

# Contents

xi	<b>The Authors</b>
xiii	<b>List of Contributors</b>
xiv	<b>Foreword</b>
xv	<b>Acknowledgments</b>
xiii	<b>Preface</b>
xv	<b>Book Introduction for Students and Instructors</b>
xi	<b>Geologic Timescale</b>
1	<b>Chapter 1. Introduction to Paleoclimate Records</b> This exercise serves as an introduction to paleoclimate records, with emphasis on sediment and ice cores. The following describes what you will do in the exercise:
2	<b>Part 1.1. Archives and Proxies</b> – compare and contrast the temporal and spatial scope of major paleoclimate archives: tree rings, speleothems, glacial ice, lake and marine sediments, and sedimentary rocks.
10	<b>Part 1.2. Owens Lake – An Introductory Case Study of Paleoclimate Reconstruction</b> – read about the 780,000 year Owens Lake core record and create a summary figure to synthesize the paleoclimatic data and interpretations.
13	<b>Part 1.3. Coring Glacial Ice and Seafloor Sediments</b> – identify the challenges and strategies for obtaining cores from glacial ice and the sub-seafloor; in addition you will consider issues of sampling, reproducibility, resolution, and cost, which are common issues for all paleoclimate archive research.
26	<b>Chapter 2. Seafloor Sediments</b> This exercise explores marine sediments using core photos and authentic datasets in an inquiry-based approach. The following describes what you will do in the exercise:
27	<b>Part 2.1. Sediment Predictions</b> – reflect on your prior knowledge of seafloor sediments.
28	<b>Part 2.2. Core Observations and Descriptions</b> – observe and describe physical characteristics of sediments cores.
35	<b>Part 2.3. Sediment Composition</b> – determine sediment composition using smear slide data and a decision tree.
42	<b>Part 2.4. Geographic Distribution and Interpretation</b> – make a map showing the distribution of the primary marine sediment types of the Pacific and North Atlantic Oceans and develop hypotheses to explain the distribution of the sediment types shown on your map.

80 **Chapter 3. Microfossils and Biostratigraphy**

This exercise explores the use of microfossil evolution in establishing relative time in marine sedimentary sequences. The following describes what you will do in the exercise:

- 81 **Part 3.1. What are Microfossils? Why are they Important in Climate Change Science?** – infer paleoecological and paleobiological information using microfossil distribution data.
- 92 **Part 3.2. Microfossils in Deep-Sea Sediments** – make initial observations about microfossil abundance data for case study work in Parts 3.3–3.5.
- 106 **Part 3.3. Application of Microfossil First and Last Occurrences** – apply a biostratigraphic zonation and interpret relative age.
- 121 **Part 3.4. Using Microfossil Datum Levels to Calculate Sedimentation Rates** – use microfossil data to calculate rates of sediment accumulation.
- 127 **Part 3.5. How Reliable are Microfossil Datum Levels?** – use microfossil data to correlate from one region of the world ocean to another.

134 **Chapter 4. Paleomagnetism and Magnetostratigraphy**

In this exercise, you will explore the paleomagnetic record of deep-sea cores. The following describes what you will do in the exercise:

- 135 **Part 4.1. Earth's Magnetic Field Today and the Paleomagnetic Record of Deep-Sea Sediments** – explore the nature of Earth's magnetic field by interpreting magnetostratigraphic records from Northern and Southern Hemisphere deep-sea sediment cores.
- 144 **Part 4.2. Paleomagnetism in Ocean Crust** – explore the nature of the paleomagnetic record preserved in ocean crust as positive and negative magnetic anomalies and relate these data preserved in the ocean basins with the paleomagnetic record preserved in deep-sea sediments.
- 151 **Part 4.3. Using Paleomagnetism to Test the Seafloor Spreading Hypothesis** – work with some of the original paleomagnetic and fossil data used to test the hypothesis of seafloor spreading.
- 158 **Part 4.4. The Geomagnetic Polarity Time Scale** – learn how paleomagnetism has been used to create the Mesozoic–Cenozoic geomagnetic polarity timescale, and explore how paleomagnetic and biostratigraphic data are integrated to provide methods of age determination.

