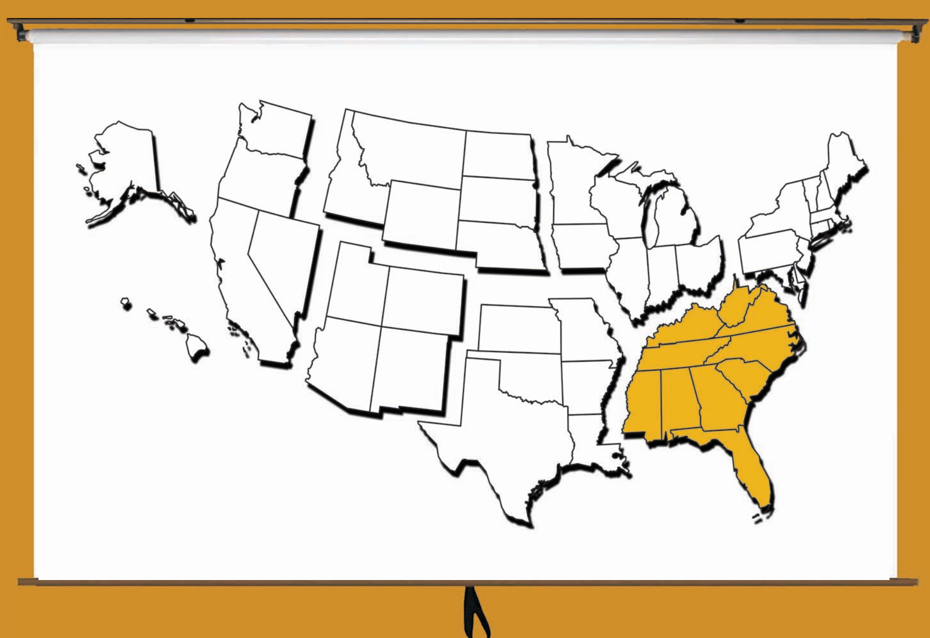
The Teacher-Friendly Guide™

to the Earth Science of the Southeastern US

2nd ed.



Edited by Andrielle N. Swaby, Mark D. Lucas, & Robert M. Ross

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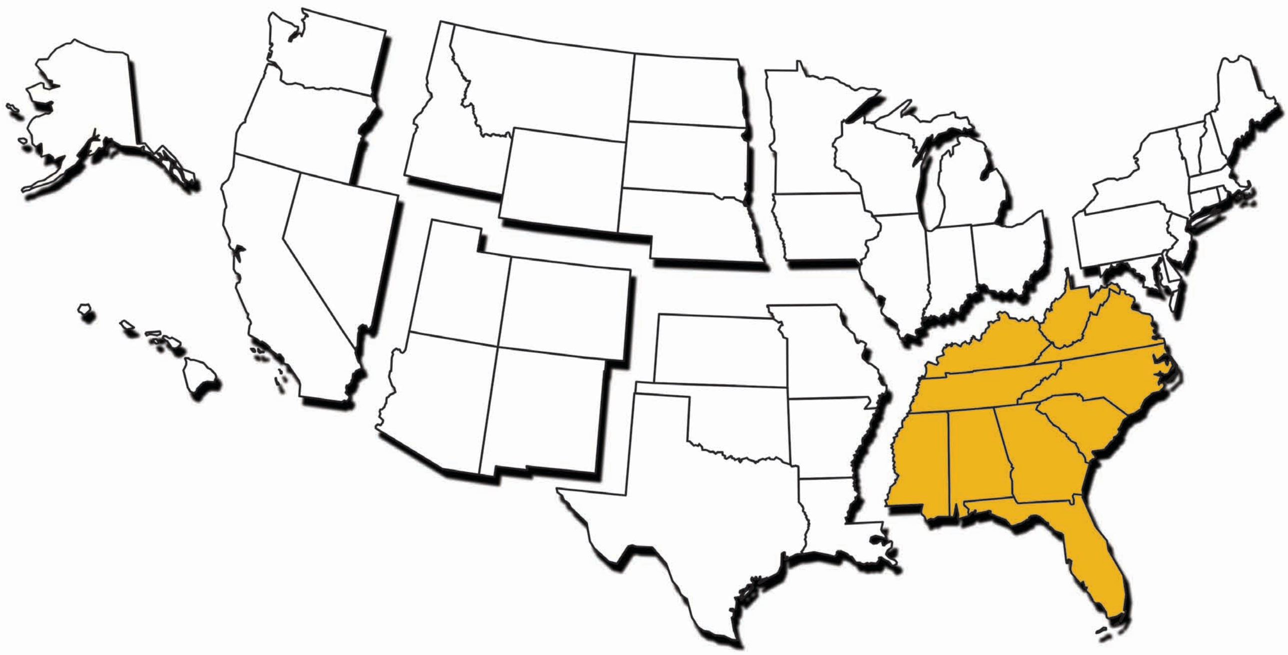

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The interactive online version of this *Teacher-Friendly Guide*™ (including downloadable pdfs) can be found at http://teacherfriendlyguide.org. Web version by Brian Gollands.

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On the back cover: Blended geologic and digital elevation map of the Southeastern US. Each color represents the age of the bedrock at the surface. Adapted from Barton, K. E., Howell, D. G., Vigil, J. F., *The North America Tapestry of Time and Terrain*, US Geological Survey Geologic Investigations Series I-2781, http://pubs.usgs.gov/imap/i2781.

Preface

Earth science is an inherently local subject. No two places share exactly the same sequence of events that led to the way they are today. In this sense, Earth science is a subject to be explored in one's own neighborhood, examining the detailed sequence of rocks for the history that has gone on under our feet. What is not possible from only one location is making sense of why this particular sequence of events took place when and where it did, particularly relative to sequences in other places around it.

The distribution of rocks and landforms can be explained by processes that shape areas covering thousands of kilometers, such as the evolution of the Gulf Coast margin of the North American continent to the more stable, ancient continental interior. These processes link widely separated sequences in a common history.

Earth science educators at the Paleontological Research Institution, in working with teachers, have noted that no single source for educators exists that attempts to make sense of the disparate local features of the Southeastern United States in terms of a basic sequence of historical events and processes. Nationally distributed textbooks make few references specifically to the Southeastern region. While a number of reasonably good resources exist for individual states, these do not take enough geographic scope into account to show why, say, the Blue Ridge Mountains contain ancient metamorphic rocks, while not far to the east are well-preserved fossil-rich sand deposits, or why West Virginia has well-known deposits of Paleozoic coal, while Florida has none. Further, these resources are not necessarily "teacher-friendly," or written with an eye toward the kind of information and graphics that a secondary school teacher might need in their classroom. This *Teacher-Friendly Guide™* is intended to fill this need for teachers.

