Principles of Radiometric Dating

The time dependent decay of naturally-occurring radioactive isotopes or in-growth of their radioactive or stable daughter products form the basis of radiometric dating of several natural processes. Developed in the beginning of the last century mainly to determine the absolute ages of rocks and minerals, radiometric chronology now plays a central role in a broad range of Earth and planetary sciences - from extra-solar-system processes to environmental geoscience. With the pre-requisite of only college level knowledge in physics, chemistry and mathematics, this concise book focuses on the essential principles of radiometric dating in order to enable students and teachers belonging to diverse fields of studies to select, understand, and interpret radiometric dating results generated and published by professionals.

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The author dedicates this book to the two authors of his being
(parents, Ramamrutham Kunchithapadam and Pattammal Kunchithapadam),
and the three authors of his becoming
(mentors, Prof V. S. Venkatasubramanian, Prof G. W. Wetherill and Prof D. Lal).

Contents

Preface

The time-dependent accumulation of helium and lead from the radioactive decay of uranium in minerals and rocks was suggested by Rutherford in 1905 as a means of determining their absolute ages. This seminal idea has been assiduously pursued in the last century by unorthodox physicists and chemists to detect and quantitatively measure numerous radioactive isotopes of widely varying lifetimes and abundances in natural systems. Absolute age determination based on these isotopes, called radiometric dating, now plays a central role in a broad range of Earth and planetary sciences: paleoseismology; paleomagnetism; paleooceanography; igneous, metamorphic and sedimentary petrology; geomorphology; geochemistry; tectonics; nucleosynthesis; cosmochemistry; planetary science; geobiology; paleoclimatology; paleoanthropology; and archeology. Assuming that the reader has only college level knowledge of physics, chemistry, and mathematics, this concise book (about 200 pages) focuses on the essential principles of radiometric dating in order to enable the students and teachers in various fields to quickly figure out the criteria to be met by parent-daughter systems and samples relevant to their specialization. This book draws heavily on three classic review articles which, in my view, capture the intellectual appeal and beauty of the subject for a very wide audience (Wetherill et al., 1981; Wasserburg, 1987; Allegre, 1987). I believe that this book will succeed in improving students' understanding and appreciation of radiometric dating results generated and published by professionals. I hope it would also stimulate interest in students to take up isotope geology as a serious study and reach out for the excellent and comprehensive books on the subject.

The material presented in each of the 11 chapters is self-contained. However, the reader is urged to read all the chapters, as they are strung together into a concise, continuous, and easily comprehensible narrative to illuminate the subject as a whole. Vital points behind radiogenic isotope chronometry are stressed upon more than once. The reference list is mainly for students interested in further reading.

Chapter 1 covers the basic facts of nuclear and atomic physics, nuclear binding energy as a measure of nuclear stability, and the variety and relative abundance of different elements in the sun and the primitive meteorites. Chapter 2, then, moves on to the transformation of composition of nuclides, either spontaneously (radioactivity) or by external agents (induced nuclear reactions), and highlights the role of feeble natural radioactivity, both in driving and dating planetary processes. It ends with a section on an important aspect of radioactivity, namely its statistical nature. Chapter 3, on nucleosynthesis, builds on the first two chapters to show that the process of formation of elements (strictly-speaking, stable and unstable nuclides) inherited by the Solar System, is due to

a complex combination of nuclear reactions induced by charged particles in the interior of stars, and by neutrons in the final stages of stellar evolution. The chapter brings out the important point that the science of radiometric chronology, pivotal in many discrete disciplines, rests on the time required by various unstable nuclides, produced in stellar and terrestrial nuclear reactions, to reach a stable nuclear composition. Chapter 4 on 'isotopics' introduces the reader to the practical unit of measuring isotope abundances, the dramatic differences in isotope effects between nuclear and atomic domains, and familiarizes the reader with the notation of isotopic mixtures of an element. The chapter ends with the simple mathematical derivations of mixtures of isotopically different elements.

There are many and somewhat different ways in which the radioactive isotopes and their daughter products are used to date natural events and processes. But, the one common feature of these different methods is that they all measure a radioactive decay interval. It is only the meaning and interpretation of a measured decay interval that depends on the scientific context, the sample analyzed, the decay system selected, and the analytical method employed. Chapter 5 builds on this underlying unifying principle to show that all known applications of radiometric dating follow from the creative use of the basic radioactive decay process and imaginative selection of natural samples. I believe that this compact and generalized treatment can enhance critical and individualistic thinking among users of radiometric age results. The mathematical equations in this chapter are difficult only superficially, as they are based on elementary mathematics.

Advancements in mass spectrometers have largely dictated the advances in radiometric dating. Chapter 6 relies on simple figures to explain the three basic components of mass spectrometers and improvements in each of them, in a reader friendly way. Chapter 7 provides a rigorous yet easily understandable treatment of statistical error analysis.

Published text typically examines each isotope system separately, chapter after chapter. In contrast, chapters 8, 9, 10, and 11 in this book explore a few aspects of the evolutionary chronology of meteorites, the least evolved planetary objects available for laboratory analysis, and the Earth, a highly evolved planet, respectively, by examining relevant isotopic systems that illuminate the temporal aspects of evolution. Illustrations or case studies have been carefully chosen to bring out the excitement of research and discovery in radiometric chronology, in particular, and radiogenic isotope geology, in general.

Finally, each chapter begins with an apt quotation(s) from famous personalities to alert the readers of its content and also to leave a lasting impression on their minds.

Readers are invited to write to me, at *gopalank1@rediffmail.com*, regarding any errors, comments, and suggestions for improvement. Positive feedbacks are, of course, welcome, if they are warranted. I do hope that readers from various fields will find this book a good investment as well as a quick reference source.

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I am grateful to Professor J. D. Macdougall and Professor M. E. Bickford for reading all the chapters of the book in order to provide constructive suggestions, improvements in its presentation, and the correction of numerous errors in the language. I am indebted to Professor R. K. O'Nions and Professor Bor-ming Jahn for their encouragement, constructive criticism and suggestions for improvement. However, all the shortcomings in this book and the errors of omission are entirely my responsibility. I thank V. Rajasekhar for the art work. I thank M. Choudhary of Cambridge University Press in India for his encouragement and taking the necessary decisions that enabled me to publish this book. I am very grateful to the Indian National Science Academy for giving me the position of the Honorary Scientist, which enabled me to write this book. Finally, my thanks go to my wife, Savithri and son, Ramesh for their understanding and support.

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