Earth History

Providing a new approach to Earth history, this engaging undergraduate textbook highlights key episodes in the history of our planet and uses them to explain the most important concepts in geology. Rather than presenting exhaustive descriptions of each period of geological time, this conceptual approach shows how geologists use multiple strands of evidence to build up an understanding of the geological past, focusing on exciting events like the extinction of the dinosaurs and the formation of the Grand Canyon and the Himalaya. Beginning with an introduction to geology, tectonics, and the origin of the universe, subsequent chapters chronicle defining moments in Earth history in an accessible narrative style. Each chapter draws on a variety of sub-disciplines, including stratigraphy, paleontology, petrology, geochemistry, and geophysics, to provide students who have little or no previous knowledge of geology with a broad understanding of our planet and its fascinating history.

Peter Copeland is Professor of Earth and Atmospheric Sciences at the University of Houston, Texas. His expertise lies in thermochronology, geochemistry, and continental tectonics, with a particular emphasis on the evolution of the continental crust. In recent years, his research has focused on the formation of the Rocky Mountains and the Himalaya. From 2001 to 2004 he was co-editor of the *Geological Society of America Bulletin*.

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"A novel, engaging approach to learning about Earth history. Instead of taking an exhaustive time-period approach that characterizes classic historical geology texts, key events are used to explore the planet's geologic evolution. Starting with general principles of geology, including planet formation, geologic time (fossil and radiometric), the unifying theory of plate tectonics, the origin of life and evolution, the text examines major events that shaped and changed our planet over its long history. Thematic events include Proterozoic Snowball Earth, the Cambrian Explosion of Life, the supercontinent Pangea, major extinction events (yes, dinosaurs too), the evolution of western North America and Southeast Asia, human evolution and modern Ice Ages, and more. The text closes with a brief exploration of today's environmental challenges, bringing ancient geologic history into today's conversation. The writing style is modern conversational, which will appeal to the college user, and the supporting illustrations are clear and informative. Instead of the past distinctions between physical geology and historical geology offerings, this text offers a fresh integration of disciplines, allowing instructors to amplify and cater to their and their students' interest. I heartily recommend this text."

Ben van der Pluijm, University of Michigan

"I am very pleased to recommend Dr. Copeland and Dr. Bhattacharya's textbook, *Earth History*, to the educational and academic community. Their book transcends the traditional, often dense, textbook format, presenting geologic science as a collection of exciting short stories in a narrative style that is both engaging and informative. Their writing style is playful yet analytical, data driven and entertaining. Using a coupled systematic and conceptual approach (with a very strong emphasis on conceptual), the authors make complex topics accessible and interesting. What sets this book apart is the fun! This book's unique blend of analytical rigor and rich storytelling is designed to capture student attention, which is no easy feat in the digital age. *Earth History* has significantly influenced the structure and tone of my own courses. I look forward to incorporating this book into my curriculum upon its release. I am confident that it will provide an enriching educational experience for my students."

Professor Jennifer Campo, Lone Star College, University Park

Earth History

Stories of Our Geological Past

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PREFACE

Geology is history, and history is a collection of stories. Rocks are books telling us about these geological stories, which are written in a variety of languages such as stratigraphy, petrology, paleontology, geochemistry, geophysics, and more. Naturally, the more languages you can speak, the more you can appreciate these stories, which is what makes the application of physics, chemistry, biology, and mathematics crucial to the understanding of the history, structure, and composition of Earth and other planets.

At the same time though, many geologists (including the authors of this book) have at least once met a curious non-geologist who has asked them questions such as: "Did the dinosaurs really die because of a meteor?," "Is California going to fall into the sea?," "Is it true that the rocks on the top of Mount Everest were formed in the ocean?," and "Are we going to run out of oil?"

The short answers to the above questions are: "It seems quite likely," "No," "Yes," and "Not really, but only because oil will get so expensive, we will have to find alternatives." In the response to such queries, some geologists make the mistake of going into way more detail than required about these events, perhaps describing the science behind them, and even resorting to the use of unnecessary jargon, therefore losing their interlocutor's interest.

This is why, in writing principally for undergraduate students taking courses on Historical Geology, Introductory Earth Science, or Earth through Time with no pre-requisites, we chose to simply tell stories. We introduce the details only in service of the story. In doing so, we hope to illustrate to the student the integrative nature of geoscience.

Our stories include highlights from all the major geologic eras from the Precambrian to the Holocene and include discussions of essential aspects of North America (the Appalachians and Rockies) and around the globe (Mediterranean salinity crisis and the Himalaya). Some stories are mostly tectonic whereas others emphasize the history of life, as recorded in the fossil record.