Explaining why (for example, certain kinds of rocks and their mineral resources are found where they are) is the most effective way of providing students with a tool to remember and predict the nature of local Earth science. The Southeastern US (though, like states, an artificial political area) is of the right scale to discuss the evolution of significant portions of sedimentary basins, but also includes ancient igneous rocks. This means most Earth processes are illustrated by rocks present within a day's drive, and that Earth phenomena can be illustrated with examples in areas students and teachers are likely to have been to or at least heard of. Since the rocks and landforms are relatively accessible, regional Earth science is an excellent subject for hands-on, inquiry-based teaching using, for example, real rocks and landforms. A transect across the Southeastern US in several places will reveal most major rock types that students should know and will come into contact with over the course of their lifetimes.

The chapters chosen are by no means an exhaustive list, but reflect especially the historical side of "solid Earth" geosciences. Each chapter starts with a brief review, then (in most chapters) describes the Earth science of three natural regions of the Southeast. There is a resource list at the end of each chapter. There is a chapter on field work, not only on suggestions for how to do it, but how to integrate the field into your curriculum through "virtual fieldwork experiences." There are chapters on Big Ideas in Earth system science—a few major conceptual ideas that run throughout the subject—and on using real-world regional Earth science in the context of the Next Generation Science Standards (NGSS).

This volume is part of a national series of seven *Teacher-Friendly Guides™* to regional Earth science, covering all 50 states. We also have two *Teacher-Friendly Guides™* to evolution, and other Guides in development.

We would hope for our students that, years from now, they will be able to make sense of the place they live and the places they visit, through a comprehension of a few Big Ideas and a basic grasp of the "big picture" story of geological history of their area. It is our hope that this book might help teachers, and their students, grasp such a coherent understanding of their regional and local Earth system science.

Robert M. Ross, Associate Director for Outreach
Don Duggan-Haas, Director of Teacher Programs
Paleontological Research Institution
January 2016

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How to Use this Guide

General philosophy of the Teacher-Friendly Guides™

This Guide is organized by regional geologic history because it helps make sense of local Earth science—*Why does this place look the way it does? Why is this particular set of rocks, soil, landforms, water bodies, and local climate here?* We recommend introducing geologic history into your curriculum early.

The idea of systems also runs through the Guide. Through systems we understand, for example, why geologic history controls where different types of rocks occur, helping us make sense of landforms and water bodies. Landforms and water bodies in turn influence local climate, and all of it influences life. Understanding a few essentials of geologic history and Earth systems allows us to make sense of the world around us.

Please incorporate ideas from the Guide into your existing curriculum. This Guide is a resource rather than a curriculum itself.

Understanding real-world Earth science is a lifelong learning experience. Don't be intimidated by rocks that you don't recognize, fossils with long names, or complicated weather patterns. Enjoy learning alongside your students and show that enjoyment.

A National Series of Guides

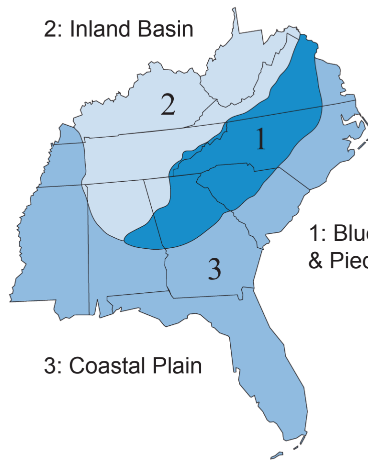
This Guide is one of seven covering the United States. There are also two *Teacher-Friendly Guides™* to evolution, one focused upon bivalves and another focused on maize genetics. To learn more, visit www.teacherfriendlyguide.org, a website of the Paleontological Research Institution.

For the interactive website version of this Guide, visit www.teacherfriendlyguide.org. To download individual chapters for printing, visit the website for the Southeastern Guide and click "Downloads" on the chapter menu to the left.

To purchase a printed grayscale copy, visit "Publications" at the Paleontological Research Institution website. Images in the printed version, which are in grayscale, are available in color in the digital versions.

Design of the Guides

Most chapters in this guide divide the Southeastern US into three broad regions, each of which has a different geologic history and thus varies in rocks, fossils, topography, mineral resources, soils, and Earth hazards. The Geologic History chapter explains the history of all three within the context of Earth history. Chapters on climate and glaciers are not divided by region because these tend to be driven by processes at broader geographic scales.



Each Guide begins with five cross-cutting Big Ideas of Earth science. These have applications across the curriculum. Deep study of specific Earth science sites gives context and meaning to these most fundamental ideas, and in turn understanding these ideas facilitates a lifetime of making sense of Earth processes anywhere.

Each Guide ends with a chapter on fieldwork— even from the classroom. You and your students can begin to interpret the Earth science in your area, and bring back photos and data to re-visit your field sites—using "virtual fieldwork"—throughout the year. More information is available at www.virtualfieldwork.org.

Use the color geologic map as a reference tool while you read this Guide. The map is on the back cover of the printed Guides and available as a downloadable graphic on the website.

Cross-referencing

You do not have to read this Guide from front to back! Each chapter is written to stand alone. Main concepts are repeated in more than one chapter. In this way you can use read just what you need, in any order, as you approach particular units through the school year.

The chapters are cross-referenced, should you need to find more information about a particular concept or region. Bold-faced words are defined in a separate glossary, with selected words defined in chapter side bars.

For Further Information...

At the end of each chapter are lists of resources specific to that topic. There are lists of national and state-based resources, many of which cover multiple topics, at the end of the Guide.

Earth System Science: The Big Ideas

Like all scientific disciplines, the Earth sciences continually evolve over time. New discoveries fuel new ideas, providing an ever-increasing understanding of the planet. But of the overwhelming number of observations, theories, and principles that form the foundation of Earth **system** science, what is essential for every American to understand? All too often, curricula are too ambitious and, as a result, may fail to cover topics in any substantial depth. An alternative approach is to build one's curriculum upon a foundation of focused, interconnected big ideas. A well-designed set of big ideas can provide an all-encompassing conceptual framework for any discipline, including Earth system science. Developed alongside scientists and Earth science teachers, this coherent set of big ideas illuminates what is fundamental to the Earth sciences:

1. *The Earth is a system of systems.*
2. *The flow of* ***energy*** *drives the cycling of matter.*
3. *Life, including human life, influences and is influenced by the environment.*
4. *Physical and chemical principles are unchanging and drive both gradual and rapid changes in the Earth system.*
5. *To understand (deep) time and the scale of space, models and maps are necessary.*

These ideas are designed to cover the breadth of any Earth science curriculum, but they must be dissected to build deep understanding. Each idea is essentially bottomless; that is, while a meaningful understanding of these ideas is readily attainable, the details contained within are endless. Each of the ideas can be understood, but the depth of understanding can vary greatly.

