# Preface

Paleontologists strive to unravel the mysteries of ancient life. Although many of us are most comfortable with a rock hammer in our hand and a camera at our side, the tools at our disposal have increased exponentially in this digital age. Statistical software packages are easily accessible and can run effortlessly on most personal computers, allowing for an increasing amount of paleontological studies relying on the interpretation of large fossil datasets. Furthermore, recent advancements in material sciences have expanded the arsenal of paleontologically-friendly instrumentation available for researchers. As these tools become increasingly available at research facilities, paleontologists have begun exploring their capabilities for the examination of fossil materials. These technologies have ultimately allowed for increased analytical power whether you wish to observe and interpret the microstructure of fossils on the sub-μm scale or determine their chemical make-up. In essence, these fields are expanding at such a rapid rate that it becomes difficult to keep up with of all of the research potential available. Our goal when we first started brainstorming about this book was to expand the breadth of understanding of numerical approaches and novel technologies available to both young and seasoned paleontologists alike, all the while making new tools more comprehensible so that they can be easily incorporated into existing paleontological research programs. Because most if not all of these tools are applicable to fossil types spanning the entire geological record, we opted to concentrate on one of the most exciting timeframes in Earth history, the Proterozoic-Cambrian transition.

The Proterozoic-Cambrian transition marks a fundamental change in the fossil record as organisms achieve, for the first time, complex macroscopic morphologies ideally suited for numerical studies. Although detailed qualitative studies dominate this time interval, recent research trends have favored quantitative approaches due in part to the fact that many of these fossils are taxonomically problematic and therefore are difficult to study from a purely qualitative means. Taxon-free numerical approaches have opened the door to novel interpretations of these fossil communities, and have been instrumental in showcasing similarities while highlighting differences between these assemblages and the familiar fossils of the Phanerozoic. Of possibly greater importance has been the incorporation of advanced microbeam technologies, including environmental scanning electron microscopy (ESEM), focused ion beam electron microscopy (FIB-EM), transmission electron microscopy (TEM), confocal laser scanning microscopy and Raman spectroscopic imagery, to the study of these fossils. The very enigmatic nature of organisms from this timeframe lends itself quite well to the expansion of advanced technological methods into the study of, for instance, fossil ultrastructure and microchemistry. These technologies have already revealed a wealth of information concerning the fossil composition and as such the likely natural history of fossils which had remained unclassifiable until now—and, without a doubt, more pioneering data are certain to come as these technologies evolve.

We went to great lengths to assemble under one banner some of the most widely used numerical approaches and novel instruments so as to juxtapose the recent advances in these fields while making these topics accessible to numerically-and-technologically-philic or phobic scientists alike. We understand the difficulty and frustration in approaching a novel methodology from an outsider's perspective, and hope to facilitate the transition into these approaches by providing a detailed description of a wide range of techniques separated into individual chapters written both by seasoned paleontologists and boundary-pushing newcomers. The chapters individually focus on describing the strengths and limitations of each approach and ultimately apply the chosen mode of attack to a real dataset. Each chapter is accompanied by an extensive reference list for further reading, which we hope will guide the reader to a broader range of applications of the technique while additionally providing alternate views or applications of the topic. We hope this collection of papers proves to be the first stop for scientists wishing to expand or diversify their research programs to include numerical techniques and broaden their experiences with advanced instrumentation—potentially saving both time and money!

*Quantifying the Evolution of Early Life* is divided into two separate parts, although in many instances individual chapters will incorporate aspects of both. The first part focuses on numerical methods while the second concentrates on technological approaches. In the numerical methods part, Chapter 1 by Matthew Clapham (*Ordination methods and the evaluation of Ediacaran communities*) describes three of the most widely used ordination methods, principal components analysis (PCA), detrended correspondence analysis (DCA), and non metric multidimensional scaling (NMDS), in order to evaluate Ediacaran paleocommunities. In Chapter 2, John Huntley (*Exploratory multivariate techniques and their utility for understanding ancient ecosystems*) extends this approach by introducing readers to several well-known ordination tasks including PCA, NMDS, DCA, in addition to Principal Coordinates Analysis (PCO), Discriminant Analysis (DA), and Canonical Variate Analysis (CVA) in order to evaluate Proterozoic microfossil assemblages. Chapter 3 by Marc Laflamme and Michelle Casey (*Morphometrics in the study of Ediacaran fossil forms*) compares traditional morphometric techniques that employ multivariate statistics such as PCA, PCO, and NMDS with geometric morphometric methods employing landmarks in order to study the size and shape variations in Ediacaran fossils. Lindsey Leighton (*Analyzing predation from the dawn of the Phanerozoic*) in Chapter 4 extends landmark studies and other techniques for analyzing predation and drillhole stereotypy in order to evaluate the role of predation in the Cambrian radiation. Leighton employs several Cambrian datasets to discuss the strengths and limitations of predation studies in the early fossil record.