The stories are rarely simple, but they are usually fascinating. However, stories can change. Many of the ideas presented in this textbook as modern consensus were either derided by many experts or non-existent just a few decades ago. Yet, new data can come along (usually because of the invention of some new technology) that challenges old ideas. Therefore, we spend time in most of our stories to not just lay out the geologic evidence but describe the people involved with the big ideas in geoscience and how they struggled with the data and with each other. Such struggles are not over; very few places on Earth are left unexplored but new eyes bring new perspectives and we hope our discussions of how old ideas were replaced by new ones will inspire the next generation to look for yet newer and broader explanations of how our world came to be and where it might be going.

The telling of the history of Earth begins with these sorts of small-scale studies, often carried out by a small number of people over just a few years. This work is then often integrated into a larger picture to tell a broader story such as the evolution of a mountain belt over hundreds of millions of years, to the evolution of life across the planet over billions of years.

The stories we tell in the following chapters are of the broader sort and are therefore compilations of the work of many people (from dozens to thousands) over many years (decades to centuries). We hope to illustrate how broad insights into the history of our solar system, our planet, its diversity of life, and our own species, have come from being able to read many geologic languages.

Conceptual Approach

Rather than offering a linear overview of each time period in detail, we take key events in Earth history to demonstrate how geologists piece together different types of geological evidence to build up a clear picture of events in Earth history.

For example, in Chapter 13, when discussing the extinction of the dinosaurs, we begin with descriptions of some sedimentary rocks in Italy and the nuances of their chemical composition, but soon move on to geophysical discoveries in Mexico and giant tsunami deposits in Texas and North Dakota. We also mention that a large part of India is covered by kilometer-thick lava deposits that erupted right at the time the dinosaurs went extinct and may have played a role in their demise. Finally, we conclude with a consideration of the likelihood of another mass extinction caused by an asteroid impact. Or in Chapter 14, when addressing the question about the fate of California, we also discuss the details of Earth's interior and the processes that operate thousands of kilometers below the surface.

Every interesting thing you've ever heard about the history of our planet started with a geologist picking up a rock. Geologists are trained to notice different aspects of rocks that give clues to their genesis and subsequent history. Some of this information can be picked up in the field, whereas some can only be obtained by analyzing the rock in the lab. Regardless, the goal is to fully interpret this rock.

Understanding the formation of the rock (e.g., from a volcano, in a lake) is the starting point, but much of what we may want to know about a rock extends far beyond this initial step. If we are interested in finding oil, for example, we need to know how old the rock is, what kind of rocks were deposited above and below it, and how deeply it was buried by younger rocks. If, on the other hand, we want to uncover the processes associated with the formation of a particular mountain belt, we need to observe the faults and folds in rocks: when did they form, what is their orientation, and how much motion has occurred on these structures?

We might start a story by asking, "Did you know that some geologists think there was a time when the Earth was completely covered by ice?" From there, we can introduce aspects of glaciology, geochemistry, geophysics, and stratigraphy. This is the approach we've tried to take with chapters concerning the biologic and tectonic evolution of Earth.

Our goal, whether the topic is paleontologic or tectonic, is to try and present individual chapters as self-contained narratives. They really aren't totally self-contained (the order isn't random) but if a reader or instructor wanted to skip some chapters, we hope that most of what is needed to understand each chapter would be right there. Although we expect most people will encounter this book as part of a course often called Historical Geology, which usually assumes an initial course in Physical Geology, we have deliberately included enough foundational material in Chapter 1, so that a reader without any background can follow the stories and appreciate Earth history.

Key Features of this Book

- Accessible and concise, primarily aimed at non-majors, including broad introductory chapters for those with no prior knowledge of geology.
- Provides a far more conceptual approach to the topic, focusing on key events in Earth history, such as the extinction of dinosaurs and the formation of the Grand Canyon, to explain key geological concepts and how geologists use multiple strands of evidence to build up an understanding of the geological past.
- Uses an engaging, narrative style of writing to make the text more interesting to students.
- Limits the discussion of paleontology to the context of key events in Earth and life history, rather than as a detailed topic in its own right.
- Avoids large species lists, which can be overwhelming to students.