Introduction of these ideas also invites discussion of the nature of science. As curricula are designed and implemented, the traditional topics of Earth system science should be complemented with ideas on how we have come to know what we know about the natural world. Within our big ideas framework, we draw attention to the nature of science with two overarching questions:

1. *How do we know what we know?*
2. *How does what we know inform our decision making?*

These questions, when addressed in concert with the big ideas, provide a gateway into the nature and utility of the range of scientific ideas.

system • *a set of connected things or parts forming a complex whole.*

energy • *the power derived from the use of physical or chemical resources.*

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Big Ideas

Big Idea 1: The Earth is a system of systems

plate tectonics • *the process by which the plates of the Earth's crust move and interact with one another at their boundaries.*

weathering • *the breakdown of rocks by physical or chemical means.*

erosion • *the transport of weathered materials.*

uplift • *upward movement of the crust due to compression, subduction, or mountain building.*

delta • *a typically wedge-shaped deposit formed as sediment is eroded from mountains and transported by streams across lower elevations.*

plates • *large, rigid pieces of the Earth's crust and upper mantle, which move and interact with one another at their boundaries.*

heat • *a form of energy transferred from one body to another as a result of a difference in temperature or a change in phase.*

The Earth is composed of many systems, which cycle and interact in both space and time. It is also part of a multitude of systems, nested in larger systems such as the solar system and the universe. Systems are composed of an untold number of interacting parts that follow simple rules; they can and do evolve. For example:

> Outlining the geologic history of any region demonstrates the concept of the Earth as a system of systems. **Plate tectonics** drives the formation of mountains. Subsequent **weathering** and **erosion** of the **uplifted** mountains leads to the formation of **deltas** in adjacent shallow seas. And with uplifted continents, shorelines change and the distribution of marine communities are altered.
>
> The planet's systems are intimately connected: the forces of one system affect other systems nested within it. As **plates** collide, systems that drive plate tectonics are obviously linked to the formation of mountains, but they are ultimately linked to and influence much smaller systems and a wide range of landscape types, not just mountains. The intense **heat** and pressure resulting from collisions can lead to the **metamorphism** of existing strata, or it can melt existing rocks to later form **igneous rocks**.
>
> Much of the bedrock within the Southeastern US is of marine origin. Plates do not simply slide across Earth's surface. Mountains and plateaus rise and fall, rifts open, and basins form. The interplay of **climate**, rock, and water has shaped every natural landscape on the planet. Humans and other living things build upon (or tear down) the foundations lain down by these other systems, furthering their interplay.

See Chapter 2: Rocks to learn more about the types of rocks found in the Southeast today.

Each of the remaining ideas operates across multiple systems within the larger Earth system.

Big Idea 2: The flow of energy drives the cycling of matter

The Earth is an open system. Energy flows and cycles through the system; matter cycles within it. This cycling is largely driven by the interaction of the differential distribution of solar radiation and internal heat: the constant flow of solar radiation powers much of Earth's ocean and **atmospheric** processes on the surface of the system, while the flow of heat from **radioactivity** within the Earth drives plate tectonics. For example:

One of the fundamental processes known to Earth system scientists is the rock cycle. The rock cycle illustrates the steps involved in the formation of one type of rock from another. It is a system that has operated since the Earth's origin, and it continues today. The energy that drives weathering and erosion, melting, or an increase in heat or pressure, drives the continuation of the rock cycle.

The landscape we see today in the Southeast has been shaped by the geologic forces of the past, and these forces are still active today. Evidence throughout the Southeast's terrain tells a story that began billions of years ago with the formation of tectonic plates, and this story continues to evolve. The movement of Earth's plates is driven by plate tectonics, illustrating how the flow of energy drives the cycling of matter—the flow of heat from radioactivity within the Earth drives plate movement. Millions of years in the past, what is now the Southeastern US was shaped by repeated continental collisions and the rifting of supercontinents, all driven by **convection** within the **mantle**. While the region is now tectonically inactive, energy flows and the cycling of matter continue to shape the landscape through erosion, deposition, sea level change, and the direct action of humans.

See Chapter 1: Geologic History for more about the tectonic processes that led to the formation of North America as we know it today.

In the recent geologic past, the Mississippi River's water has moved a tremendous mass of sediment from the interior of North America into the Gulf of Mexico. Within the Southeastern US, this includes the Inland Basins, the western side of the Blue Ridge and Piedmont, and the section of the Coastal Plain nearest the Mississippi. Sediment in roughly half of the region, in other words, is carried to the Gulf by the Mississippi. The flow of sediment is, of course, driven by the water cycle. Like the rock cycle, and plate tectonics, the water cycle is driven by convection. Without convection, Earth would be extraordinarily different, if it were here at all.

metamorphic rocks • *rocks formed by the recrystallization and realignment of minerals in pre-existing sedimentary, igneous, and metamorphic rocks when exposed to high enough temperature and/or pressure.*

igneous rocks • *rocks derived from the cooling of magma underground or molten lava on the Earth's surface.*

climate • *a description of the average temperature, range of temperature, humidity, precipitation, and other atmospheric/hydrospheric conditions a region experiences over a period of many years (usually more than 30).*

atmosphere • *a layer of gases surrounding a planet.*

radioactivity • *the emission of radiation by an unstable atom.*

convection • *the rise of buoyant material and the sinking of denser material.*

Big Ideas

Big Idea 3: Life—including human life—influences and is influenced by the environment

greenhouse gas *• a gas in the atmosphere that absorbs and emits heat.*

global warming *• the current increase in the average temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere.*

fuel *• a material substance possessing internal potential energy that can be transferred to the surroundings for specific uses.*

soil *• the collection of natural materials that collect on Earth's surface, above the bedrock.*

Across its four-billion-year history, the course of life's evolution has been intimately tied to the Earth's physical environment. Global cooling led to the relatively recent spread of grasslands, which then triggered an evolutionary shift in many herbivorous mammals from browsing to grazing. Conversely, the evolution of life has altered the physical environment. Photosynthetic bacteria released free oxygen into the early oceans and atmosphere, making Earth habitable for later types of organisms. Humans, with their increasing population and expanding technology, have altered the landscape and the distribution of flora and fauna, and they are changing atmospheric chemistry in ways that affect the climate. Earth system processes also influence where and how humans live. For example:

With human populations increasing the world over, the emission of **greenhouse gases** has also increased dramatically. These gases alter the chemical composition of the atmosphere and directly influence the planet's climate. It is generally agreed that the rapid and immense pouring of carbon dioxide into the atmosphere will lead to **global warming**, which will have incredible impacts throughout the world.

