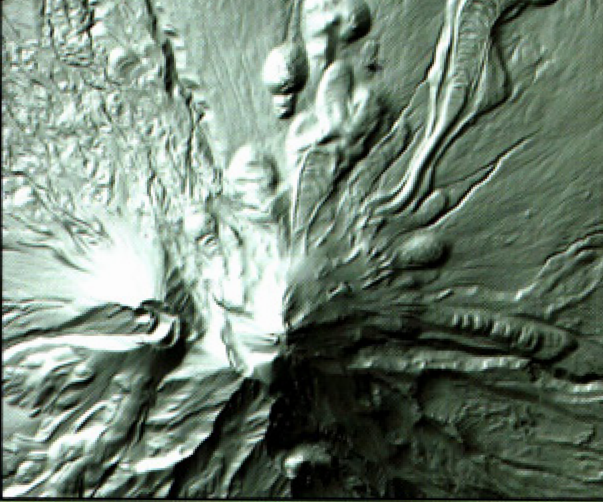
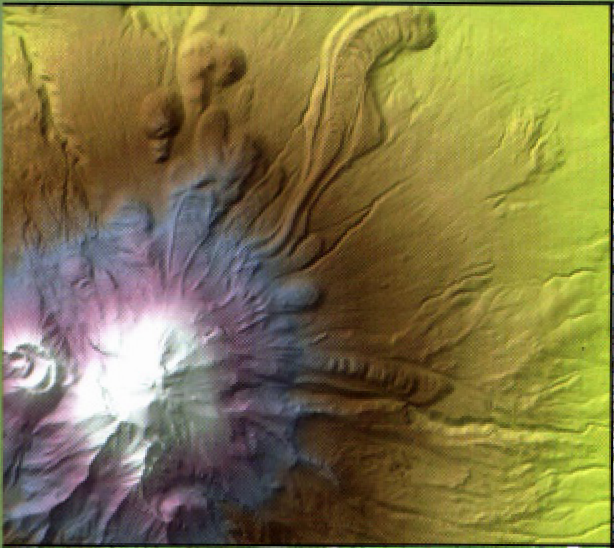
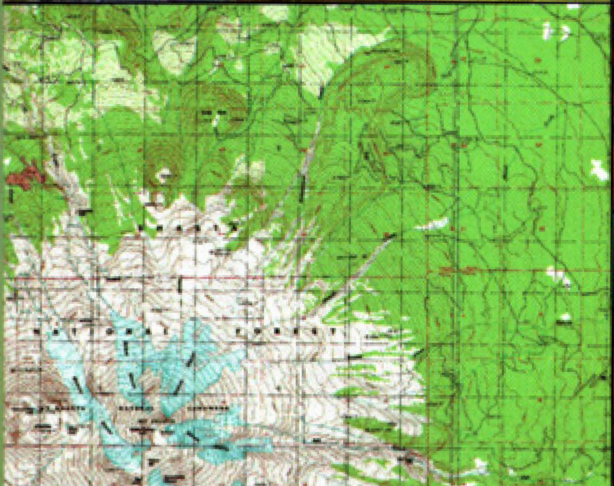
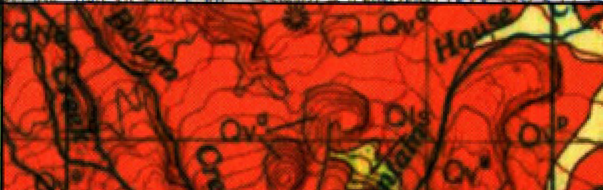


EARTH SCIENCE

GOD'S WORLD, OUR HOME







KEVIN NELSTEAD

Earth Science

God's World, Our Home

A Mastery-Oriented Curriculum

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Earth Science

God's World, Our Home

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Contents

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Preface

For Teachers

Mastery, Integration, and Kingdom Perspective

The book you have before you is clearly not a typical middle school Earth Science text. It is not two inches thick, it does not weigh five pounds, and it does not attempt to cover every topic in all of earth and planetary science. These are not accidents.

We believe that science education, including textbook design, needs a major overhaul. The design philosophy behind this text represents our idea of where to start. Our philosophy of pedagogy—and thus textbook design—is based on three core principles—*Mastery*, *Integration*, and *Kingdom Perspective*. We summarize these principles this way:

Mastery

The norm for classes in contemporary schools is what we call the *Cram–Pass–Forget cycle*. Students cram for tests, pass them, and then forget most of what they crammed in just a few weeks. Teachers across the nation know exactly what this looks like because they see it day after day. This cycle is a waste of time for teachers and students. Instead, students should *learn*, *master*, and *retain* what they have learned. Realizing this in the classroom requires both the teacher and the students to make significant changes in the ways they approach the tasks of teaching, testing, practicing, and studying. For textbooks, a mastery orientation requires that the curriculum cover fewer topics, and cover them deeply. When students engage with content, their efforts should be directed at comprehension, practice, and retention of important concepts, not mere exposure to masses of material they will not remember. Methods that promote the Cram–Pass–Forget cycle must be replaced with more effective methods.

In a mastery-oriented learning environment, students will notice that the workload is demanding, and initially some of them will resist. But all the students will learn far more than they ever have in a course. They will remember the material for years, and most of them—even those who aren't much interested in school—will come to recognize the value of such a learning experience. Some will recognize this immediately, some only after they go off to college and find themselves ahead of their peers because of things they remember from many years before.

For more information about how mastery concepts should be implemented with this text, see the sections below entitled *Companion Book and Resource CD* and *Notes on Using this Text*.

