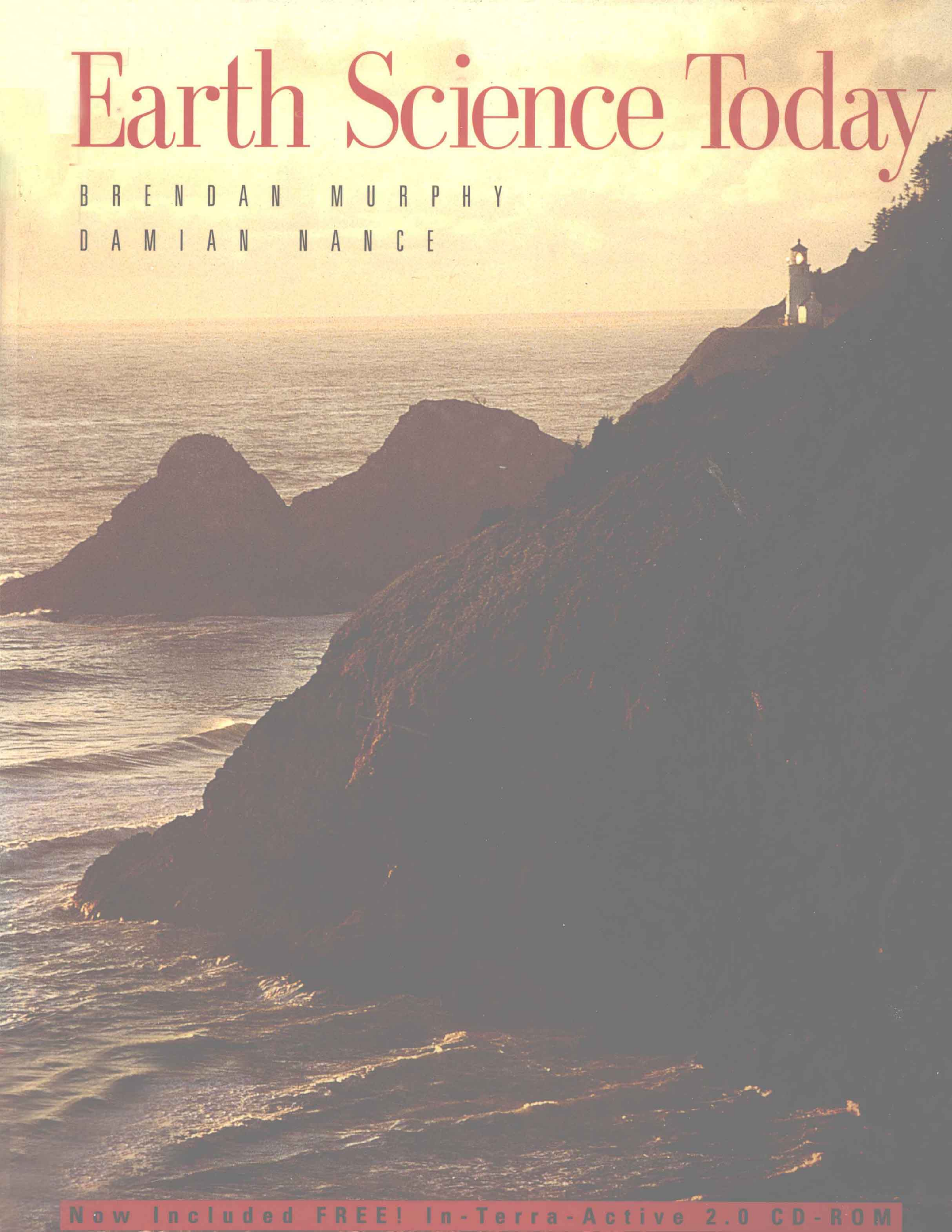
Earth Science Today

BRENDAN MURPHY
DAMIAN NANCE



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Earth Science Today

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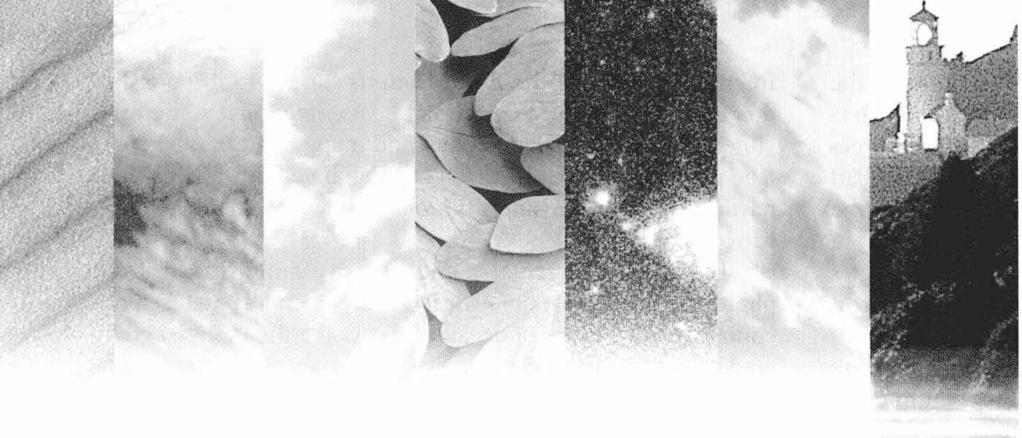
Dedication

To our parents, our families, and our teachers



Preface

To The Instructor

Our Approach

Today's students are tomorrow's decision-makers, whether their future careers are in politics, finance, technology, medicine, or basic science. It is their decisions that collectively will decide the fate of our planet. As instructors in Earth science or geology, therefore, we have a most important mission. We must ensure that our students have the opportunity to obtain a basic understanding of the Earth so that they are equipped to make informed, environmentally responsible decisions in their future careers.

We hope that our textbook helps you, the instructor, attain these goals, and that the student's appreciation of our amazing planet and its place in the cosmos is enhanced. We attempt to convey the message that understanding the Earth is exciting, and that it enriches and heightens our sense of awareness of the world around us.

To achieve this, we adopt an integrated, interdisciplinary Earth systems approach to planet Earth that involves the study of its geology, biology, chemistry, and physics. Our book emphasizes that Earth systems are an interplay of the traditional sciences and do not respect the artificial boundaries we tend to place between them. If our goal is to understand our planet, therefore, we must break down these barriers. Only through this approach, we believe, can we hope to gain an understanding of global environmental problems and so be in a position to address them.

We recognize that students taking an introductory course in Earth science or geology may come from widely varying academic backgrounds. Many may not have taken a science course in high school, never mind a course in Earth science. We also recognize that for a significant proportion of students, this will be their only formal exposure to Earth science. So, we believe that we have a dual mission. We must not only provide a strong fundamental background for students who wish to pursue geology or Earth science in more advanced courses, but we must also offer all students the opportunity to learn about the processes that shape the planet in which they live. In addition, we hope that some students who are unsure about what they might select as a career will at least consider geology or Earth science as a potential major.