See Chapter 9: Climate to learn more about the effect of greenhouse gases.

Around three million years ago, a land bridge formed between North and South America. For the first time in more than 150 million years, the two continents were linked, and the mammals inhabiting both lands migrated across the bridge. Horses, mastodons, cats, and dogs moved south, while opossums, porcupines, ground sloths, and armadillos moved north (to name a few). Today, half the mammal species in South America are descended from North American migrants.

Throughout the Southeastern US, forest cover has changed and continues to change remarkably. Beginning in Colonial times, large areas of forest were harvested for both building materials and for **fuel**. By the turn of the last century, much of the eastern US was deforested. Now, in much of the Southeastern US, forests are heavily managed as cropland. In just the 12 years between 2000 and 2012, 30% of the forestland within the Southeastern US was either regrown or cleared. Such changes in vegetation impact the flow of water, the structure and movement of **soils**, and much more. When we ask,"Why does this place look the way it does?" the role of humans must be central to our answer.

Big Idea 4:
Physical and chemical principles are unchanging and drive both gradual and rapid changes in the Earth system

The Earth processes operating today—everything from local erosion to plate tectonics—are the same as those operating since they first arose in Earth's history, and these processes are obedient to the laws of chemistry and physics. While the processes that constantly change the planet are essentially fixed, their rates are not. Tipping points are reached that can result in rapid changes cascading through Earth systems. For example:

During the **Precambrian**, the evolution of photosynthetic organisms led to significant changes in the planet's atmosphere. Prior to this event, there was little free oxygen in the atmosphere, but with photosynthesis producing oxygen as a waste product, the very existence of these organisms flooded the seas and atmosphere with free oxygen, changing the planet forever. But life's evolution represents just one of the processes working upon Earth systems.

Tectonic processes have been at work in the same way for billions of years, opening and closing oceans and building up and tearing down landscapes. The folded mountains that stand in the eastern US are markers of past continental collisions, and the apparent continuation of those mountains in Europe are testaments to the separation of the supercontinents formed during those collisions.

***Precambrian** • a geologic time interval that spans from the formation of Earth (4.6 billion years ago) to the beginning of the Cambrian (541 million years ago).*

Big Ideas

Big Idea 5: To understand (deep) time and the scale of space, models and maps are necessary

The use of models is fundamental to all of the Earth sciences. Maps and models aid in the understanding of aspects of the Earth system that are too big or small for direct observation, or where observation is not possible. They also help make complex systems comprehensible through strategic simplification. When compared to the size and age of the universe, humanity is a speck in space and a blip in time; models assist in the comprehension of time and space at both sub-microscopic and immense scales. For example:

> Much of scientists' understanding of the inner workings of our planet is derived from mathematical modeling. It is not possible to directly measure the movement that occurs below Earth's surface, but modeling of convection currents brings us closer to the true nature of these monumental geologic phenomena.
>
> The observation of natural phenomena today, such as deposition along a riverbed, is critical for interpreting the geologic record. But for processes that operate on much larger, slower scales, modeling within the lab is required. The formation of mountain ranges such as the Appalachian Mountains is better understood by examining the effects of stress and strain in the laboratory.

In Conclusion

Taken individually, these big ideas and overarching questions represent important aspects of Earth system science, but together they are more significant. Keeping these ideas in mind—and considering how they arose through scientific methods and investigation—is invaluable as one proceeds throughout his or her curriculum, and it can provide a conceptual framework upon which to build an enduring understanding of the discipline.

Big Ideas

Resources

Books

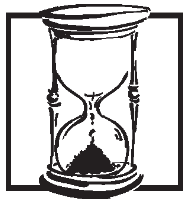
Donovan, S., & J. Bransford. 2005. *How Students Learn: Science in the Classroom*. National Academies Press, Washington, DC, http://books.nap.edu/catalog.php?record_id=10126.

Wiggins, G. P., & J. McTighe. 2005. *Understanding by Design, 2nd edition.* Association for Supervision and Curriculum Development, Alexandria, VA, 382 pp.

Wiske, M. S., ed. 1998. *Teaching for Understanding: Linking Research with Practice.* Jossey-Bass, San Francisco, CA, 379 pp.

Websites

Exploring Geoscience Methods with Secondary Education Students, by J. Ebert, S. Linneman, & J. Thomas, http://serc.carleton.edu/integrate/teaching_materials/geosci_methods/index.html.



Chapter 1: Geologic History of the Southeastern US: Reconstructing the Geologic Past

Geologic history is the key to this guide and to understanding the story recorded in the rocks of the Southeastern US. By knowing more about the geologic history of your area, you can better understand the types of rocks that are in your backyard and why they are there. In this chapter, we will look at the history of the Southeast as it unfolded: as a series of major events that created and shaped the area over the past one billion years. These events will act as the framework for the topics in the chapters to follow and will shed light on why our region looks the way it does!

The shape and position of North America has changed dramatically over the last billion years, and geologic processes continue these changes today. The Earth's outer layer—the **crust**—is dynamic, consisting of constantly moving **plates** that are made of a rigid continental and oceanic **lithosphere** overlying a churning, plastically flowing **asthenosphere**—part of the Earth's **mantle** (*Figure 1.1*). These plates are slowly pulling apart, colliding, or sliding past one another with great force, creating strings of **volcanic islands**, new ocean floor, **earthquakes**, and mountains. The continents are likewise continuously shifting position relative to each other. This not only shapes the land, but also affects the distribution of rocks and **minerals**, natural resources, **climate**, and life.

How do we know what the past is like?

Reconstructing the geologic past is a lot like solving a mystery. Geologists use scraps of evidence to piece together events they have not personally observed, but to do so they must contend with two major complications. First, the overwhelming majority of geologic history occurred long before there were any human witnesses. Second, much of the evidence for the older events is highly fragmented. By studying rocks, **fossils**, and other geologic features, however, scientists can still reconstruct a great deal of what the ancient Earth might have looked like.

Rocks and sediments are indicators of past geologic processes and the environments in which those processes took place. In general, **igneous rocks**, created through tectonic activity, reflect the history of molten rock, both below the surface (**plutonism**) and at the surface (**volcanism**). Likewise, **metamorphic rocks**, created

See Chapter 2: Rocks to learn more about the different types of rocks found in the Southeast.

crust • *the uppermost, rigid outer layer of the Earth.*

plates • *large, rigid pieces of the Earth's crust and upper mantle, which move and interact with one another at their boundaries.*

lithosphere • *the outermost layer of the Earth, comprising a rigid crust and upper mantle broken up into many plates.*

asthenosphere • *a thin semifluid layer of the Earth, below the outer rigid lithosphere, forming much of the upper mantle.*

mantle • *the layer of the Earth between the crust and core.*

volcanic island • *one of a string of islands created when molten rock rises upward through oceanic crust.*

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1 Geologic History

Reconstructing

granite • a common and widely occurring type of igneous rock.

ultramafic rocks • igneous rocks with very low silica content (< 45%), which are composed of usually greater than 90% mafic minerals.

metamorphic rocks • rocks formed by the recrystallization and realignment of minerals in pre-existing sedimentary, igneous, and metamorphic rocks when exposed to high enough temperature and/or pressure.

heat • a form of energy transferred from one body to another as a result of a difference in temperature or a change in phase.

sedimentary rock • rock formed through the accumulation and consolidation of grains of broken rock, crystals, skeletal fragments, and organic matter.