Integration

For a variety of complex reasons, effective science instruction requires a number of content areas to be deeply embedded in the science curriculum—content areas often considered tangential and not represented adequately in curriculum materials. These content areas include scientific process, basic epistemology, mathematics, scientific history, and English language usage. Typically, science classes do not place the necessary emphasis on these areas, and as a result, students fail to have a coherent and effective learning experience. Science teachers need to think deeply about how their courses are addressing the need for these and other key areas of integration and make adjustments to curriculum, teaching methods, assessments, and coordination between science courses.

An example of how integration is realized in this text is that the questions and exercises in every chapter and in every experiment require students to write out answers in complete sentences. Another example is the introduction of graphical (and thus quantitative) methods in both the text and experiments. A third example is the discussion of science and theories in Section 3.1. This discussion is essentially about epistemology—kinds of knowledge and how we know what we know—although the term epistemology is not used in the text. We strongly assert that without a proper epistemology students will not correctly understand the nature of scientific theories or the role they play in the ongoing process of scientific research. Nor will they understand the difference between scientific claims and truth claims. Thus, it is critical for every science text to engage these questions at an age-appropriate level.

Kingdom Perspective

The study of science provides us with unique ways of seeing God's creative presence in the world. Bringing biblical faithfulness to science classes is not accomplished by simply folding in a few Bible verses or prayers. In fact, much more is involved. Science and math teachers need to think broadly about how we fulfill Christ's mandate to love God with all of our mind, how we teach our students effectively to engage issues, and how we perceive God's fingerprints in creation.

We also need to engage thoughtfully with the scientific claims of our day. It is not a scientific claim to say that the universe got here by itself; that is a metaphysical claim based on an atheistic worldview. But it is a scientific claim to say that the universe began with the Big Bang and is now 13.77 billion years old. The scientific evidence behind this claim is vast, and we believe an appropriate science text is one that teaches students productively to engage such claims. We do not believe it is appropriate to teach students to be dismissive of claims like this one simply because they do not line up with certain ways of interpreting Genesis. We hold this as those who fully believe the Bible, who love reading Genesis and the rest of Scripture, and who accept the strong evidence for an old universe.

Our ideas about all three parts of this core philosophy are described in more detail in John D. Mays' book *Teaching Science so that Students Learn Science*. This book and a more detailed description of our textbook philosophy may be found on our website, novarescienceandmath.com.

Our Position on Controversial Topics

As mentioned above, we accept the mainstream scientific view that the universe is 13.77 billion years old and Earth is about 4.6 billion years old. Topics relating to the age of the Earth appear in several chapters in this text. For both Biblical and scientific reasons, we believe it is time to put the age-of-the-Earth debate behind us. We find that according to the soundest principles of Biblical exegesis, the literalistic model of an Earth approximately 10,000 years old is not a necessary inference from Genesis. Further, this literalistic model is in conflict with the "other book" of God's revelation—the creation itself. From Psalm 19 and other passages, we believe the creation reveals the glory of the Lord. Since Scripture and creation both come from the same God, they cannot be in conflict. And when both are rightly understood, they won't be.

An important comment is critical here regarding the other famously controversial topic in science books for Christian schools—the theory of evolution. Evolution is not mentioned or discussed in this text, and we make no claims—explicit or implicit—about the theory one way or the other. In Chapter 11, there are statements about fossils, adaptation of organisms, and the increasing complexity of organisms in the geologic column. Each of these statements is simply a statement of scientific fact and should not be regarded as an implicit claim about evolution. The facts about fossils are what they are; we leave it to the instructor to make of these facts what you will.

Considerations for Science Programming

This text has been specifically developed for application in grade seven or eight. If used in seventh grade, teachers may consider as optional parts of Section 4.1 on Atoms, Elements, and Crystals, especially Section 4.1.4 on Chemical Bonds. For students who study Physical Science in sixth or seventh grade and use this text in eighth grade, Section 4.1 will provide a good review of material covered in the physical science course.

Lab Journals and Lab Reports

The overall goal of experiment documentation for middle school students is to continue laying the foundation for writing full lab reports—from scratch—when they get to high school. The target is for students to begin writing lab reports in ninth grade, and the standard for such reports is presented in John D. Mays' book *The Student Lab Report Handbook* (available on our website). Toward that end, we believe lab reports at the middle school level should focus on students describing what they did, presenting their results, and engaging with the questions.

Part of integrating English language development into science instruction is accomplished through the use of lab journals. Each of the experiments included in this text requires students to document their work in a lab journal. Details about using lab journals are in the Preface for Students, as well as in the first chapter of *The Student Lab Report Handbook.*

In each of the Experimental Investigations, we have posed questions for students to engage with as they consider their results and observations. We have left decisions about the specifics of the student reports to the individual instructor; requirements should be based on the preparedness and background of the students in a given class.

Conducting Experiments

It is very important for all students to conduct the experiments included in this text. Interacting with content about the Earth through the text alone is an inadequate approach to this subject. Students need to study the actual topographic maps and handle actual minerals and rocks.

The instructions written in the Experimental Investigations provide the information students need. Additional details on resources, materials, suppliers, costs, and ways to enhance the lab activities are included on the Resource CD for this text (available at novarescienceandmath.com).

Companion Book and Resource CD

As mentioned at the beginning of this preface, a mastery-based learning environment entails new teaching methods and new study techniques. These are described in detail in *Teaching Science so that Students Learn Science*, and we encourage teachers to read that book and implement the strategies discussed there. In particular, the discussion in Chapter 7 (Science as a Cumulative Discipline) reviews the philosophy of mastery-based learning and methods necessary to realize it. Two of the most important strategies discussed in that chapter are the weekly cumulative quiz and the Weekly Review Guides.

