendra Lal. I have tried to stand on their shoulders.

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PREFACE

Isotope geology is the offspring of geology on one hand and of the concepts and methods of nuclear physics on the other. It was initially known as “nuclear geology” and then as “isotope geochemistry” before its current name of isotope geology came to be preferred because it is based on the measurement and interpretation of the isotopic compositions of chemical elements making up the various natural systems. Variations in these isotope compositions yield useful information for the geological sciences (in the broad sense). The first breakthrough for isotope geology was the age determination of rocks and minerals, which at a stroke transformed geology into a quantitative science. Next came the measurement of past temperatures and the birth of paleoclimatology. Then horizons broadened with the emergence of the concept of isotopic tracers to encompass not only questions of the Earth’s structures and internal dynamics, of erosion, and of the transport of material, but also problems of cosmochemistry, including those relating to the origins of the chemical elements. And so isotope geology has not only extended across the entire domain of the earth sciences but has also expanded that domain, opening up many new areas, from astrophysics to environmental studies.

This book is designed to provide an introduction to the methods, techniques, and main findings of isotope geology. The general character of the subject defines its potential readership: final-year undergraduates and postgraduates in the earth sciences (or environmental sciences), geologists, geophysicists, or climatologists wanting an overview of the field.

This is an educational textbook. To my mind, an educational textbook must set out its subject matter and explain it, but it must also involve readers in the various stages in the reasoning. One cannot understand the development and the spirit of a science passively. The reader must be active. This book therefore makes constant use of questions, exercises, and problems. I have sought to write a book on isotope geology in the vein of Turcotte and Schubert’s *Geodynamics* (Cambridge University Press) or Arthur Beiser’s *Concepts of Modern Physics* (McGraw-Hill), which to my mind are exemplary.

As it is an educational textbook, information is sometimes repeated in different places. As modern research in the neurosciences shows, learning is based on repetition, and so I have adopted this approach. This is why, for example, although numerical constants are often given in the main text, many of them are listed again in tables at the end. In other cases, I have deliberately not given values so that readers will have to look them up for themselves, because information one has to seek out is remembered better than information served up on a plate.

Readers must therefore work through the exercises, failing which they may not fully understand how the ideas follow on from one another. I have given solutions as we go along,

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sometimes in detail, sometimes more summarily. At the end of each chapter, I have set a number of problems whose solutions can be found at the end of the book.

Another message I want to get across to students of isotope geology is that this is not an isolated discipline. It is immersed both in the physical sciences and in the earth sciences. Hence the deliberate use here and there of concepts from physics, from chemistry (Boltzmann distribution, Arrhenius equation, etc.), or from geology (plate tectonics, petrography, etc.) to encourage study of these essential disciplines and, where need be, to make readers look up information in basic textbooks. Isotope geology is the outcome of an encounter between nuclear physics and geology; this multidisciplinary outlook must be maintained.

This book does not set out to review all the results of isotope geology but to bring readers to a point where they can consult the original literature directly and without difficulty. Among current literature on the same topics, this book could be placed in the same category as Gunter Faure's *Isotope Geology* (Wiley), to be read in preparation for Alan Dickin's excellent *Radiogenic Isotope Geology* (Cambridge University Press).

The guideline I have opted to follow has been to leave aside axiomatic exposition and to take instead a didactic, stepwise approach. The final chapter alone takes a more synthetic perspective, while giving pointers for future developments.

I have to give a warning about the references. Since this is a book primarily directed towards teaching I have not given a full set of references for each topic. I have endeavored to give due credit to the significant contributors with the proper order of priority (which is not always the case in modern scientific journals). Because it is what I am most familiar with, I have made extensive use of work done in my laboratory. This leads to excessive emphasis on my own laboratory's contributions in some chapters. I feel sure my colleagues will forgive me for this. The references at the end of each chapter are supplemented by a list of suggestions for further reading at the end of the book.

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