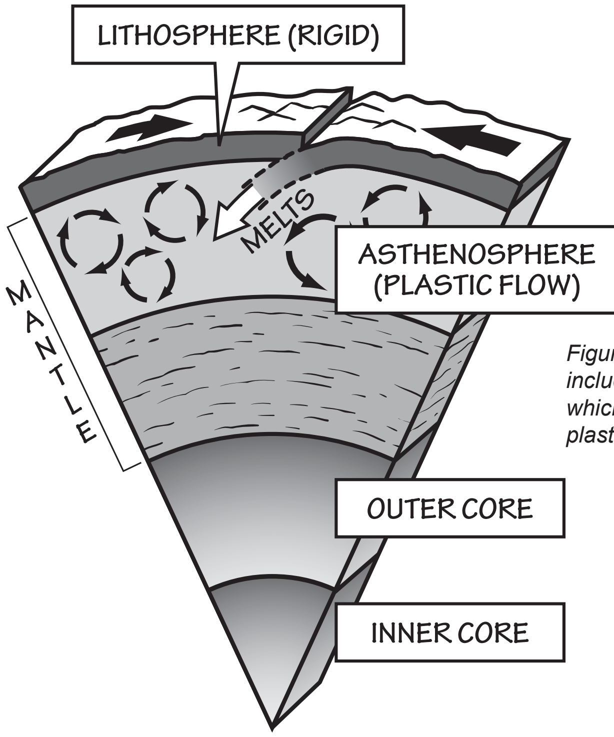


Figure 1.1: The layers of the Earth include the rigid crust of the lithosphere, which is constantly moving over the plastically flowing asthenosphere.

Lithosphere and Asthenosphere: What's the difference?

The lithosphere is the outermost layer of the Earth, a rigid layer of crust and upper mantle broken up into fragments called plates. Although the rock of the asthenosphere would seem very solid if you could observe it in place, under long-term stress it slowly bends and flows, like very thick syrup. The difference between crust and mantle is mainly chemical: the lithosphere's composition typically varies between basalt in oceanic crust and *granite* in continental crust, while the mantle is composed of homogenous *ultramafic* material. The boundary between rigid lithosphere and flowing asthenosphere is usually found within the mantle, and is largely a result of temperature increase with depth beneath the surface. In tectonically active regions of extension such as a mid-ocean ridge, where temperature rises rapidly with depth compared to more tectonically stable regions, the asthenosphere begins nearly at the base of the crust.

when sediment is subjected to intense **heat** and pressure, provide important clues about past mountain-building events, and geologists often use them to map the extent of now-vanished mountain ranges. **Sedimentary rocks** tell perhaps the most comprehensive story of the Earth's history, as they record characteristics of far-away mountain ranges, river **systems** that transported the sediments, and the final environment in which the sediments accumulated and **lithified**. The size and shape of sediments in sedimentary rocks, as well as the presence of fossils and the architecture of sedimentary rock layers (sedimentary structures), can help us infer how the sediments were transported and where they were finally deposited. However, because rocks are often reformed into different rock types, ancient information is lost as the rocks cycle through the igneous, metamorphic, and sedimentary stages.

Fossils indicate both the type of life that once flourished in an area and the kind of climate in which that life existed. Paleontologists use groups of fossils found in the same place to construct pictures of ancient ecosystems. These ecosystems of the past are matched to similar present-day ecosystems, whose climate conditions are then used to infer what sort of climate the fossilized organisms lived in. Unfortunately, few organisms can be easily preserved as fossils, and many environments also do not lend themselves to preserving organisms as fossils. As a result, the clues that fossils give us provide only incomplete glimpses of the ancient world, with many important details missing.

See Chapter 3: Fossils for more information about the Southeast's prehistoric life.

Landscapes and geologic structures are also indicators of past geologic processes and the environments in which they occurred. For instance, the shape of a valley reflects the forces that carved it. Valleys with V-shaped profiles tend to be the products of stream **erosion**, whereas U-shaped valleys are more likely to have been carved by **glaciers**. Layers of intensely folded rock indicate a violent past of tectonic plate collisions and mountain building. Sedimentary structures, such as **ripple marks** or **cross-bedding**, can demonstrate the direction and energy level of the water that transported the sediment. Although landscapes tell us much about the geologic processes that created them, they inevitably change over time, and information from the distant past is overwhelmed by the forces of the more recent past.

See Chapter 4: Topography for more detail about the landscape of the Southeastern states.

Ultimately, geologists rely upon the preserved clues of ancient geologic processes to understand Earth's history. Because younger environments retain more evidence than older environments do, the Earth's recent history is better known than its ancient past. Although preserved geologic clues are indeed fragmentary, geologists have become increasingly skilled at interpreting them and constructing ever more detailed pictures of the Earth's past.

Reconstructing

system • *a set of connected things or parts forming a complex whole.*

lithification • *the process of creating sedimentary rock through the compaction or sementation of soft sediment.*

erosion • *the transport of weathered materials.*

glacier • *a body of dense ice on land that does not melt away annually and has sufficient mass to move under its own weight.*

ripple marks • *surface features created when sediment deposits are agitated, typically by water currents or wind.*

cross-bedding • *layering within a bed in a series of rock strata that does not run parallel to the plane of stratification.*

1 Reconstructing

Geologic History

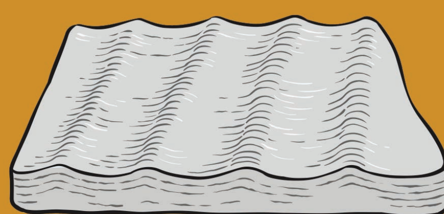
geologic time scale • a standard timeline used to describe the age of rocks and fossils, and the events that formed them.

Archean • a geologic time interval that extends from 4 billion to 2.5 billion years ago.

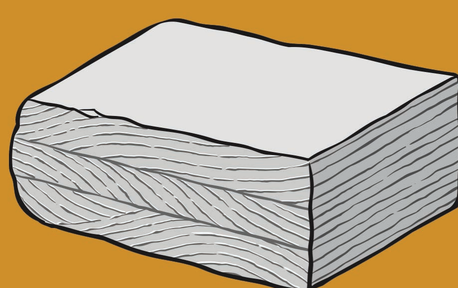
Proterozoic • a geologic time interval that extends from 2.5 billion to 541 million years ago.