The Resource CD available to accompany this text includes a full year's worth of weekly quizzes, Weekly Review Guides, semester exams, and sample answers to questions. As described in *Teaching Science so that Students Learn Science*, for students at this level we promote the use of a 30-minute, *cumulative* weekly quiz in place of chapter tests. Cumulative quizzes include questions each week from Objectives Lists throughout the portion of the text previously covered, all the way back to the beginning of the course. This assessment method is a thoroughly demonstrated way to realize significant improvements in student retention.

To enable students to succeed at the weekly cumulative quizzes, particularly after the sixth or eighth quiz when the quantity of material to remember becomes significant, teachers must consistently engage students with correct study methods.

One of the essential components of the mastery-based program is the Weekly Review Guide. This important tool helps students to know how to study—and what to study—each week when long-term retention is the goal. The Resource CD includes a year's worth of Weekly Review Guides, which teachers should begin issuing to students in the third week of the course.

Notes on Using this Text

One of the major motivations behind the design of this text is for students to be delivered from the Cram–Pass–Forget cycle alluded to earlier. Compared to other texts, this book is small. An appropriate amount of content has been assembled for students to master in a single year of study.

But for mastery to be realized, certain practices need to be a regular part of the classroom experience. Regular review, rehearsal, and practice of older material must occur alongside the study of new material. Otherwise, students simply forget things a few weeks after being tested on them.

Here are a few specific practices that should be regularly present in classes using this text. These practices simply represent good teaching and should be part of any well-structured course.

1. *Class Discussion* Discuss concepts, ask questions, and give students opportunities to express concepts in their own words. Use the "Learning Check" questions at the end of each section and the Chapter Exercises as questions to stimulate discussion. All these questions should be discussed in class. Take time with this type of discussion and don't hurry. This is why the book is modestly sized—so there will be adequate time for extended discussion and deep engagement with the material.

2. *Group Study* Divide students into groups for teamwork on answering some of the more difficult questions in the Chapter Exercises. Then have teams take turns reporting their answers to the class. Stimulate discussion between teams about the merits of different answers to a particular question, and seek a class consensus on a well-formed answer.

3. *Review Discussion* Go through questions again from past chapters. It is also fun to create competitions among teams in which teams score points by giving good answers to review questions. Some kind of activity like this should occur at least once every 3–4 weeks throughout the duration of the course.

4. *Enrichment Activities* Although concepts are covered thoroughly in the text, understanding will be enhanced and memory will be strengthened when students engage with the content in activities outside the text. Classes should incorporate full-length instructional videos, classroom samples of different rocks and minerals, internet images, You Tube videos, games, student presentations, projects, nature field trips, and other activities. Teachers should em-

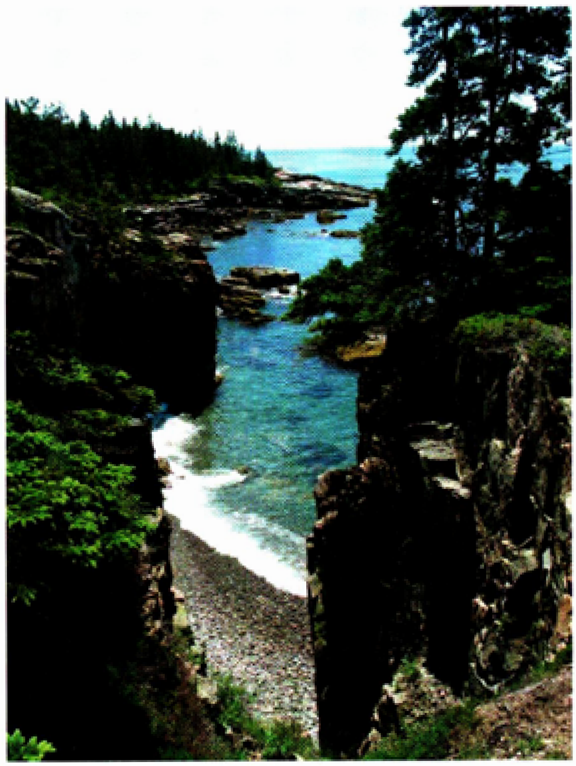
phasize activities designed to make students *active* participants in the learning process, rather than simply passive observers.

5. *Learning Rock Names* The vocabulary list for Chapter 5 can appear daunting. Encourage your students to study these terms—as well as the terms from all other chapter vocabulary lists—using flashcards and frequent review. For challenging lists of terms such as the Chapter 5 vocabulary list, teachers should stretch out the learning process over an extended period of time. Mix class discussions with frequent use of classroom samples of the specific types of rocks listed in the vocabulary list, and use games and competition to make learning remembering the terms exciting and rewarding.

Preface

For Students

This world belongs to God, our Father and Creator. As the 24th Psalm states: "The earth is the Lord's and the fullness thereof, the world and all those who dwell therein, for he has founded it upon the seas and established it upon the rivers." God's world is a wonderful and precious gift to us, for it is our home. Adam was placed in the garden of Eden "to work it and keep it." This biblical language (*work* and *keep*) means that Adam was to *develop* the garden so that it would be fruitful, and *preserve* the garden so that it would always continue to provide a suitable home for human beings and all the other creatures. This charge to Adam from God is often called the *Cultural Mandate*—a mandate from God for the human race wisely to develop and care for all the gifts we have received, including our minds, skills, communities, technologies, and, of course, the beautiful world God made. As hymnist Maltbie Babcock wrote in 1901,



> This is my Father's world, and to my listening ears
> All nature sings, and round me rings the music of the spheres.
> This is my Father's world: I rest me in the thought
> Of rocks and trees, of skies and seas;
> His hand the wonders wrought.

Stewarding God's Gifts

God's world—our home—is fascinating and fun to learn about. We have really enjoyed preparing this text and we hope you enjoy using it as part of your study of Earth Science. One of our goals for you is that you develop a *love* for the Earth. We want you to appreciate its beauty and the delicate way the systems and organisms in this world are balanced. The intricate balance and beauty we see in nature are breathtaking!

