COSMOGENIC NUCLIDES

Principles, Concepts and Applications in the Earth Surface Sciences

This is the first book to provide a comprehensive and state-of-the-art introduction to the novel and fast-evolving topic of *in-situ* produced cosmogenic nuclides. It presents an accessible introduction to the theoretical foundations, with explanations of the relevant concepts, starting at a basic level and then building in sophistication. It incorporates, and draws on, methodological discussions and advances achieved within the international CRONUS (Cosmic-Ray Produced Nuclide Systematics) networks. Practical aspects, such as sampling, analytical methods and data interpretation are discussed in detail and an essential sampling checklist is provided. The full range of cosmogenic isotopes is covered and a wide spectrum of *in-situ* applications are then described and illustrated with specific and generic examples of exposure dating, burial dating, erosion and uplift rates, and process model verification.

Graduate students and practitioners will find this book a vital source of information on the background concepts and practical applications in geomorphology, geography, soil science and geology.

TIBOR J. DUNAI is a Reader in Geomorphology at the University of Edinburgh and has extensive research experience in the field of cosmogenic nuclides and their applications to Earth sciences. He was the initiator and coordinator of CRONUS-EU and is on the steering committee of CRONUS-Earth, and his methodological work on cosmogenic-nuclide production has been fundamental to the research of these networks. Dr Dunai has taught at several specialist training workshops, and organized the CRONUS-EU summer school on methodology and Earth science applications of cosmogenic nuclides. This book stems from these training events and is designed to address the expressed requirements of the participants, who included experienced practitioners as well as novices to the technique.

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Preface

Cosmogenic nuclides have become a widely used tool to address scientific questions in Earth surface sciences. Major advances in analytical sensitivity, accuracy and precision in the late 1980s made application to problems in Earth sciences feasible. In particular, widespread use of *in-situ*-produced cosmogenic nuclides has revolutionized Earth surface sciences in the last 15 years. The capabilities to quantify the geomorphic stability of surfaces exposed to cosmic rays and to determine long-term erosion rates were quickly adopted to address, and resolve for the first time, a wide range of first-order problems in the fields of geomorphology, glaciology, palaeoclimatology, palaeoseismology, soil science, volcanology and geohazard research. In the pioneering days of cosmogenic nuclide methodology, it was commonly the same researchers who developed, as well as applied, the methodology; with increasing specialization and division of work, and with new researchers entering the fields as users, this is becoming relatively rare. While it is not feasible, and probably not necessary, for every user of the cosmogenic methodology to know *every aspect* of the methodological basis, a firm knowledge of the fundamentals is crucial for applying the method safely in the natural environment. This is because scientific questions and field situations may often be similar, but they are rarely identical, usually requiring a knowledgeable adaptation of generic 'recipes' to design a particular scientific approach and sampling strategy. Also, readers of scientific findings based on evidence derived from cosmogenic nuclides (users *sensu lato*) should be able to assess the robustness of data in the light of the method's strengths and limitations. These user requirements have set the initial framework of this book: providing an as simple as possible and as complete as necessary account of the current state of cosmogenic nuclide methodology used in Earth surface sciences. As a consequence, this book was written with the

aim to enable interested users to 'think cosmogenic', i.e. to appreciate scientific approaches used by others, as well as successfully design research applications of cosmogenic nuclides for their own research. However, I also hope that seasoned practitioners in the field will find this compendium useful.

In a textbook of this kind, it is necessary to strike a balance between the amount and type of literature cited to keep it readable, while giving sufficient guidance to readers to find their way through the plethora of pertinent literature. The literature cited must be wide ranging, but cannot be complete. I have attempted to find an equilibrium between giving appropriate acknowledgment to the pioneering studies, while, at the same time, pointing the reader in the direction of the most recent developments in the field. Also, where available for special topics, I provide references to recent review papers or papers that summarize a certain topic in an exemplary way, instead of listing the papers they rely on. I trust that I will receive feedback if I haven't got this balance right.

The past 10 years have seen a remarkable activity on aspects of cosmogenic nuclide methodology, particularity of how best to determine cosmogenic nuclide production rates for any location on Earth. At the time of writing, the research results of two international research consortia CRONUS-EU (EU-funded, 2004–2008) and CRONUS-Earth (NSF-funded, 2005–2010) indicate that one of their original goals, the ability to reproducibly obtain cosmogenic nuclide production rates better than 5%, is within reach. A wide range of additional methodological improvements (refinement of half-lives; production pathways; sampling strategies etc.) were achieved by CRONUS and other researchers world-wide over this period. As far as fitting the scope of this book, these new developments were incorporated.

This book profited inestimably from continuous discussions with fellow researchers of *CRONUS-EU* and *CRONUS-Earth*, and from exchanges with colleagues on joint cosmogenic sampling expeditions over the past 12 years. Some of these discussions were heated, and I am particularly grateful for those. The questions asked by participants of the *CRONUS-EU* workshops and summer school made me realise that there may be a gap in the literature that would be worth filling; this realization was particularly keen at moments when I struggled to give simple answers to relatively simple questions. I am very grateful for the critical eyes of my colleagues Nat Lifton, Steve Binnie, Fin Stuart and Richard Philips who have read and commented on drafts of the manuscript/chapters. They provided valuable suggestions that helped to

improve the final version significantly. Any lingering omissions or factual mistakes remain my responsibility. Rachel Walcott transformed essential climate data used in Figure 3.2 into a format I could handle, which is gratefully acknowledged. Further, I am grateful for the Leverhulme research fellowship, which enabled me to create time to write this book, and for the patience of the editor Susan Francis while waiting for its delivery.

Overall, my greatest debt is to my wife Karin; without her moral support and patience, proof-reading and help with drawing and editing, the book would probably not have been finished before the publisher (and I) had lost faith in the project. This book is, therefore, for her.

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