Sedimentary Structures

Sedimentary rocks often reveal the type of environment in which they formed by the presence of structures within the rock. Sedimentary structures include ripple marks, cross-beds, mud cracks, and even raindrop impressions. Consider the type of environments in which you see these sedimentary structures today in the world around you.



Ripple marks suggest the presence of moving water (though wind can also create ripples and even dunes). Mud cracks indicate that the sediment was wet but exposed to the air so that it dried and cracked.



Cross-beds form as flowing water or wind pushes sediment downcurrent, creating thin beds that slope gently in the direction of the flow as migrating ripples. The downstream slope of the ripple may be preserved as a thin layer dipping in the direction of the current, across the natural flat-lying repose of the beds. Another migrating ripple will form an additional layer on top of the previous one.

Earth's Timeline

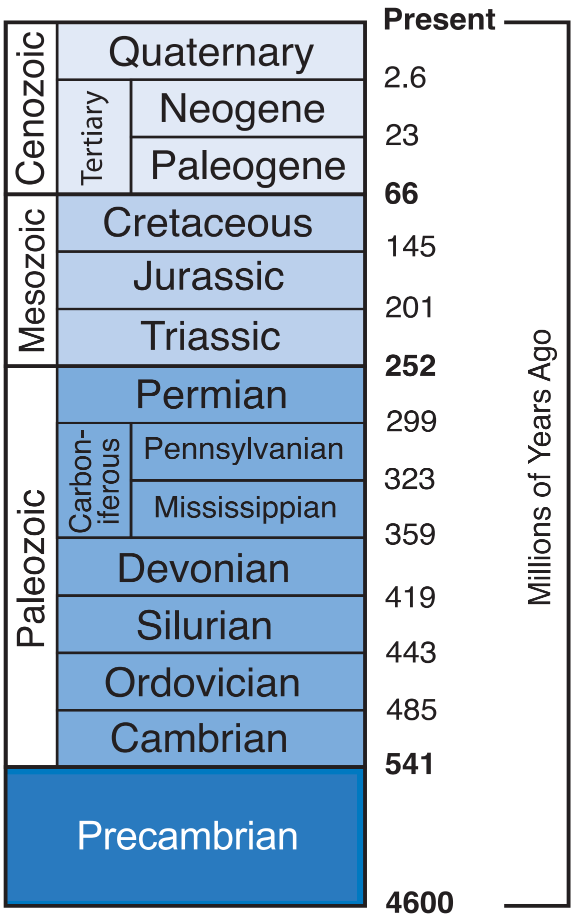
The **geologic time scale** (*Figure 1.2*) is an important tool used to portray the history of the Earth—a standard timeline used to describe the age of rocks and fossils, and the events that formed them. It spans Earth's entire history and is divided into four principal sections.

The first of these four divisions, the **Precambrian**, extends from the beginning of the Earth, around 4.6 billion years ago, to the beginning of the **Cambrian** period, around 541 million years ago. The Precambrian is subdivided into two sections: the **Archean** (before 2.5 billion years ago) and the **Proterozoic** (2.5

Geologic History

1

Reconstructing



About the Time Scale:
The time scale in The Teacher-Friendly Guides™ *follows that of the International Commission on Stratigraphy (ICS). The Tertiary period, though it was officially phased out in 2008 by the ICS, remains on the scale in the Guides, since "Tertiary" is found extensively in past literature. In contrast, the Carboniferous and Pennsylvanian & Mississippian periods all enjoy official status, with the latter pair being more commonly used in the US.*

Figure 1.2: The Geologic Time Scale (spacing of units not to scale).

Geologic Time

How did geologists come up with the timeline for the history of the Earth? The geologic time scale was developed over the course of many years—beginning in the early 19th century—and through the combined work of many geologists around the world. No single location on Earth contains the complete sequence of rocks from Precambrian to present. Geology as a science grew as geologists studied individual stacks or sections of rock and connected them to each other. Gradually, successions of fossils were discovered that helped geologists determine the relative ages of groups of rocks. These layers could then be correlated with similarly aged rock units from around the world. The names you see for the different periods on the geologic time scale have diverse origins; most are based on geographic areas where rocks of that age were first well studied. Time periods were named after dominant rock types, geography, mountain ranges, and even ancient tribes like the Silures of England and Wales, from which the "Silurian" period was derived.

1 Geologic History

Big Picture

Paleozoic • *a geologic time interval that extends from 541 to 252 million years ago.*

Mesozoic • *a geologic time period that spans from 252 to 66 million years ago.*

dinosaur • *a member of a group of terrestrial reptiles with a common ancestor and thus certain anatomical similarities, including long ankle bones and erect limbs.*

Cenozoic • *the geologic time period spanning from 66 million years ago to the present.*

extinction • *the end of species or other taxonomic groups, marked by death of the last living individual.*

weathering • *the breakdown of rocks by physical or chemical means.*

rift • *a break or crack in the crust that can be caused by tensional stress as a landmass breaks apart into separate plates.*

billion to 541 million years ago). Less is known about the Earth during the Precambrian than during later parts of its history, since relatively few fossils or unaltered rocks have survived. Nevertheless, the evidence that has been preserved and discovered reveals much about the planet's first several billion years, including clear evidence that life first appeared on the planet some 3.9 billion years ago in the form of single-celled organisms.

The second division, the **Paleozoic**, extends from 541 to 252 million years ago. Geological evidence shows that during this time period, continents moved, mountains formed, and life evolved in the oceans and gradually colonized the land.

The third division, the **Mesozoic** (from 252 to 66 million years ago), is also called the "Age of Reptiles" since **dinosaurs** and other reptiles dominated both marine and terrestrial ecosystems. It is also noteworthy that during this time the last of the Earth's major supercontinents, **Pangaea**, formed and later broke up, producing the Earth's current geography.

Pangaea, meaning "all Earth," began to assemble over 300 million years ago and lasted for almost 150 million years. All of the Earth's continents were joined as one to form a giant supercontinent.

The last and current division, the **Cenozoic**, extends from the **extinction** of the dinosaurs, nearly 66 million years ago, to the present. With the demise of the dinosaurs, mammals became much more diverse and abundant. We humans didn't come into the picture until the last two million years. To get some perspective on this, if the entire geologic time scale were reduced to 24 hours, we wouldn't come onto the stage until two seconds before midnight!