It is important for us to act as good *stewards* of the gifts God has given to us. The Earth is certainly a great gift, and in our time the Earth is in need of our care and attention. But we humans generally do not properly care for things unless we love them, and we generally don't love things unless we spend time with them. We encourage you to find ways to spend time with the Earth—not just riding in cars around town, but exploring streams, walking in the woods, playing in the ocean, and hiking in the mountains. If you are going on vacation with your family, we encourage you to suggest to your parents to include stops at National Parks, National Forests, or other natural spots during the trip so that you can experience the glories of this beautiful planet for yourself.

As you develop your understanding of Earth's processes, we hope you will also understand that our lovely planet is under a great deal of stress right now. The health of our environment and the millions of creatures that inhabit it cannot be sustained unless people everywhere work together to develop new habits of land management, new attitudes toward recycling and conservation, and new energy technologies. As a young person, you will soon be entering adulthood and making decisions about how to direct your energies as a servant in God's Kingdom. We hope you will make your decisions with godly stewardship of the Earth well in mind.

Mastery

Another of our goals for you in this course is mastery: we don't want you simply to cram for tests, pass them, and then about three weeks later forget what you crammed. Instead, we want you to *learn*, *master*, and *retain* what you learn about the beautiful planet God has made for us to inhabit. For this reason, the weekly quizzes we have made available to your instructor always include questions about things you studied in previous chapters. This happens all year long, and your quizzes when you are in Chapter 14 will still be asking you questions from Chapters 2, 4, 6, and all the other chapters.

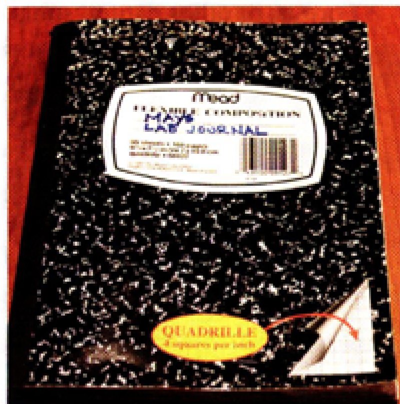
To succeed at the weekly quizzes, you need to study in particular ways. First, we suggest that you make flashcards for the vocabulary terms in each chapter and that you review these flashcards regularly. Second, we suggest that you make use of the Weekly Review Guides that are available to your instructor. Go through the review activities carefully each week so that you can remember the material from early chapters. Third, you should also study the Objectives List at the beginning of each chapter and make sure you can perform every item on the list.

Learning any subject is frustrating if you feel like you are jumping through hoops but not accomplishing anything that is valuable or lasting. But learning is *a lot* more fun when you feel like you are truly learning, remembering, and growing. The study and review techniques listed above, and others that your instructor will introduce to you, will make the study of Earth Science a wonderful experience.

Who knows? You may even find that you love this subject so much that you want to become a geologist, climate modeler, or environmental researcher!

Lab Journals

A third goal for our course is that you will expand your English language skills so that you can express yourself clearly and write accurate answers to scientific questions. One way to practice using English in scientific study is carefully to document your experimental work in your own lab journal. Here is some advice about using a lab journal with the Experimental Investigations in this text:



1. Keep your lab journal very neat and well organized. Don't doodle in it or mess it up.
2. Don't use a spiral notebook. Use a bound composition book with quadrille (graph) paper. (Quadrille paper makes it easy to set up tables and graphs.) A popular one to use is the Mead 09127, available at office supply stores and pictured to the right.
3. Put your name on it in case you misplace it.
4. For every experiment you work on, enter the following information:
   - the date (always enter the date again every day you work, as one always does with a journal)
   - the names of team members working with you (enter these also every day you work, so you have a record of who is there and who is not each time you meet)
   - a list of all equipment, apparatus, materials, and supplies you use in conducting the experiment
   - tables with *all* your data, with the original units of measure
   - calculations or unit conversions you perform as part of the experiment
   - observations or notes about anything that happens that you may need to write about in your report or remember later, including records of work that must be repeated and why
   - methods or procedures you use, and the reasons for using them

There are other items to enter in your journal that will become more important as you get into high school and college (such as sources, contacts, and prices for special chemicals or parts you have to order), but the list above should cover the things that you need to worry about for now. Take pride in maintaining a thorough lab journal. Make it your habit always to have it with you when you work on your experiments and always to document your work in it.

Earth Science

God's World, Our Home

A Mastery-Oriented Curriculum

Chapter 1

Earth In Space

In December 1968, three astronauts went into orbit around the moon in the Apollo 8 spacecraft. This was the first time humans had gone further from Earth than just a few hundred kilometers above the surface. As they circled the moon, the Apollo 8 crew were the first people to have a direct, close-up view of the desolate craters, plains, and mountains of another world. Since radio signals cannot go through or around the solid sphere of the moon, they were out of radio contact with Earth for about thirty minutes each time they went behind the moon. As they came back from their fourth journey behind the moon, they saw something that caught their attention far more than the unexplored surface of the moon—they saw Earth rising above the lunar horizon. The moon was gray and barren; Earth on the other hand hung brilliantly in the sky with its blue oceans, white clouds and ice caps, and variously-hued continents. They journeyed 384,000 kilometers to the moon, but then realized that the most important object in their view was not the moon, but Earth.

Objectives

After studying this chapter and completing the exercises, you should be able to do each of the following tasks, using supporting terms and principles as necessary.