169 **Chapter 5. CO<sub>2</sub> as a Climate Regulator during the Phanerozoic and Today**

This exercise explores how the exchange of carbon into and out of the atmosphere is a primary factor in regulating climate over time scales of years to hundreds of millions of years. The following describes what you will do in the exercise:

- 170 **Part 5.1. The Short-Term Global Carbon Cycle** – make initial observations about the short term global carbon cycle, its reservoirs, and the rates of carbon transfer from one reservoir to another.
- 175 **Part 5.2. CO<sub>2</sub> and Temperature** – investigate how CO<sub>2</sub> directly and indirectly affects temperature. This understanding is developed through quantitative analysis of the changes in radiative forcing of CO<sub>2</sub> and other factors (e.g., land surface albedo) between 1750 and 2005 based on IPCC

climate models, and by constructing qualitative logic scenarios of positive and negative feedbacks in Earth's climate system.

**Part 5.3. Recent Changes in CO<sub>2</sub>** – examine instrumental and ice core records of atmospheric CO<sub>2</sub> levels, and identify which parts of the carbon cycle are most important for regulating climate over historical time periods.

**Part 5.4. Long-Term Global Carbon Cycle, CO<sub>2</sub>, and Phanerozoic Climate History** – investigate the long-term global carbon cycle, CO<sub>2</sub>, and Phanerozoic climate history. Using proxy data and general circulation model results you will identify greenhouse and icehouse times, and place modern climate change in a geologic context.

## **Chapter 6. The Benthic Foraminiferal Oxygen Isotope Record of Cenozoic Climate Change**

This exercise explores one of the most widely accepted and scientifically cited evidence of global climate change, the 65 million year-long composite stable oxygen isotope record derived from benthic foraminifera. The following describes what you will do in the exercise:

**Part 6.1. Introduction** – familiarize yourself with some of the graphic elements of the oxygen isotope record and make some initial observations.

**Part 6.2. Stable Isotope Geochemistry** – unravel the effects that movement through the hydrologic cycle has on the distribution of the two most common stable isotopes of oxygen.

**Part 6.3. A Biogeochemical Proxy** – examine the biogeochemical connections that allow scientists to extract such a detailed record of long-term oceanic, continental, and atmospheric change.

**Part 6.4. Patterns, Trends and Implications for Cenozoic Climate** – build on the knowledge gained from Parts 6.1–6.3 to identify and interpret patterns and changes in trends in benthic foraminifera  $\delta^{18}\text{O}$ , and thereby recognize some of the most significant climatic events that have occurred over the past 65 million years.

## **Chapter 7. Scientific Drilling in the Arctic Ocean: A Lesson on the Nature of Science**

This set of activities investigates the scientific motivations, logistical challenges, and recent history of Arctic Ocean scientific drilling. The following describes what you will do in the exercise:

**Part 7.1. Climate Models and Regional Climate Change** – investigate IPCC climate models as a complimentary method of studying climate change that possesses its own benefits and challenges, and address the question “Why drill there?” from a modeling perspective.

**Part 7.2. Arctic Drilling Challenges and Solutions** – explore the technological and logistical question of “How to recover deep cores from the Arctic seafloor?”

**Part 7.3. Need for Scientific Drilling** – evaluate the spatial and temporal records of past Arctic seafloor coring expeditions and build a scientific rationale for drilling deep into the Arctic Ocean seafloor to study regional and global climate change.

**Part 7.4. Results of the Arctic Drilling Expedition** – identify some of the key findings of the Arctic Coring Expedition (ACEX), as well as the unexpected challenges encountered in this scientific endeavor.