The Southeastern States

The Big Picture

The geologic history of the Southeastern United States is a story of active mountain building and the quieter processes of **weathering**, erosion, and deposition of sediments. The Southeast is at the edge of a continent (North America), but in the middle of a plate (the North American plate), which extends from the mid-Atlantic ridge to the West Coast. Today this part of North America is tectonically inactive, but this was not always the case. Millions of years ago, the Southeast was the site of multiple continent-continent collisions and the **rifting** of supercontinents. Repeated episodes of mountain building, sea level changes, and the erosion and deposition of sediment shaped the Southeast as we know it today.

In this volume, the Southeastern states are divided up into three different geologic provinces or regions (*Figure 1.3*): the Blue Ridge and Piedmont (1), the Inland Basin (2), and the Coastal Plain (3). Each of these regions

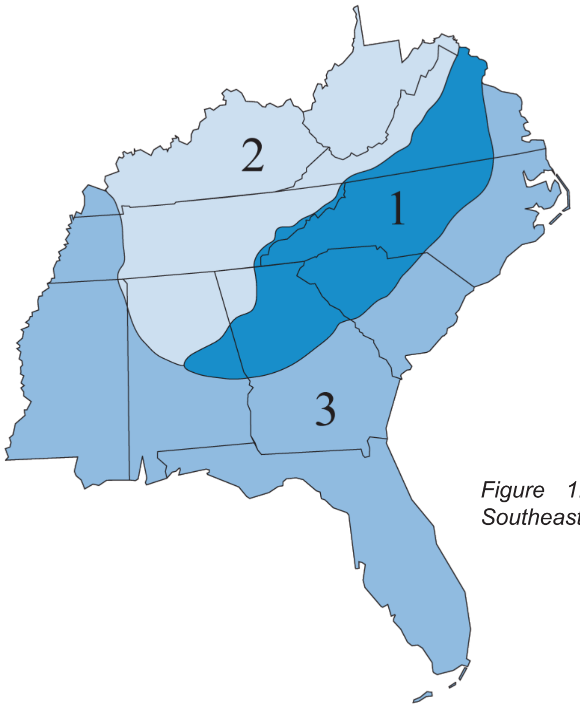


Figure 1.3: Geologic regions of the Southeast.

has a different geological history, and thus varies in terms of rocks, fossils, **topography**, mineral resources, **soils**, and other geological features. The Blue Ridge and Piedmont is composed of the peaks and foothills found at the southern end of the chain of mountains known as the Appalachians. This is the core or "backbone" of Southeastern geology. The Inland Basin, to the west of the Appalachians, includes a number of structural depressions that have filled with sediment, mostly eroded from the mountains. To the east and south is the Coastal Plain, a gently sloping area between the mountains and the ocean.

Southeast Mountain Building, Part 1

The Grenville Mountains

The Earth is estimated to be approximately 4.6 billion years old—an age obtained by dating **meteorites**. Rocks dating to around four billion years old are found on almost every continent, but they are not found at the Earth's surface anywhere in the Southeast. The oldest rocks known on Earth are 4.3-billion-year-old rocks found along the eastern shore of Hudson Bay in northern Quebec. These are part of the **Canadian Shield**, the ancient core of the North American continental landmass, which has experienced very little tectonic activity (**faulting** and folding) for millions of years. Shields, or **cratons**, are the stable cores of all continents and are often covered by layers of younger sediments. They formed and grew during pulses of **magmatic** activity, as bodies of molten rock deep in the Earth's crust contributed to form new crust. The oldest rocks exposed in the Southeast are Precambrian **gneisses** from Roan Mountain, on the border between North Carolina and Tennessee. These rocks, dated at more

topography • *the landscape of an area, including the presence or absence of hills and the slopes between high and low areas.*

soil • *the collection of natural materials that collect on Earth's surface, above the bedrock.*

meteorite • *a stony or metallic mass of matter that has fallen to the Earth's surface from outer space.*

Canadian Shield • *the stable core of the North American continental landmass, containing some of the oldest rocks on Earth.*

fault • *a fracture in the Earth's crust in which the rock on one side of the fracture moves measurably in relation to the rock on the other side.*

craton • *the old, underlying portion of a continent that is geologically stable relative to surrounding areas.*

magma • *molten rock located below the surface of the Earth.*

Mtn Building 1

***Grenville Orogeny** • a mountain-building event, about 1.3 to 1 billion years ago, that played a role in the formation of the supercontinent Rodinia.*

***compression** • flattening or squeezing as a result of forces acting on an object from all or most directions.*

***Rodinia** • a supercontinent that contained most or all of Earth's landmass, between 1.1 billion and 750 million years ago, during the Precambrian.*

***orogeny** • a mountain-building event generally caused by colliding plates and compression of the edge of the continents.*

than 1.8 billion years old, were later metamorphosed during a major episode of mountain building called the **Grenville Orogeny**.

The shape and position of North America has changed dramatically over the last billion years, and geologic processes continue these changes today. **Compression** from colliding plates, tension from plates pulling apart, the addition of land to North America, weathering, and erosion have all combined to slowly sculpt the form of the continent. The Grenville Orogeny was one of several Precambrian continental collisions that led to the assembly of the supercontinent **Rodinia** between about 1.4 billion and 900 million years ago (Figure 1.4). During the **orogeny**, a number of smaller continental blocks and offshore islands were added to the much older core of the proto-North American continent, called Laurentia. Sediment eroded from the mountains that formed during this stage was transported by rivers and streams across the ancient continental margins and into the adjacent oceans. The sediment deposited in the ocean waters on the eastern margin of Laurentia composes a series of rocks that geologists call the Grenville Series (or the "Grenville Belt" in older literature).

The name Grenville comes from a unit of metamorphosed sedimentary rocks located in Quebec, Canada. It is used to refer both to an event (the Grenville Orogeny), and to rocks that formed as a result of that event (Grenville rocks).

The ancient Grenville rocks tell a story of repeated collision-related mountain building on North America's east coast. Intense heat and pressure associated with these continent-continent collisions produced molten rock that was injected into the crust, metamorphosing sediments that had eroded from the craton. The

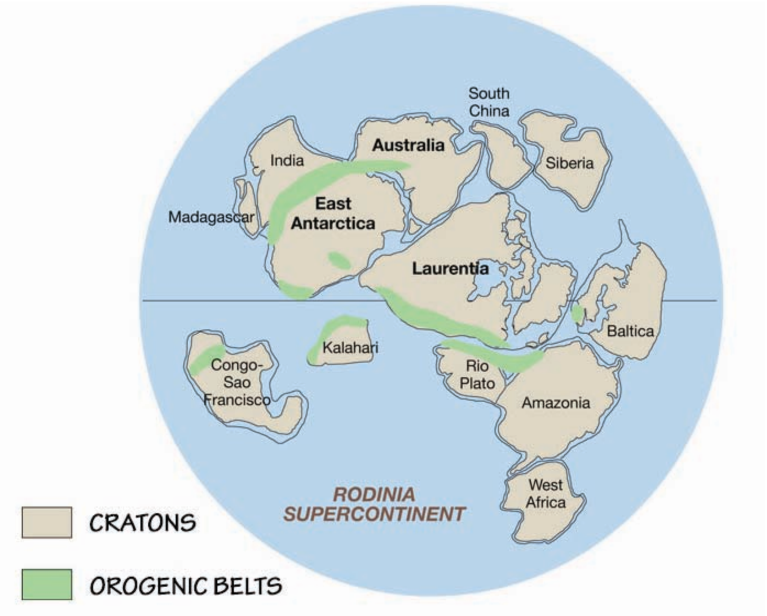


Figure 1.4: The supercontinent Rodinia, around 1.1 billion years ago. Laurentia represents proto-North America. (See TFG website for full-color version.)

