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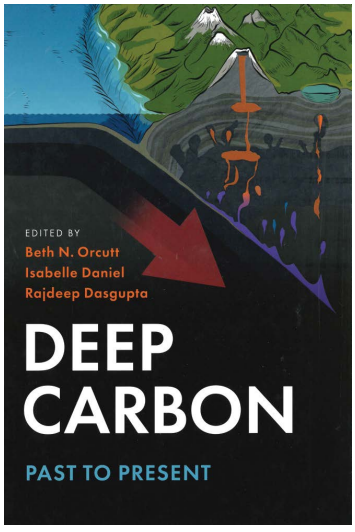
Book Review

Book Review: Deep Carbon: Past to Present. (2020) Edited by Beth N. Orcutt, Isabelle Daniel, and Rajdeep Dasgupta. Cambridge University Press. ISBN 978-1-108-47749-9, 684 pages, $79.99 Hardcover. Also available as an Open Access text at https://doi.org/10.1017/9781108677950.



Carbon is essential to the origins and evolution of life, the behavior of the climate system, and a host of Earth-surface processes. It is therefore astounding that an estimated 90% of Earth's carbon is concentrated deep beneath the surface: in the core, mantle, and deep crust. Not all of this "deep carbon" is permanently buried—plate tectonic activity and magmatic processes drive the continual flux of carbon into and out of these deep reservoirs, intricately linking carbon in the deep Earth with carbon at the surface—but these processes offer only a limited glimpse into what is going on beneath the surface of our planet.

To study the diversity of carbon's forms, behaviors, environments, and histories at great depth requires knowledge and instrumentation that have only recently become available and been put to the task. From 2009 to 2019, an interdisciplinary coalition of nearly a thousand scientists from three dozen countries—united under the umbrella of the Deep Carbon Observatory (DCO)—engaged in a collective effort to study the nature of Earth's deep carbon; to probe its origins, quantities, and movements (and how these have changed over eons); and to characterize its relationships to other elements, to planetary processes, and to life on (and in!) the planet.

Deep Carbon: Past to Present summarizes in one volume some of the most exciting developments that have arisen from this collaborative research effort. The book itself is a representation of the collective work undertaken by this international initiative: individual chapters are written by the investigators who undertook research in the chapter's subject; the volume was compiled and edited by DCO members; and numerous original figures, which are gorgeous and take advantage of the book's full-color format, were drafted especially for this publication by a member of the collaborative.

The structure of the book is logical and follows from the organization of the DCO into four thematic communities. Chapters 2 through 7 summarize the work of the Extreme Physics and Chemistry Community, including the mechanisms and timing of carbon's origins on Earth, its distribution throughout the planet's interior over time, its forms and movements, and the effects of those dynamics on planetary processes at various temporal and spatial scales. Chapters 8 through 11 report on the research of the Reservoirs and Fluxes Community, including the delivery of carbon to the surface through subaerial and submarine volcanism, its return to the interior via subduction, and the influence of these processes on the surface carbon cycle and, in turn, on the climate, the hydrosphere, and life at the surface.

Chapters 12 through 15 cover the work of the Deep Energy Community, with discussions of the structure, transport, and reactivity of carbon-bearing phases under the unique conditions of the deep Earth, the processes that can generate these materials, and ways to study and characterize them in a laboratory setting. Chapters 16 through 19 detail the investigations of the Deep Life Community, including the distribution and diversity of organisms in the subsurface, their interactions with and influences on the cycling of carbon-bearing materials, and the sources of energy for these processes. Chapter 20 (Deep Carbon Through Deep Time: Data-Driven Insights) concludes the volume by exhibiting the transformational power of applying state-of-the-science analysis and visualization methods to the wealth of presently available geological and biological data.

The text is highly readable. Chapters are information-rich without being information-dense and range in length from about 25 to 50 pages, including references. Each chapter explicitly highlights connections between deep carbon and surface carbon, in addition to thoroughly discussing the techniques—experimental, analytical, and theoretical—used to interrogate the chapter's topic. The descriptions of processes, phenomena, and their analysis are more technical and in-depth than in most textbooks while retaining a slightly more casual tone than might be expected in a journal manuscript. This intermediate style serves the material well by rendering it readable and interesting to seasoned researchers and students alike.