In Chapter 5, Andrew Bush, Richard Bambach, and Douglas Erwin (*Ecospace utilization during the Ediacaran radiation and the Cambrian eco-explosion*) summarize a theoretical ecospace technique that is highly applicable to the study of ecosystems through time. Their case study focuses on Ediacaran and early Cambrian faunas and how they compare to modern communities in terms of tiering, motility, and feeding strategies. Chapter 6 by Katherine Marenco and David Bottjer (*Quantifying bioturbation in Ediacaran and Cambrian rocks*) reviews and describes a number of established methods for quantitatively studying bioturbation, both from bedding plane surfaces and vertical outcrops or core sections, in addition to describing a new grid-based technique directly applicable to early life studies. In Chapter 7, Sara Pruss and Hannah Clemente (*Assessing the role of skeletons in Early Paleozoic carbonate production: insights from Cambro-Ordovician strata, western Newfoundland*) continue the trend of ecosystem analysis by highlighting a simple and effective point-counting method to evaluate the relative contribution of various skeletal components to carbonate successions, and presents an excellent case study of a Cambrian-Ordovician succession in western Newfoundland. Rounding out the numerical methods section in Chapter 8 is Amelinda Webb and Lindsey Leighton (*Exploring the ecological dynamics of extinction*), whose chapter reviews techniques applicable to exploring both the taxonomic and ecological dynamics of extinction events by using an Early Cambrian data set.

The second part deals with technological approaches applied to fossil studies. Jonathan Antcliffe and Martin Brasier (*Fossils with little relief: using lasers to conserve, image, and analyze the Ediacara biota*) present a review of laser scanning and imaging techniques specifically applied to the Ediacara biota in Chapter 9. The authors showcase how laser scanning and imaging techniques are instrumental in conservation efforts when dealing with rare fossils and have the possibility of increasing access to rare or protected fossils through electronic distribution of digital versions of specimens. Continuing with laser technologies in Chapter 10, William Schopf and Anatoliy Kudryavtsev (*Confocal laser scanning microscopy and Raman (and fluorescence) spectroscopic imagery of permineralized Cambrian and Neoproterozoic fossils*) provide a thorough introduction to confocal laser scanning microscopy and Raman (and fluorescence) spectroscopic imagery specifically applied to the study of early prokaryotic and metazoan life. These techniques allow for accurate reconstruction of permineralized fossils in three-dimensions in addition to analyzing the chemical composition of the fossils and the embedding matrix. Chapter 11, presented by Patrick Orr and Stuart Kearns (*X-ray microanalysis of Burgess Shale and similarly preserved fossils*), follows with a systematic overview of the physical principles underpinning SEM-based x-ray mapping (energy dispersive x-ray spectroscopy), offer a detailed discussion of sample preparation and appropriate analytical methodologies, paying special attention to the effects of beam working conditions (i.e., current and accelerating voltage) on analysis of 2D Burgess Shale-type fossils. Sebastian Willman and Phoebe Cohen (*Ultrastructural approaches to the microfossil record: assessing biological affinities by use of transmission electron microscopy*), in Chapter 12, offer a detailed explanation of how TEM enables high resolution studies of cross-sections of specimens, while focusing on what information can (and cannot!)

be extracted from microfossils with controversial biological affinities. Continuing with sub-surface imaging technologies in Chapter 13 are James Schiffbauer and Shuhai Xiao (*Paleobiological applications of focused ion beam electron microscopy (FIB-EM): an ultrastructural approach to the (micro)fossil record*), focusing on high resolution analysis using the FIB-EM which combines the best aspects of SEM (surface) and TEM (sub-surface) analysis into a single powerful workstation. The authors illustrate a method of sequential sectioning, or FIB-EM nanotomography, which permits detailed 3D fossil reconstructions at unsurpassed spatial scales. In Chapter 14, Christian Hallmann, Amy Kelly, Neal Gupta, and Roger Summons (*Reconstructing deep-time biology with molecular fossils*) shift the focus to geochemical techniques by providing an overview of the use of organic biomarkers in Precambrian molecular paleontology. They outline how to identify likely sample contamination and properly interpret data, all the while providing a theoretical and practical introduction into the field of organic geochemistry as applied to biomarkers. Finally with Chapter 15, Kathleen McFadden and Amy Kelly (*Carbon and sulfur stable isotopic systems and their application in paleoenvironmental analysis*) provide a review of carbon and sulfur stable isotope geochemical systems focusing on their applications in the study of ancient paleoenvironments. These systems are then employed to evaluate a case study of the single largest negative carbon isotopic excursion, the Neoproterozoic Shuram anomaly.

This collection is by no means a comprehensive review of either numerical or technological approaches to paleontological study, but rather serves as a starting point for delving into these types of approaches in one's own research. As enigmatic (or familiar) fossils from this timeframe and beyond are further studied, our numerical approaches must undoubtedly adapt accordingly. Similarly, as advanced instrumentation evolves, so does the methodology required for data collection—and for that matter, the type of data acquirable. Therefore, we feel strongly that continued discussion and collaboration between scientists—regardless of field of study—is not only a necessity, but will allow these modes of paleontological science to grow and develop.

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