1. Define and describe the four major Earth systems.
2. Give examples of specialties practiced by different kinds of Earth scientists.
3. Describe Earth's location in the solar system, galaxy, and universe.
4. Define what a habitable zone is, and apply this definition to Earth's place in the solar system and the solar system's place in the Milky Way galaxy.
5. Give examples of ways in which Earth seems to be "just right" for complex life.
6. Describe Earth's orbit around the sun.
7. Explain how the tilt of Earth's axis causes the seasons.
8. Explain why it is hot in the summer and cold in the winter in the Northern Hemisphere.
9. List, in order, the phases of the moon throughout the lunar cycle.
10. Describe the position of the sun, Earth, and moon for each phase of the lunar cycle.
11. Explain what causes partial and total solar eclipses and explain why they do not occur every month.
12. Explain the cause of lunar eclipses.
13. Explain how solar, lunar, and lunisolar calendars work and give an example of each.
14. Compare the Julian and Gregorian calendars, explaining how the Gregorian calendar corrected a flaw in the Julian calendar.

Vocabulary Terms

You should be able to define or describe each of these terms in a complete sentence or paragraph.

1. Antarctic Circle
2. aphelion
3. Arctic Circle
4. atmosphere
5. autumnal equinox
6. biosphere
7. ecliptic
8. first quarter
9. full moon
10. galaxy
11. geocentric model
12. geology
13. Gregorian calendar
14. habitable zone
15. heliocentric model
16. hydrosphere
17. Julian calendar
18. last quarter
19. lithosphere
20. lunar calendar
21. lunar phase
22. lunisolar calendar
23. meteorology
24. Milky Way galaxy
25. new moon
26. oceanography
27. partial solar eclipse
28. penumbra
29. perihelion
30. solar calendar
31. solar eclipse
32. summer solstice
33. total lunar eclipse
34. total solar eclipse
35. Tropic of Cancer
36. Tropic of Capricorn
37. umbra
38. universe
39. vernal equinox
40. waning crescent
41. waning gibbous
42. waxing crescent
43. waxing gibbous
44. winter solstice

1.1 An Introduction to Earth Science

The image on the opening page of this chapter is a picture taken by astronauts on the spacecraft Apollo 17, the final mission to the moon in 1972. From space, one can see that Earth is not a monotonous place. Some of its land surface is brown and barren, and other parts are covered with lush vegetation. Greater than 70% of the surface is covered by oceans. Both land and the oceans near the poles are covered with water in a different form: snow and ice. Forming a thin layer on top of all these is the atmosphere, with its ever-changing patterns of clouds.

1.1.1 Earth Systems

What you see from space can be categorized into different Earth systems, illustrated in Figures 1.1 through 1.5. Scientists think of these systems as concentric spheres, with the solid Earth at the center, then water, then the air. Living organisms are present in all three. This gives us four primary Earth systems: the lithosphere, the hydrosphere, the atmosphere, and the biosphere.

The *lithosphere* is the rigid outer layer of Earth, composed mostly of solid rock. The lithosphere includes Earth's crust and the upper part of the underlying mantle. The rocks of the crust are exposed in many places at the surface of Earth. There are two basic types of crust: continental crust and oceanic crust. The continental crust is composed largely of a lighter-colored rock called granite and averages about 30 to 40 km (20–30 mi) in thickness. On the other hand, the oceanic crust is typically about 5 km (3 mi) thick and composed of a dark, dense igneous rock (that is, formed from molten rock) called basalt. Beneath the lithosphere is the rest of Earth's rocky mantle, and beneath the mantle is Earth's iron core. You will learn more about Earth's crust, mantle, and core in Chapter 7.

The *hydrosphere* is the part of Earth that is made out of water. This water is present as a liquid in the oceans, seas, lakes, and rivers, and as groundwater in pores in rocks and soil. Additionally, water is present as a solid—snow and ice—on land and the polar oceans, and as a gas in the atmosphere. Most of Earth's water is present as salt water in the oceans. The greatest amount of fresh water—that is, non-salty water—is contained in ice, primarily in the ice caps that cover Greenland and Antarctica. Compared to the oceans and ice caps,

Figure 1.1. Lithosphere—the solid, rigid outer layer of Earth. This quarry is in Australia.

there is only a tiny amount of water in lakes and streams.

Figure 1.2. Hydrosphere—Earth's water. Havasu Falls is in the Grand Canyon in Arizona.

Earth is surrounded by a layer of gases called the *atmosphere*. The thickness of the atmosphere compared to the rest of the planet is like the peel of an apple compared to the rest of the fruit. The most abundant gas in the atmosphere is nitrogen (78%), followed by oxygen (21%). The remaining 1% is made up of argon, carbon dioxide, and a number of gases that are present in small proportions. The atmosphere also contains a variable amount of water vapor—water in its gaseous state.

The atmosphere serves a number of functions. The oxygen in the atmosphere is necessary for respiration for most living things, and the carbon dioxide is necessary for photosynthesis. The atmosphere also helps to maintain the temperature of the surface of Earth in a range that is suitable for advanced organisms such as plants and animals. In addition, the gases of the atmosphere help prevent various types of harmful radiation from the sun and deep space from reaching Earth's surface.

The *biosphere* is made up of all organisms that live on Earth, together with the environments in which they live. Life exists in almost every environment on Earth:

Figure 1.3. Atmosphere—The gaseous layer that surrounds Earth. This thunderstorm occurred over New Mexico.

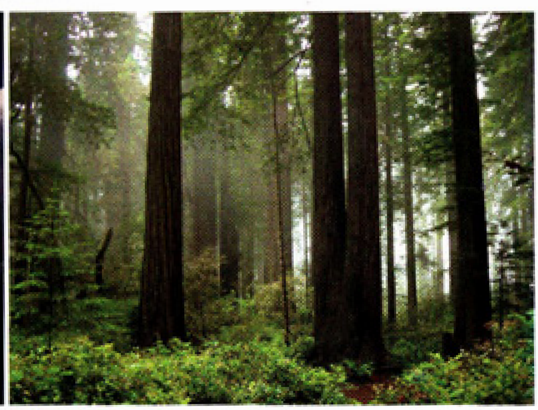


Figure 1.4. Biosphere—All living things on Earth. This temperate rainforest is in Redwood National Park in California.