The goal of this text is to provide an understanding of, and appreciation for, the Earth. Our approach is to stress concepts, processes, and principles because these should serve all students well. A thorough grasp of any science requires some basic knowledge of facts and terminology, the language of the science. However, we are careful about overtaxing the student. In our experience, *excess* terminology at an introductory level leads to rote-learning. Students tend to navigate from one term to the next and fall into the trap of thinking that by learning the terminology they will understand the concepts and principles. The trap is sprung at exam time! Furthermore, knowledge of terminology fades with time, especially for those students for whom this is a terminal course in Earth science. A course with an emphasis on the understanding of concepts and principles, we believe, has a much longer shelf-life.

For example, we stress how gases released from volcanoes over the 4.6 billion years of Earth history have had a first order influence on the evolution of our atmosphere, how water pumped from volcanoes contributed to the oceans and the origin of life, and why, in this respect, the Earth is unique in the solar system. We consider the vast array of terminology that describes these volcanoes and their various types of volcanic eruptions to be of secondary importance at an introductory level, the lexicon of terms sometimes distracting the student from the primary message. This terminology, we feel, is better learned in the appropriate upper level courses.

At the same time, we do not wish to sacrifice or dilute the conceptual content of the material. Our challenge, then, is to present concepts and processes in a straightforward manner rather than risk losing student interest by burying them in unnecessary terminology. If, at the end of your course, the students display an appetite for learning more, then we will have achieved our goal.