Although the book is best read as a complete volume, individual chapters have the potential to serve as standalone references either for interested professionals or for educators wishing to provide their students with comprehensive overviews of selected topics. For example, Chapter 2 (Origin and Early Differentiation of Carbon and Associated Life-Essential Volatile Elements on Earth) might be appropriate as a reading for students in an introduction to geochemistry, while Chapter 11 (A Framework for Understanding Whole-Earth Carbon Cycling) could be included in a course on the climate system.

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The "Questions for the Classroom" section at the end of many chapters is an attractive feature, though the style of the questions varies somewhat from chapter to chapter. In Chapter 16 (Carbon in the Deep Biosphere: Forms, Fates, and Biogeochemical Cycling), for example, the questions are open-ended prompts for discussion that require the reader to integrate the chapter's overarching points with its technical details, inviting extrapolation, creativity, and conjecture. In some chapters, including Chapter 13 (A Two-Dimensional Perspective on CH_4 Isotope Clumping) and Chapter 17 (Biogeography, Ecology, and Evolution of Deep Life), the questions act as more of a content check to ensure the reader has understood the main points and can explain them clearly. Other chapters, such as Chapter 4 (Carbon-Bearing Phases throughout Earth's Interior: Evolution through Space and Time), Chapter 9 (Carbon in the Convecting Mantle), and Chapter 14 (Earth as Organic Chemist), contain a mix of question types and exercises, inviting various modes of engagement from the reader. Overall, the "Questions" offer the reader a valuable opportunity to reflect on and engage with the material, whether alone, in a group, or in the classroom.

It bears noting that, in addition to expecting a fundamental background in Earth sciences, many chapters assume literacy in general chemistry, including thermodynamics; notation and processes related to elemental abundances and isotopes; and some differential calculus. Though unfamiliarity with these subjects should not preclude a decent understanding of most of the material, the text is most comfortably geared toward those with prior coursework in mathematics, chemistry, Earth science, and physics at the college level.

Making such high-caliber scholarship available in an open access format is outstanding and unfortunately rare, and it should be celebrated. The text's online availability reinforces its suitability for use as a classroom reference. The open access version of the text includes hyperlinks to referenced literature and from one chapter to another, and it also makes available many of the high-quality figures mentioned previously, which can be expanded for a closer view or downloaded. Although a few animations and data tables are included on the open access site, other supplementary material—including databases and resources for students and educators—are hosted on the DCO website (deepcarbon.net).

The book does lack some of the unity and consistency one might hope for in an edited volume. The introduction heralds the text as a "synthesis of the transformational discoveries in interdisciplinary deep carbon science that have occurred over the past decade" (p. 1). The text, however, does little to synthesize the separate but related topics covered in each chapter. Although each chapter provides its own summary, I would really like to have seen a concluding chapter devoted to drawing together (1) the advances in deep carbon science since the origins of the DCO that are covered throughout the volume, (2) the state of the field now, and (3) a sketch of the way forward: What outstanding questions are most pressing? What next steps will be key to addressing them? And how do the discoveries of the past decade set the stage for these future investigations?

In a way, the volume itself serves as this synthesis. When read as a complete unit, the book is more than the sum of its chapters. What shines through is the truly masterful work done by this collaborative of researchers in producing a text that is at once deeply technical and highly readable, simply yet beautifully presented, logically structured while touching on nearly every field of science and technology—all within a year of the conclusion of the DCO's decade-long endeavor. Particular praise is due to the individual chapter authors and the editors of the volume, who have evidently made great efforts to ensure the validity, relevance, and accessibility of the content in each chapter and throughout the book, an objective which has been decisively met. As a text reflecting the fundamental interdisciplinarity of the DCO's research, *Deep Carbon: Past to Present* offers a wealth of insight into the workings of our planet that should be of interest to scientists from any field. Anybody with an interest in the science of Earth stands to enjoy the book as a whole.

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