Figure 1.5. All four Earth systems—lithosphere, hydrosphere, atmosphere, and biosphere—are interacting along this Atlantic Ocean coastline in Maine.

the surface, the soil, the air, the deep sea, hot springs, ice, and even cracks in hot rocks thousands of meters beneath the surface.

These four systems all interact with each other. It is obvious that organisms in the biosphere are dependent on the lithosphere, hydrosphere, and atmosphere for oxygen, water, nutrients, and space to live. However, not only does the biosphere use resources from the other systems, the biosphere in turn affects those systems as well. Plants have changed the atmosphere by producing oxygen. Plants also help to break down minerals in the soil by removing nutrients and exchanging water with the hydrosphere. Likewise, there are interactions between the lithosphere, hydrosphere, and atmosphere. For example, water—coming from the atmosphere—falls on Earth and causes erosion of the soil, which is part of the lithosphere. Many of the interactions between the solid Earth, water, air, and life are extraordinarily complex and are not fully understood.

1.1.2 Subdivisions of Earth Science

Figure 1.6. A geologist sampling 1150°C (2100°F) lava at Kilauea, a volcano in Hawaii.

Earth scientists work in a number of specialties. Traditionally, these are broken down into three major subdivisions: geology, oceanography, and meteorology, illustrated in Figures 1.6 through 1.8.

Geology is the study of the materials that make up Earth and the processes that change Earth over time. Geologists, of course, study rocks, but they also study a range of materials and processes that will be covered in this book, such as volcanoes, earthquakes, fossils, streams, glaciers, water resources, mineral resources, and energy resources.

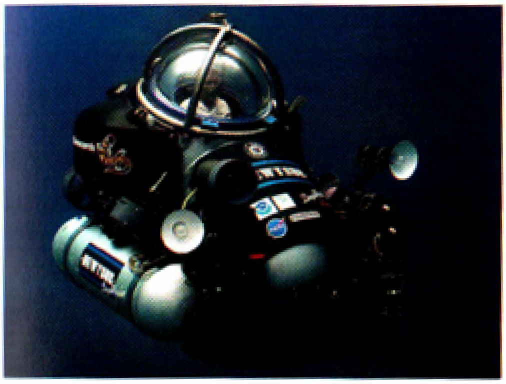


Figure 1.7. Oceanographers use submersibles such as DeepWorker *to explore the ocean's depths.*

Figure 1.8. Meteorologists using radar to study a tornado.

Oceanography is the study of the oceans. An oceanographer might study ocean currents, processes that occur on beaches, mineral resources on or beneath the ocean floor, or organisms that live in the ocean.

Meteorology is the study of the atmosphere. Meteorologists not only make weather observations and forecasts. They are also interested in studying air pollution and understanding long-term trends and changes in climate at various places.

1.1.3 Further Specializations

Due to the explosive growth of scientific knowledge, it is impossible for a geologist, oceanographer, or meteorologist to have complete knowledge of his or her subject. Usually, Earth scientists have a broad knowledge of the sciences and a specialty that is the focus of their work. Some specialties of Earth sciences include:

- Climatology — The study of climate, which is the long-term average of weather conditions in an area.
- Ecology — The study of the interactions between organisms and their environments. Ecology is often considered to be a topic in biology, but it is also an important topic in Earth sciences. Organisms affect Earth, and Earth affects the organisms that live on it.
- Geochemistry — The use of chemistry to understand Earth processes.
- Geophysics — The use of physics to understand Earth, including its shape, interior, magnetism, and surrounding space.
- Hydrology — The study of the movements and quality of water, either on Earth's surface or under it.
- Marine biology — The study of life and ecosystems in the oceans.
- Mineralogy — The study of the formation, composition, and distribution of minerals.
- Paleontology — The study of past life on Earth and how it has changed over time.
- Petroleum geology — The study of the location, migration, and production of oil and gas resources.

- Petrology — The study of rocks.
- Planetary geology — The application of geological principles to other worlds, such as planets, moons, and asteroids.
- Volcanology — The study of volcanoes.

This list represents only some of the many specializations within the Earth sciences. Even within these specialties, a scientist usually focuses on an even narrower topic. A climatologist might be most interested in desert climates, a paleontologist might specialize in coral fossils of the Jurassic Period, or a volcanologist might focus on the chemical composition of volcanic rocks produced from volcanoes like the ones in Hawaii. However, even within these specializations the best scientists are those who can relate their data to work being done by workers in other specializations. Because of this, scientists often work in teams and attend meetings with other scientists so they can exchange ideas and look for interactions and relationships between their work and that of others.

Learning Check 1.1

1. Distinguish among the lithosphere, hydrosphere, atmosphere, and biosphere.
2. Suggest two ways that the biosphere interacts with each of the other Earth systems.
3. Give a definition for each of the three major subdivisions of Earth science that you will be learning about in this course.

1.2 Earth in the Solar System, Galaxy, and Universe

We cannot completely understand Earth without having an understanding of Earth's place in the solar system, galaxy, and universe. After all, things that happen at a great distance from Earth can greatly influence our planet. Energy from the sun, produced by nuclear fusion of hydrogen and helium in the sun's core, constantly bathes Earth's land, water, and air in the form of electromagnetic radiation. There is gravitational attraction between Earth and the sun, moon, and other planets in the solar system. Rare astronomic events can influence Earth as well, such as the collision of large meteorites or even asteroids with Earth.