Organization of the text

The book is divided into seven parts. The first four parts deal with each of the Earth's surface reservoirs in turn. In Part I, we introduce the foundations of modern geology and continue with an examination of the solid Earth. In Part II, we discuss the hydrosphere, followed by the atmosphere in Part III. Since a detailed study of the modern biosphere is more appropriate in an introductory biology course, Part IV looks at the evolution of the biosphere over geologic time in the context of the other Earth systems. This part also serves as a summary of Earth history.

In Part V, we examine the Earth within the context of the solar system and the cosmos. Equipped with this basic background, we then discuss the balance between Earth resources (Part VI) and environmental responsibility (Part VII). In Part VII, we also address specific environmental issues using the principles and concepts developed in the previous chapters. In a way, this part serves as a thematic review and demonstrates how a thorough knowledge of Earth systems provides important insights into modern environmental problems.

Each part is subdivided into chapters. The chapters are designed to be as freestanding as possible, the beginning of each chapter identifying the important portions of the previous text that form the basis for what follows. An overview at the beginning of each chapter also prepares the student for the concepts that follow. Each chapter ends with a summary and a listing of key concepts and terms to facilitate that essential last-minute brush-up before tests! Finally, two sets of questions brings each chapter to a close. The Review Questions focus on the most important parts of the chapter. The Study Questions require further thought on the part of the student and a working knowledge of the preceding chapters in the text.

In dividing the text into parts based on Earth systems, we run the risk of failing to follow our own advice. However, we repeatedly stress the processes that bridge the traditional sciences and link the various reservoirs. This linkage will be apparent in many parts of the text. The most important linkages will be highlighted with "Process in Action Icons" and in the Visual Summaries at the end of each part (see box in "To the Student").

In Part I, we describe the basic principles of modern geology, and then use these to describe the solid Earth. Following an introduction (Chapter 1), Chapter 2 discusses minerals and rocks, the basic materials that compose the solid Earth. This part acknowledges that much of our modern understanding of the Earth is rooted in classical geology. In Chapter 3, we gain an impression of the scale and duration of natural processes. We acquire a sense of geologic time by examining the age of the Earth and the methods by which geologic events are dated. By discussing the basic principles of relative and absolute time, we show how rocks and minerals may be used to piece together geologic history and so reveal the evolution of the Earth through geologic time. In so doing, we gain important insights into the pace of evolutionary change. Finally, in Chapter 4, we set the stage for our treatment of the solid Earth by examining the fascinating story behind the development of plate tectonic theory, a story that we also use to illustrate the scientific method.

In our treatment of the solid Earth (chapters 5 to 7), we focus on the processes that introduce new chemical constituents to the surface of the Earth. Chapters 5 and 6 examine the processes that govern the evolution of the Earth's surface. Here we outline the principles of plate tectonics, the fundamental unifying concept in the Earth sciences that accounts for the origin and evolution of the Earth's major surface features such as the continents and oceans, and explains the distribution of global phenomena such as earthquakes, volcanoes, and mountain belts. Here we get a sense of the dynamic nature of our planet. In Chapter 7, we examine the internal structure of the Earth from its surface to its core. In doing so, we discover the internal heat engine that is the driving force behind plate tectonics and many of the Earth's surface processes. We also learn that some ingenious techniques have given us a surprisingly thorough knowledge of the chemistry of our planet.

In Part II (Chapters 8, 9, and 10), we examine the hydrosphere. We first look at the hydrologic cycle and the factors that control the chemistry of ocean water. Using the material covered in Part I as a background, we then analyze the origin and ultimate fate of the oceans. Chapter 9 deals with the circulation of ocean water on both a global and local scale. Here we find the major influences to include radiant energy from the Sun, the spin of the Earth about its own axis, and the temperature contrast between the poles and the equator. We use the phenomenon of El Niño as a prime example of the importance of understanding global circulation patterns. Chapter 10 is devoted to fresh water on continental landmasses, a vital aspect of life on our planet.

