or the distinction of individual versus community versus superorganism.

At issue is the conflict of how science perceives and represents reality. It is the debate between reductionism and holism, of clarifiers and turbidifiers, of analytics versus emergence, and of generalizing from a defined or settled set of information or inferring from incomplete data. Quammen does a convincing job of showing how Woese's claim of a third form of life (until he came into the story there were just two—animals and plants as kingdoms). That third form is now known as archaea. They differ in their ribosomal structure from bacteria and eukaryotic organisms. Unlike eukaryotic organisms that have many ways they can be classified, bacterial cells (and archaea) are more difficult to classify into species or well-defined groups. Their morphology is not a guide. It was not until protein sequencing and nucleic acid sequencing became available that chemical approaches could be used to distinguish sequences (and their genetic functions) among bacteria, archaea, and eukaryotes. What they revealed only made the attempts at classification more complex. In general, eukaryotes use vertical transfer of information through sexual reproduction to pass genes from parent to child. Unicellular bacteria and archaea, however, do not have a vertical transfer. They are more often subject to different forms of horizontal transfer of genetic material. This can be transformation, transduction transfection through contact, ingestion, sex-like factors, viruses, or clusters of contiguous genes that hop from cell to cell. The result (not a surprise) is that most organisms are mosaics of genes from the same species and from utterly unrelated organisms that might not even be in the same kingdom. The heroes the author follows include Mereschkowski, Haeckel, Wallin, Griffith, Avery, Margulis, Pauling, McClintock, Fox, and Doolittle.

I am not as quick to dismiss phylogenetic trees as Quammen nor Darwinian natural selection in its branching model. At the level for which they are pertinent, keep them. Clearly, they do not work at the level of life on Earth before the rise of eukaryotic cells. It may well be that there will never be a historically accurate representation of the origin of bacterial cells or the origin of archaea cells. But there is more to work with for eukaryotic cells with their endosymbiotic origins from archaea and bacteria. If life has almost a two- to three-billion years of evolutionary history, I take comfort in knowing that there is an immense amount of sequencing information and physiology and molecular biology to be worked out before we know how the first cells formed or how endosymbionts became organelles. Despite that limitation imposed on science by the complexity or reality, Quammen's book is a stimulating history and analysis of our current knowledge of how we became cellular creatures with only a partial insight into who we are at a biological level.

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PALEONTOLOGY

Life in Deep Time: Darwin's "Missing" Fossil Record.

By J. William Schopf. Boca Raton (Florida): CRC Press (Taylor & Francis Group). $59.95 (hardcover); $29.95 (paper). xix + 229 p.; ill.; index. ISBN: 978-1-138-39037-9 (hc); 978-1-138-38549-8 (pb). [A Personal Account of Paradigm-Changing Science.] 2019.

This book is a scientific memoir by J. William Schopf, a prominent paleobiologist best known for his work on Precambrian microfossils. The volume recounts, among other episodes, his early work on microfossils from Canada's Gunflint chert, as well as the formation of the Precambrian Paleobiology Research Group (PPRG) in the late 1970s. The author opens the book by discussing his family history and education and how those paved the way for his later contributions. The volume provides historical context for his scientific discoveries and shows how the personal lives and backgrounds of scientists affect their motives and shape their intellectual journeys. The book concludes with an overview of the current state of play in Precambrian paleobiology, as well as reflections about possible future directions.

Schopf began his quest to reconstruct the missing history of life on Earth in the early 1960s when he was an honor student at Oberlin College. The volume follows his academic trajectory from there to Harvard and then UCLA, culminating with his documentation of fossilized microorganisms that are over three and a half billion years old. The characterization and study of these "missing" Precambrian fossils indeed represents a significant contribution to our understanding of evolutionary history. Schopf's work helped to fill in our understanding of about 85% of the history of life on Earth, setting the stage for new research on the earliest forms of life.

Throughout the book, the author portrays his own work as a contribution to "paradigm-changing" research. One concern about this framing is that it is not clear how much the discovery of Precambrian fossils from the deep past has reshaped our understanding of evolution. It has certainly challenged older assumptions about the incompleteness of the Precambrian fossil record. Although the ancient

fossils from Canada's Gunflint chert or Australia's Apex chert have extended our knowledge further back into the past and help constrain ideas about life's earliest origins, they do not shed much light on more recent major transitions, such as the Cambrian explosion. Thomas Kuhn conceived of paradigm shifts as radical reframings involving profound changes from one way of seeing the world to another. It is not clear that anything quite like that occurred here.