1.2.1 Earth in the Solar System

Until the 16th and 17th centuries, most scientists believed that Earth was at the center of the physical universe. It was thought that the sun, moon, and five planets known at the time (Mercury, Venus, Mars, Jupiter, and Saturn) all orbited around Earth in perfectly circular orbits, as illustrated in Figure 1.9. In this model, the stars were points of light that also revolved around Earth. This Earth-centered picture of the universe is known as a *geocentric* model. The story of how scientists changed their minds about this model of the universe is fascinating and was an important turning point in the history of science, but it is a topic for another course. It took about one hundred years from the work of Nicolaus Copernicus (1473–1543) until after the death of Galileo (1564–1642) for most scientists to abandon the geocentric model of the universe.

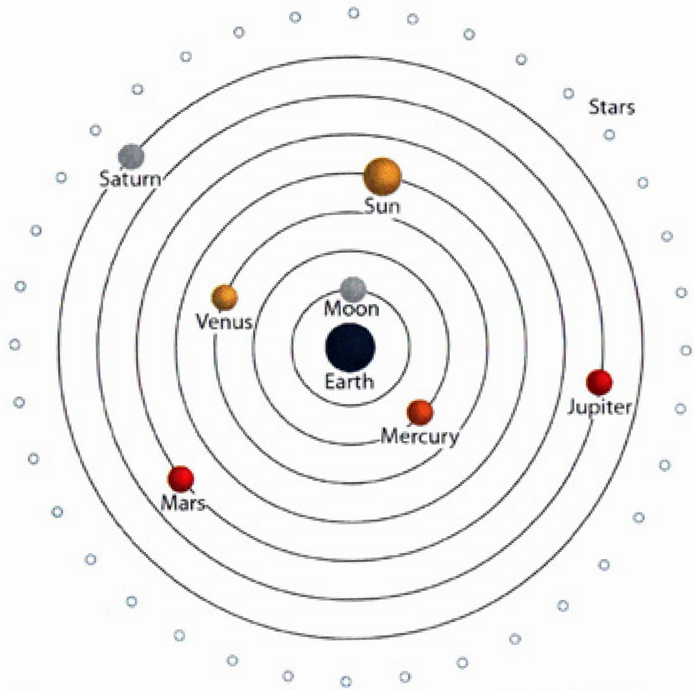


Figure 1.9. In the geocentric model, Earth is at the center of the universe, and all other bodies orbit Earth.

Today we have a very different picture of the place of Earth in the solar system and of the universe as a whole, illustrated in Figure 1.10. We now understand that the sun, not Earth, is at the center of the solar system. This model of the solar system is known as a *heliocentric* model. Earth is one of eight planets that orbit the sun. The four innermost plan-

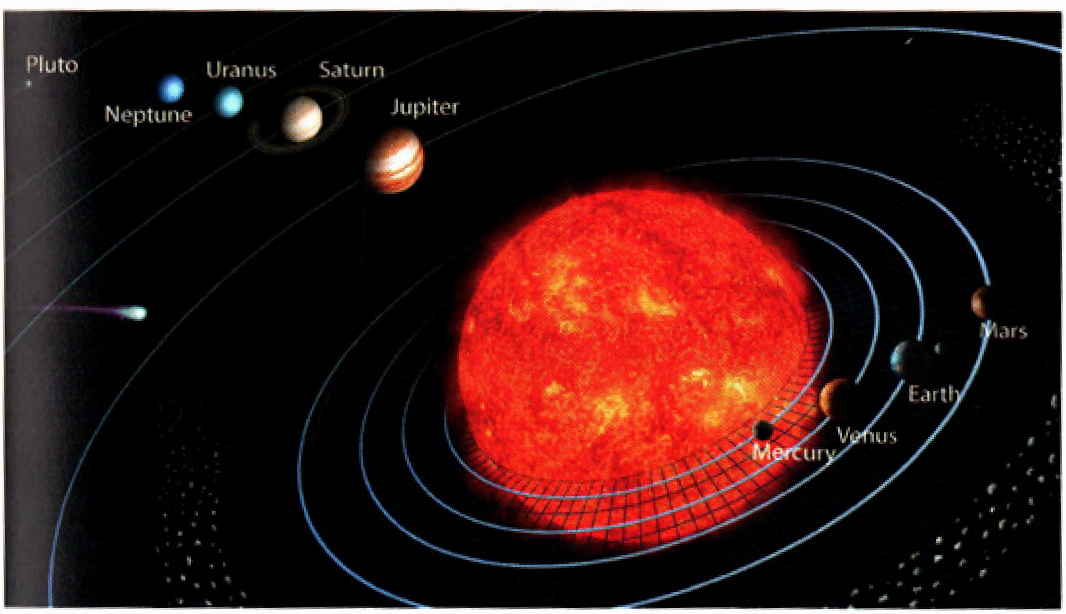


Figure 1.10. In the heliocentric model, planets, asteroids, comets, and other solar system bodies orbit the sun. Our sun is just one of over 100 billion stars in the Milky Way galaxy.

ets—Mercury, Venus, Earth, and Mars—are composed largely of rock and are known as the terrestrial (Earth-like) planets. As Figure 1.11 suggests, we can apply what we know about Earth to the study of the other terrestrial planets because they have similar compositions. Similarly, we can apply what we learn about Mercury, Venus, and Mars back to our study of Earth. The outer four planets—Jupiter, Saturn, Uranus, and Neptune—are much more massive. They are composed largely or entirely of gas and known as the gas giants.