Part III (chapters 11 and 12) deals with the atmosphere and follows a similar approach to that used in Part II. We first examine in Chapter 11 the average composition and temperature of the atmosphere and, once again, find that the material covered in the preceding parts plays a key role in our understanding of the evolution of the Earth's atmosphere and the controls behind past and future climates. In Chapter 12, we look at the motion of air masses and the factors that influence modern climates and our day-to-day weather patterns. We also examine the processes that lead to weather "events," such as hurricanes, tornadoes, and monsoons, and the global disruption of typical weather patterns brought about by an El Niño. We show how satellites are our "eyes in the sky" and how the use of this technology has resulted in amazing advances in our understanding of the dynamic forces behind our weather and climate. We also show how improved weather forecasting now provides advanced warning of dangerous weather and can help predict catastrophes such as widespread drought or the failure of the monsoon rains.

The biosphere is explicitly dealt with in courses in the life sciences. In Part IV (chapters 13 and 14), however, we focus on the origin and evolution of the biosphere and the ways in which it interacts with the solid Earth, hydrosphere, and atmosphere. In a sense, this part serves as a synthesis of Earth history, emphasizing the evolution of the Earth systems and the key events and processes that have governed our planet's development from its origin to the present day. In Chapter 13, we outline the evolution of life and the Earth systems in the Precambrian and follow this, in Chapter 14, with a similar treatment of the Phanerozoic Eon. Chapter 14 also describes our most recent history and deals with the forces that shaped our modern landscape.

In Part V, we broaden our horizons to look at the planets of the Solar System (Chapter 15) and the Sun and stars in the universe beyond it (Chapter 16). The study of other planets in the Solar System provides some very important perspectives on the evolution of our own planet. The uniqueness of planet Earth can be placed in the context of its position in the Solar System, its size and composition, and its distance from the

Sun. We find that these factors, in particular, have caused the Earth to take a different evolutionary path from those of its nearest planetary neighbors. Recent evidence that there may once have been microbial life on Mars adds further fuel to the debate that has pre-occupied us for centuries. Is there anybody out there or are we alone in this vast universe?

Our knowledge of our place in the cosmos is improving rapidly, thanks to amazing advances in both land-based and orbiting telescopes, such as the Hubble space telescope. Exciting breakthroughs like those that suggest there may be other solar systems similar to our own, are typical of the information explosion that confronts us almost daily. No doubt, this trend will continue into the immediate future. Our challenge, then, is to lay the groundwork so that students can both understand and assess this information as each new discovery is made.

We start our examination of the universe with the star we know best, the Sun. Earth systems are greatly influenced by radiant energy from the Sun. Although the Sun played little direct influence in the *origin* of our atmosphere and hydrosphere, it is the major external influence on the global-scale circulation of these two reservoirs and has a profound effect on our weather and climate, as we know from personal experience. Indeed, the Earth's surface is where solar energy and the Earth's internal processes interact. In our treatment of the Sun, we concentrate on solar processes and phenomena that influence the Earth today, and may have influenced the planet in the past. By examining the universe beyond, we gain an appreciation for our position in the cosmos.

In Part VI, we deal with Earth resources and the factors that influence the generation of economic deposits of minerals (Chapter 17) and energy reserves (Chapter 18). Nowhere is the interaction of the Earth's reservoirs more closely linked to the development of human society than it is in our exploitation of the planet's natural resources. It is the demands of society that make a deposit economically feasible to exploit. These demands have changed dramatically over the past 20 years and will continue to do so in the foreseeable future. Our treatment of mineral resources emphasizes our dependence on metallic and industrial minerals, the inequity of their distribution, and the important natural processes that concentrate them. It also examines some of the methods used in mineral exploration and the environmental consequences of mineral exploitation. The underlying principles of a source, a medium of transport, and an environment of deposition that concentrates the commodity are common themes in the formation of many of our natural resources. Our treatment of energy examines the issues of supply and demand, and looks at the variable contributions of each of the Earth's reservoirs in providing our energy needs. We find that energy sources derived from the solid Earth, such as fossil fuels and nuclear power, are convenient but nonrenewable, whereas those obtained from the hydrosphere, atmosphere, and biosphere, such as hydroelectric power, solar energy, and biomass fuel, are renewable but often difficult to harness. Since questions concerning the future of our finite mineral and energy reserves are likely to become major issues in Earth science as we enter the 21st Century, we end our survey of the Earth's natural resources with a look at what the future may hold.