Pedagogical Features

Individuals learn in different ways. We therefore provide a variety of pedagogical aids to be used as the student chooses. Each chapter includes the following:

- Learning Objectives: to help students in clarifying, arranging, and prioritizing their learning.
- Introductions: to highlight the topic covered in each chapter and how it fits within the big picture, all whilst piquing the reader's interest.
- Color figures and photographs: to complement the text and provide a visual representation of the concepts discussed.
- KEY POINT boxes: to easily spot the main concepts covered in each section.
- Boxes: to highlight interesting and relevant side stories or information.
- Chapter Summary: to summarize the major points of the chapter and allow the reader to reflect on what they have learnt.
- Key Words: boldface within the text and listed at the end of each chapter for easy review. A full Glossary of key words appears at the end of the book.
- Further Reading and References: to help extend the coverage of topics that are not dealt with in so much detail within the chapter, or for students that need more information than can be presented in the chapter.
- Review Questions: to encourage students to think about what they have covered, and for guiding instructors' quiz or test questions.

Text Organization

The first six chapters provide much of the foundation for the remainder of the book, highlighting specific stories that we believe are both essentially interesting but also provide a systematic and sequential overview of most of the major events in Earth history calling on the variety of disciplines required to explain what we know about the subject. These chapters are organized in chronological order and cover most of the major tectonic and biologic events in Earth history that are traditionally covered in an Earth History course, but we emphasize the narrative versus a compendium of fact, events, and dates.

The remainder of the chapters discuss individual episodes in Earth history (restricted in both space and time). These in no way represent an exhaustive treatment but are chosen because of the way they illustrate the need to speak the several languages of geoscience in order to read the history of our planet.

Chapter 1 reviews the basic principles of geology and covers material usually taught in a Physical Geology course, followed by a review of the history of geology and the philosophies of geologic thought that have shaped geologic investigation over several centuries. Here, we take a fieldtrip (narrative-type) approach by using the Grand Canyon to illustrate many of the basic principles of physical geology. What can the reader learn about geology on a trip to the Grand Canyon, versus a systematic listing of the various types of rocks and minerals?

Chapter 2 covers the way that geological thinking developed and introduces the concepts of Neptunism, Plutonism, uniformitarianism, and actualism, using the Channeled Scablands as an example. The idea is for students to get a feel for how geologists think.

Chapter 3 tells the story of the origin of the universe, the formation of our solar system and the Earth–Moon system and Earth's early atmosphere and hydrosphere.

Chapter 4 uncovers how deep time was discovered and how we know that Earth is 4.56 billion years old.

Chapter 5 provides an overview of plate tectonics and how this theory was developed.

Chapter 6 concludes the first part of the book with a discussion of the process of natural selection that explains the observation that life has evolved through the immensity of deep time.

Chapter 7 discusses the biogeochemistry and stratigraphy that informs our understanding of the origin of life on Earth.

Chapter 8 reviews the paleomagnetism, geochemistry, glaciology, and stratigraphy that led to the snowball Earth hypothesis.

Chapter 9 describes the paleontological oddities of the Ediacaran fauna and the Cambrian explosion and what these fossils tell us about the mechanisms of evolution and the diversification of life.

Chapter 10 details the closing of Iapetus and the formation of Pangea from the perspective of the Appalachian Mountains.

Chapter 11 describes the changes in life on Earth during the Paleozoic and the paleontology, geochemistry, and volcanology that informs our understanding of the Great Dying at the end of the Permian.

Chapter 12 chronicles the rise of dinosaurs and their variety.

Chapter 13 details the geochemistry, geophysics, and stratigraphy that led to the giant impact hypothesis for the end-Cretaceous extinction.

Chapter 14 tells the tectonic history of western North America from Jurassic to present with reference to stratigraphy, magmatism, deformation, and geophysics.

Chapter 15 tells the story of the Himalaya using structure, geophysics, stratigraphy, and geochemistry.

Chapter 16 uses geochemistry, stratigraphy, and geophysics to tell the story of the drying of the Mediterranean during the Messinian salinity crisis.

Chapter 17 chronicles human evolution with paleontology and stratigraphy as well as a discussion of the cultural complications of these studies.

Chapter 18 describes the Pleistocene ice ages with glaciology, stratigraphy, and geochemistry.

Chapter 19 concludes the book by looking forward as well as to the past with a discussion of the effects of humans on the climate using stratigraphy, modeling, and geochemistry.