The title of the book might suggest that this is an accessible introduction to Precambrian paleobiology that could be used in courses. However, it is more of a practitioner's reflection on his own intellectual development and the course of his career. It includes many personal details—e.g., about a visit to Salvador Dali's home—whose connection to the scientific narrative seems tenuous. Schopf also made a stylistic decision to refer to himself in the third person throughout.

This retrospective might provide an important test case for philosophers of science interested in questions about optimism versus pessimism in reconstructing the deep past. This is a case where methodological innovation has enabled scientists to extract more information about life in deep time than earlier researchers ever suspected was possible, but new discoveries continuously highlight remaining gaps in our understanding of life's early history.

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THE STORY OF THE DINOSAURS IN 25 DISCOVERIES: AMAZING FOSSILS AND THE PEOPLE WHO FOUND THEM.

By Donald R. Prothero. New York: Columbia University Press. $35.00. xv + 472 p.; ill.; index. ISBN: 9780231186025 (hc); 9780231546461 (eb). 2019.

Dinosaurs are arguably the most fascinating and compelling creatures that ever walked the Earth, and so it is unsurprising that veteran paleontologist and prolific author Donald Prothero would turn his hand to a book about them. He chose as his vehicle his "25 discoveries" book series, whose "great reception" (p. xi) as he describes it in the book's introduction, seemed to augur well for the format.

The study of dinosaurs is, however, literally exploding with new publications (several per week); new taxa (a new species is formally described approximately every three weeks) and new (by 20th-century standards) interpretations: feathered dinosaurs, colored dinosaurs, endothermic dinosaurs, polar dinosaurs, weird dinosaurs, dinosaur growth rates, dinosaur embryology, dinosaur pathologies, dinosaur soft tissues, birds-as-dinosaurs, and red blood cells from dinosaurs, among other topics. Prothero needed to somehow encompass all of this ferment within 25 iconic dinosaur genera and the histories of their discovery. Of course he could not, and so each of the 25 genera becomes a gateway to related forms and *their* history of discovery and, thus, the book ramifies into many dinosaurs and much complexity.

Nonetheless, the author serves up a readable, modern, detailed treatment. Paleontological details are leavened by historical vignettes: the quirks of Owen, Cope, Marsh, Andrews, Stromer, and Nopcsa (among so many others) make for great reading, as do the romance of expeditions to places such as Tendaguru, the Gobi Desert, the Bahariya Oasis, and the "Valley of the Moon." His descriptions of all of these do not disappoint. Phylogenetic organization precludes historical organization, and yet somehow Prothero manages to maintain the historical thread of the narrative as the book proceeds through both biological and historical complexity. It is a deft and remarkable accomplishment.

Several issues, however, hobble this volume. Once again, Columbia University Press has produced an expensive book cheaply. Like its "25 discoveries" stablemates, its pages are thin and show the print from the other side. The illustrations are dark, grainy black-and-white photographs that barely reveal what they are supposed to show; the diagrams are small; and drawings (including the cover) are crude.

This volume shows some evidence of the writing having been hurried: there is a tendency to be repetitive and even contradictory. For example, the Argentinian titanosaurs are likely the largest/longest dinosaurs to have walked the Earth, supplanting brachiosaurs (pp. 156–158), although earlier, *Diplodocus* was "the longest dinosaur ever found even today" (p. 122). Then too, attribution is not consistently given to the sources of both text and figures.

Moreover, at whom was this book aimed? For beginners, such as is implied by the question at the beginning of Chapter 5 ("What is a dinosaur?"), noting later on that page that "Many people think any large extinction animal is a dinosaur" (p. 59)? Or is the volume designed to furnish already knowledgeable readers with more information about dinosaurs, such as is implied 13 pages earlier in the following sentence?

> Most analyses of *Cetiosaurus* tend to suggest that it is related to the more advanced Neosauropoda, along with the Chinese taxon [*sic*] *Shunosaurus*, *Omeisaurus*, and *Mamenchisaurus*; the Argentinian *Patagosaurus*; *Barapasaurus* from India; and *Chebsaurus* from Africa—although it is slightly more advanced and closer to Neosauropoda than