With this background, we are now equipped to evaluate Earth systems and the environment (Part VII). In fact, just as our current environmental problems provide a test of the extent to which we truly understand our own planet, this part will test the students' understanding of the key concepts developed in each of the preceding chapters.

Chapters 19 and 20 demonstrate how the Earth's reservoirs are linked and discuss the exciting new scientific discipline of biogeochemistry. In Chapter 20, we address key environmental issues in a deliberately provocative fashion to encourage debate among students and between students and the course instructor. Can we really sustain the resource exploitation needed to support modern development? In recognizing rhythms in the natural interaction among Earth systems, can we detect the distortion associated with modern development and our own tampering with the Earth's reservoirs? And in understanding the mechanisms that drive these rhythms, can we learn how best to alleviate some of our current environmental problems?

In the Afterword, we attempt to point out to students the importance of environmental responsibility and some of the important challenges and influences that will affect their lives. We stress that important and fulfilling work in Earth science remains to be done. This may convince students that a career in Earth science is worthwhile, although that is not our main objective. Most students will not have taken a course in Earth science or geology in high school, and this chapter is intended to give them an idea of the basic research that remains to be done. It is also important to impress upon our future decision makers the importance and urgency of basic research and its relationship to society.

Through our emphasis on the concepts and principles of Earth science, we hope to provide students, majors and nonmajors alike, with a measure of understanding about the planet on which they live.

Acknowledgments

An undertaking such as this one is impossible to complete without the help and expertise of many people. The team at Brooks/Cole, and before that, at Wadsworth, encouraged and advised us every step of the way. Their expertise and cheerfulness kept us motivated and ensured that we completed the task at hand and made it a pleasurable experience. Heather Dutton, Senior Developmental Editor, navigated us through many revisions, deadlines, and revised deadlines, and her expert editing made substantial improvements to the text and artwork. We greatly appreciate her commitment and the weekly conference calls in which timely words of encouragement and advice kept us to the task at hand. Kim Leistner-Little, Acquisitions Editor for Earth Science, and Gary Carlson, Publisher for Sciences, shared our initial enthusiasm for the project and were largely responsible for us becoming involved with the Brooks/Cole team. Stacey Purviance, who took over from Kim as Acquisitions Editor during the course of the project, provided important guidance as the book began to take shape and headed towards completion. Her expertise and patience were invaluable in keeping the project on track. We greatly acknowledge the impressive skills of Tanya Nigh, Senior Project Editor; Bob

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To The Student

We live in amazing times. In the past 20 years we have learned an enormous amount about our planetary home, and new information confronts us almost daily. We can scarcely watch the news or read a newspaper without learning of some new and exciting discovery that relates to the Earth and our position in the cosmos. At the same time, we are receiving mixed messages about the state of our local and global environment. This information now comes at us at such a bewildering pace, it is difficult to assimilate it all.

As we enter the 21st Century, it is appropriate to remind ourselves that just a century ago the world and our knowledge of it was entirely different. Our forbearers could never have visualized the scientific and technological advances of the 20th Century. We now have a comprehensive understanding of the origin of mountains and oceans, and explanations for the origins of earthquakes and volcanic activity. We have devised ingenious methods that allow us to image the Earth's interior, determine its composition, and understand some of the internal processes that go on thousands of kilometers below its surface. Even weather forecasts have become more reliable through the use of satellites as our eyes in the sky. Our forays into space have given us a new appreciation of the tiny portion of the universe we occupy. At the same time, we have come to realize that our planet is fragile and that our own actions may compromise our very existence.

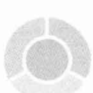
Our goal in this textbook is to convey the wonder and excitement of discovery while heightening your knowledge, appreciation, and interest in the planet on which we live. Indeed, since we all use its resources, we have a certain obligation to learn something of the way in which the Earth works. And who is to say that the technological advances of the 20th Century will not continue or even accelerate into the 21st? So it may well be in your best interest to have a working knowledge of the world around you.

Each one of us has a daily impact on our planet in some small way. Cumulatively, this impact may be enormous. In the near future, your decisions, big and small, may impact the environment on a local, regional, and even global scale. Faced with such decisions, we hope that this book, in some small way, will help you make the right ones.