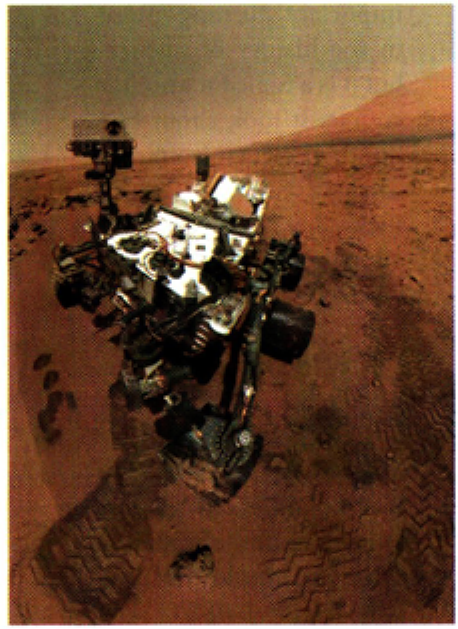


Figure 1.11. The Curiosity rover on Mars, one of the four terrestrial planets. Many of the geologic features that occur on Earth, such as volcanoes, sand dunes, and stream channels, can also be studied on Mars.

1.2.2 Earth—A "Just Right" Planet

Most places in the solar system—and in the universe as a whole—are quite hostile to complex life. Complex life is life that is more sophisticated than bacteria, and includes all plants and animals. In most places in the universe, the temperatures are too hot or too cold, or there isn't water, or the right elements—such as carbon—aren't present, or there is too much damaging electromagnetic radiation for living organisms to thrive.

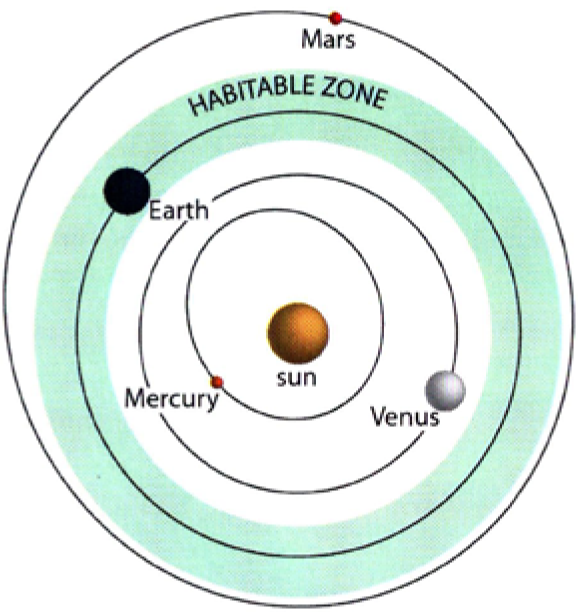


Figure 1.12. Our solar system's habitable zone, tinted in BLUE. There is debate about exactly where the inner and outer limits of the habitable zone are. The sun and planets are not drawn to scale.

Within the solar system, Earth occupies a special location. If Earth were somewhat closer to the sun, the temperature would be hot enough to boil the oceans. Living organisms, from bacteria to humans, are dependent on liquid water to exist. Even on Venus, the next planet closer to the sun, the temperature on the surface is around 460°C (860°F)! On the other hand, if Earth were farther away from the sun, it would be cold enough to freeze all water on the surface. As an example, consider Mars, with an average surface temperature of around –55°C (–67°F), though temperatures can rise above freezing (0°C) on a summer day near the Equator. So far as we know, Mars is currently a lifeless planet. It certainly cannot support the abundance of life that exists on Earth.

The region around a star in which liquid water can exist on the surface of planets—and which therefore can support advanced life—is known as the *habitable zone*, illustrated in Figure 1.12. Determining the inner and outer limits of the habitable zone is not a straightforward task, but certainly Venus is too close to the sun, and Mars is at or near the outer edge of our solar system's habitable zone. Sometimes astronomers refer to planets in the habitable zone as "Goldilocks planets," where the temperature is neither too hot, nor too cold, but just right. There may be places outside of the habitable zone where conditions are just right for life—such as in warm water beneath the surface of some of the moons of Jupiter—but it is considered unlikely by most scientists that these environments could support life more sophisticated than microscopic bacteria.

Earth is also "just right" in other ways:

1. Earth seems to be an ideal size. If it were considerably smaller, it would not have strong enough gravity to hold onto most of its atmosphere. Mars has only 10.7 percent of the mass of Earth, and has a very thin atmosphere. If, on the other hand, Earth were considerably larger, it would probably have a much denser atmosphere due to stronger gravity. This would likely lead to much higher surface temperatures.

2. Earth has a good amount of water. There is enough water to support life, but not so much as to completely cover Earth with water.

3. Earth seems to have just the right chemical composition. For example, Earth has a small amount of carbon, an essential element for all the primary molecules of life, such as proteins, sugars, and DNA. But if it had considerably more carbon, the composition of both the solid Earth and the atmosphere would be radically different, and inhospitable to life. Earth also has an iron core, which causes Earth's magnetic field and helps to protect the surface from harmful radiation from space (the solar wind). The chemical composition of Earth's crust also seems to be just right for the long-term maintenance of life.

4. Many scientists believe that gravitational interactions between Earth and the moon—the same interactions that cause ocean tides—keep Earth's axis tilted at a fairly constant angle near 23.5°. If Earth didn't have such a large moon—all other moons in the solar system are small compared to the size of their parent planets—occasional changes in the angle of Earth's tilt could cause catastrophic changes to the climate, which would make the continued existence of complex life difficult. We will take a closer look at Earth's axis in the next section.

5. Earth has plate tectonics, which, as you will learn in Chapter 6, is the process that moves continents and other parts of the lithosphere around on Earth's surface. It turns out that plate tectonics is a process which helps to make Earth a suitable home for the flourishing of life. Geologists believe that a number of factors have

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