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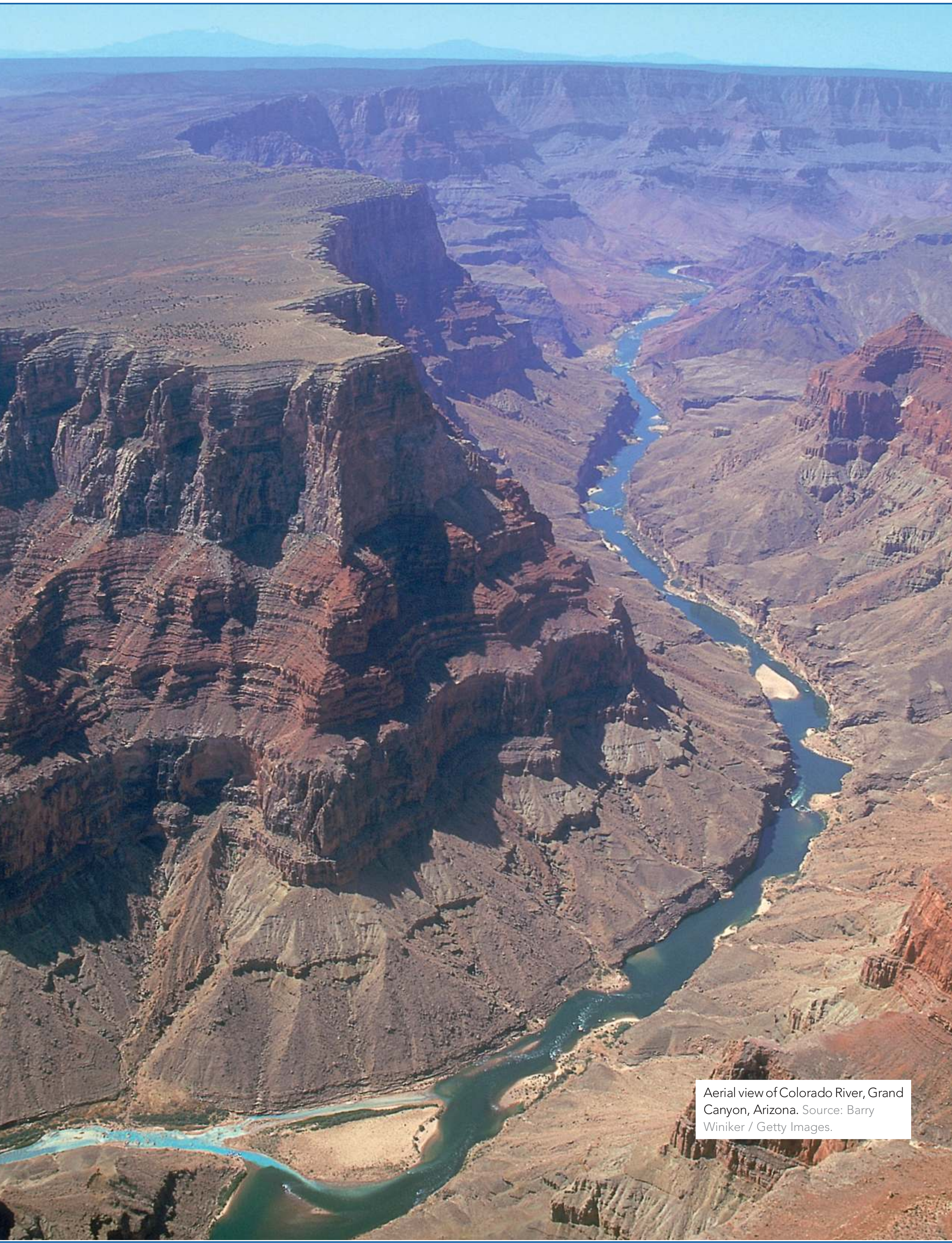
Names and dates of units in the timescale figures for Chapters 7 to 19 are based on the Geologic Time Scale v. 6.0: Geological Society of America (Walker, J.D., and Geissman, J. W., compilers, 2022, Geologic Time Scale v. 6.0: Geological Society of America, https://doi.org/10.1130/2022.CTS006C), which is itself based on data from Cohen, K.M., Finney, S., and Gibbard, P.L., 2012, International Chronostratigraphic Chart: International Commission on Stratigraphy, https://stratigraphy.org/ICSchart/ChronostratChart2012.pdf (accessed Sept. 2022), Cohen, K.M., Finney, S.C., Gibbard, P.L., and Fan, J.-X., 2013 (updated), The ICS International Chronostratigraphic Chart: Episodes, v. 36, p. 199–204, http://www.stratigraphy.org/ICSchart/ChronostratChart2021-10.pdf (accessed Sept. 2022) and Gradstein, F.M, Ogg, J.G., Schmitz, M.D., et al., 2012, The Geologic Time Scale 2012: Boston, USA, Elsevier, https://doi.org/10.1016/B978-0-444-59425-9.00004-4. Colors follow the standard colors advised by the International Commission on Stratigraphy (administered by the International Geological Map of the World project in Paris - CCGM).



Aerial view of Colorado River, Grand Canyon, Arizona. Source: Barry Winiker / Getty Images.