Believe it or not, it was not so very long ago that we were students like you, and we remember only too well how hectic student life can be. If channeled properly, however, these will be some of the most rewarding years of your life, full of heightened intellectual and social experiences. We also remember how much easier it was to learn if the material we were studying was presented in an interesting and dynamic way. Luckily for us, we both had excellent teachers in our introductory courses. In the classrooms where we now teach, we try to inspire our students through our own fascination and enthusiasm for the science, and by showing them that learning is fun. We hope that this also comes across in our textbook. If, in addition, you are considering a career in geology or Earth science, we encourage you to do so. We have both thoroughly enjoyed our own careers and most geologists would say the same. A healthy appreciation and respect for the working of the world around us has a wonderfully calming influence when the waters of life get a little rough!

As you read the book, you will find that we emphasize concepts and processes over excess terminology. Perhaps this is because we are both plagued with poor memories and we know all too well how one's memory of terminology fades with time! While terminology is important to the language of science, it is through concepts and processes that science is understood. We therefore believe that courses that are process-oriented will have a far longer shelf-life than those based on terminology.

If you choose a career in Earth science, you will have the opportunity to contribute directly to our understanding of planet Earth. Should you choose a different career path, we hope that this textbook will increase your understanding of the planet on which we live. Our challenge is to present the material to you in language that is as jargon-free as possible and to capture the excitement and wonder of our planet. We hope we achieve these goals and, if you are sitting comfortably, we will begin.



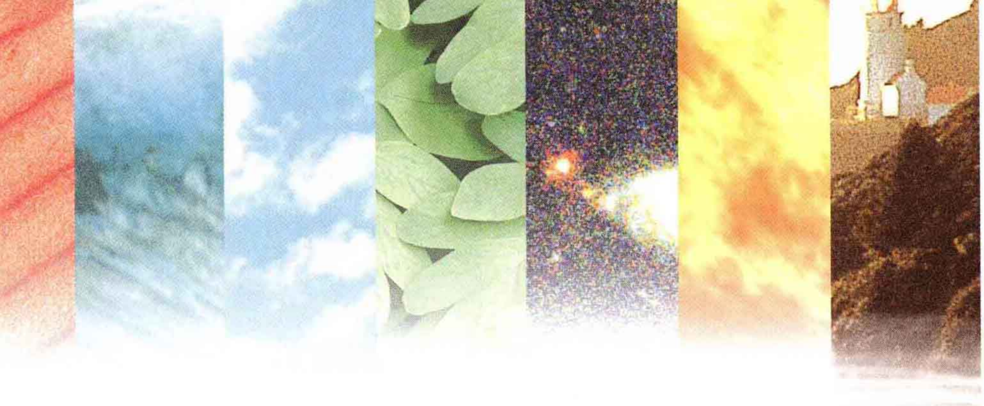
Earth Science Today has visual cues to help students really see the interactions described in the text. **Visual Summaries** close each part and cover all the key interactions within that group of chapters. Two **Process in Action** icons visually emphasize the interconnectedness of the chapters and the information within them. Interactions between chapters are shown by the large icon. Those within chapters are marked by the smaller icon.

Each part opens with the large **Process in Action** icon. This icon helps to reinforce the nature of the interactions between the Earth's surface reservoirs—the solid Earth, hydrosphere, atmosphere, and biosphere. Each of the Earth's reservoirs is allocated a segment within the large **Process in Action** icon. The solid Earth is positioned in the center, reflecting its influence on all the reservoirs. Other reservoirs are positioned along the periphery, reflecting their connections to the solid Earth, the Sun, and each other. Textures within each reservoir's segment mark the heads in all the chapters, giving the student another visual cue to where they are.

The small **Process in Action** icon positioned throughout the chapters (and seen at the beginning of this box) is designed to send a signal that two or more reservoirs are interacting. When they come across the icon, students can then ask themselves what reservoirs are working together to make this particular event occur.

Visual Summaries are designed to help the student make a visual connection between the concepts. The **Visual Summaries** also offer the student a way to conceptualize the integration, movement, and change described in each part. They illustrate the "big picture" by showing the interdependence of the processes, concepts, and principles involved in Earth science.

Damian Nance and Brendan Murphy



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