239 **Chapter 8. Climate Cycles**

This exercise explores cyclic climate change from the geologic record, and the explanation of that change using astronomical theory. The following describes what you will do in the exercise:

- 240 **Part 8.1. Patterns and Periodicities** – examine a variety of records displaying cyclic climate change, calculate the periodicities of these records, and reflect on sources and implications of scientific uncertainty.
- 260 **Part 8.2. Orbital Metronome** – reflect on your knowledge of seasonality. Then you will explore the long-term orbital variations of eccentricity, obliquity, and precession and connect these orbital drivers to the periodicities in the climate proxy records from Part 8.1.
- 267 **Part 8.3. A Break in the Pattern** – assess the CO<sub>2</sub> record of the last 400-kyr to characterize greenhouse gas levels during past glacial–interglacial periods and today. You will identify a distinct break in the cyclicity and develop hypotheses to explain this change in climate.

270 **Chapter 9. The Paleocene–Eocene Thermal Maximum (PETM) Event**

The Paleocene–Eocene Thermal Maximum (PETM) is one of the best examples of a transient climate state; it is marked by a brief and intense interval of global warming, and a massive perturbation of the global carbon cycle. The following describes what you will do in the exercise:

- 271 **Part 9.1. The Cenozoic  $\delta^{13}\text{C}$  Record and an Important Discovery** – you will consider how carbon isotopes are used as a proxy for climate change in the context of the global carbon cycle.
- 279 **Part 9.2. Global Consequences of the PETM** – evaluate evidence of the impact and cause of the event from multiple sites around the globe, including the deep-sea, continental shelf, and continental deposits. A synthesis of these observations will help you construct initial hypotheses about the cause of the PETM.
- 315 **Part 9.3. Bad Gas: Is Methane to Blame?** – read an article that introduces methane hydrates, and assess their possible effect on oceanic and atmospheric carbon reservoirs, and the role they may have played in the PETM.
- 317 **Part 9.4. How fast? How long?** – look at different types of data, which will allow you to evaluate various rates, estimate how fast the PETM was initiated and how fast the ocean–climate system recovered from a major perturbation of the global carbon cycle.
- 325 **Part 9.5. Global Warming Today and Lessons from the PETM** – apply your new understanding of the PETM and pose the question “*How does it compare with the rate of global warming today?*”

334 **Chapter 10. Glaciation of Antarctica: The Oi1 Event**

The rapid glaciation of Antarctica approximately 33.7–Ma is one of best examples of a threshold event in the ocean–climate system. The following describes what you will do in the exercise:

- 335 **Part 10.1. Initial Evidence** – evaluate some of the early evidence for the glaciations of the Antarctic.

- 340 **Part 10.2. Evidence for Global Change** – evaluate direct and indirect evidence for glaciations and global climate change. You will make connections between different data sets and consider the influence of climate feedbacks in triggering the Oi1 event.
- 363 **Part 10.3. Mountain Building, Weathering, CO<sub>2</sub> and Climate** – explore the relationship between chemical weathering and atmospheric CO<sub>2</sub> and learn about strontium isotopes as a proxy for chemical weathering. You will also consider the role of climate feedbacks leading up to the glaciation of Antarctica.
- 370 **Part 10.4. Legacy of the Oi1 Event: The Development of the Psychrosphere** – explore how the Oi1 event influenced the evolution of global ocean circulation, in particular the formation of the cold deep waters of the global ocean.

378 **Chapter 11. Antarctica and Neogene Global Climate Change**  
This investigation introduces you to the status and role of Antarctica in Neogene climate change, and sets the stage for evaluating the two sediment cores retrieved from the floor of McMurdo Sound by the Antarctic Geologic Drilling Project (ANDRILL) in 2006 and 2007 (introduced in Chapter 12). The following describes what you will do in the exercise:

- 379 **Part 11.1. What Do We Think We Know About the History of Antarctic Climate?** – review your understanding of the oxygen isotope curve, interpret global climate conditions from this curve, and assess the validity of your global interpretations based on the global distribution of sediment cores.
- 384 **Part 11.2. What is Antarctica's Geographic and Geologic Context?** – become familiar with the geography and geologic units of the Ross Sea region of Antarctica and review or build your knowledge of southern-hemisphere seasons, sea-ice, ice-shelves, and the challenges associated with obtaining a sediment core from the floor of McMurdo Sound. You will also build and use your understanding of simple geologic maps, cross sections and the geologic time scale, so you can explain the reasons for selecting drill sites in McMurdo Sound.
- 395 **Part 11.3. Selecting The Best Drill Sites for the Science Objectives** – review the existing data from sediment cores in the Ross Sea region of Antarctica, and use the knowledge gained in Parts 11.1 and 11.2 to identify a target stratigraphic interval and select two sites to drill.

401 **Chapter 12. Interpreting Antarctic Sediment Cores: A Record of Dynamic Neogene Climate**  
This set of investigations focuses on the use of sedimentary facies to interpret palaeoenvironmental and paleoclimatic changes in Neogene sediment cores from the Antarctic margin. Particular attention will be given to the characteristics of high latitude settings close to the ice and far from the ice in high-latitude settings. The following describes what you will do in the exercise:

- 402 **Part 12.1. What Sediment Facies are Common on the Antarctic Margin?** – build your knowledge of polar sediment lithologies and the corresponding facies through conceptual diagrams, geological reasoning, and use of core images and core-logs.

- 416 **Part 12.2. ANDRILL 1-B The BIG Picture** – examine the core log (a graphical summary of the sediments) for the entire ANDRILL 1-B core (1285-m), characterize each of the key lithostratigraphic sub-units, and use your knowledge of depositional facies to write a brief history of the Neogene climatic and environmental conditions in the Ross Sea region.
- 422 **Part 12.3. Pliocene Sedimentary Patterns in the ANDRILL 1-B Core** – use your core-log reading skills and facies knowledge to evaluate patterns in the Pliocene sediments from ANDRILL 1-B. You will quantitatively correlate patterns in your dataset with cycles in insolation, influenced by changes in the Earth's orbit during the Pliocene.
- 430 **Chapter 13. Pliocene Warmth: Are We Seeing Our Future?**  
There is abundant evidence that early to mid-Pliocene time (approximately 5–3 Ma) was warmer and the global sea level was higher than today. Pliocene, plate configurations, mountain belts, and ocean circulation were more like today than any other time in Earth history. For these reasons, paleoclimatologists are very interested in studying the Pliocene as a possible analog for the evolving trends of global warming today. The following describes what you will do in the exercise:
- 431 **Part 13.1. The Last 5 Million Years** – consider evidence for global warmth and the role of greenhouse gases in causing this warmth, specifically carbon dioxide (CO<sub>2</sub>).
- 442 **Part 13.2. Sea Level Past, Present, and Future** – consider the magnitude of sea levels during the early to mid-Pliocene (approximately 5–3 Ma) and compare this with the ongoing rise in sea levels today.
- 450 **Chapter 14. Northern Hemisphere Glaciation**  
This exercise is an introduction to the characteristics and possible causes of the Cenozoic northern hemisphere glaciation. The following describes what you will do in the exercise:
- 451 **Part 14.1. Concepts and Predictions** – make predictions about where and why continental ice sheets form.
- 453 **Part 14.2. What is the Evidence?** – examine geological, geochemical, and paleontological data to infer the spatial extent and temporal history of the late Cenozoic northern hemisphere glaciation.
- 466 **Part 14.3. What Caused It?** – critically read abstracts from seven peer-reviewed papers to decipher proposed mechanisms for the expansion of northern hemisphere glaciation at approximately 2.6 Ma and reflect on the scientific value of multiple working hypotheses.

### COMPANION WEBSITE

This book has a companion website:  
[www.wiley.com/go/stjohn/climatehistory](http://www.wiley.com/go/stjohn/climatehistory)  
 with Figures and Tables from the book and supplementary  
 material for downloading