Ancient Continents and Their Names

It has taken hundreds of millions of years for the continents to take on the shapes we see today. Ancient continents looked very different. To simplify descriptions of ancient geography, geologists have given names to earlier "proto-continents" to distinguish them from their modern counterparts. Proto-Europe (northwestern Europe without Ireland and Scotland) in the early Paleozoic is known as Baltica; proto-North America is known as Laurentia; and proto-Africa was part of a larger continent known as Gondwana, which included what are now Africa, Australia, Antarctica, India, and South America. To simplify descriptions of geological events on these ancient continents, compass directions generally refer to modern, rather than ancient orientations. Thus, "eastern Laurentia" means the margin of proto-North America that today faces east, but which faced south during the Paleozoic.

collisions created a tall (perhaps Himalaya-scale) mountain range, the Grenville Mountains, which stretched from Canada to Mexico. Orogenic compression folded (and even completely overturned) the metamorphosed sedimentary rocks and igneous **intrusions** of these mountains, forming the **basement rock** of today's Appalachians. At this point in geologic time, very little existed of the Southeast as we now know it. The rocks of the Piedmont and the basement rocks of Florida would not be attached to Laurentia until hundreds of millions of years later. The sediments that eventually solidified into the rocks of most of the present Gulf and Atlantic coastal states had not yet been deposited.

Weathering and erosion are constants throughout the history of time. Rocks are constantly worn down and broken apart into finer and finer grains by **wind**, rivers, wave action, freezing and thawing, and chemical breakdown. Over millions of years, weathering and erosion can reduce a mighty mountain range to low rolling hills. Just as mountains continually erode today, the Grenville Mountains eroded for the next few hundred million years after their formation. In most areas, ancient Grenville rocks are now covered by thousands of meters of younger rocks. However, in the Southeast, weathering left the ancient mountain cores exposed in such places as Blowing Rock in North Carolina, Red Top Mountain in Georgia, and Old Rag Mountain in Virginia (Figure 1.5).

See Chapter 2: Rocks for more information about geologic windows.

intrusive rock • *a plutonic igneous rock formed when magma from within the Earth's crust escapes into spaces in the overlying strata.*

basement rocks • *the foundation that underlies the surface geology of an area, generally composed of igneous or metamorphic crystalline rock.*

wind • *the movement of air from areas of high pressure to areas of low pressure.*

1st Breakup

ice sheet *• a mass of glacial ice that covers part of a continent and has an area greater than 50,000 square kilometers (19,000 square miles).*

basalt *• an extrusive igneous rock, and the most common rock type on the surface of the Earth.*

Iapetus Ocean *• the proto-Atlantic Ocean, located against the eastern coast of North America's ancestral landmass before Pangaea formed.*

rift basin *• a topographic depression caused by subsidence within a rift.*

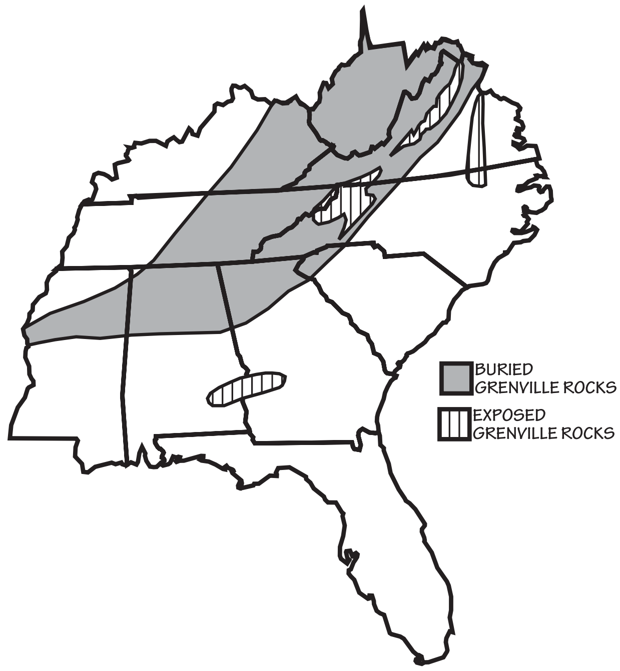


Figure 1.5: Extent of buried and exposed Grenville-aged rocks in the Southeast.

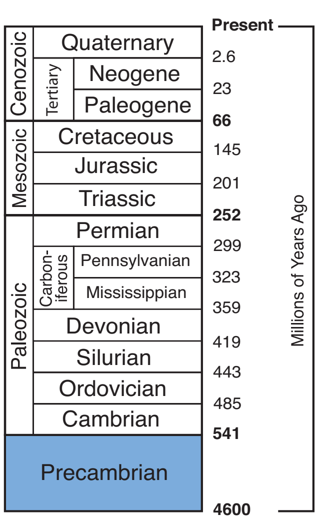
Ancient Rifting

The First Breakup

Following Rodinia's assembly around 700 million years ago, Laurentia began to break away from the rest of the supercontinent as a result of tensional forces beneath the continental crust. A series of cracks known as rifts formed throughout the landmass. During this time, the Earth experienced the most extreme episodes of glaciation in its history, with **ice sheets** spreading all the way into tropical latitudes. One place in which glacial sediment from this interval can be seen is near Valle Crucis in Watauga County, northwestern North Carolina. Around 565 million years ago, the continents split apart completely at a major rift that was floored by oceanic (**basaltic**) crust and flooded by ocean water. Geologists call this ocean the **Iapetus Ocean** (or proto-Atlantic), because the modern Atlantic Ocean opened up in a similar way and position relative to modern-day North America and Europe.

Not all of Rodinia's rifts broke completely across the continent. Instead, some of them remained as **rift basins** within the continental crust, formed when crustal blocks slid downward along faults (*Figure 1.6*). These basins filled with sediment, some of which is preserved in the rocks of Grandfather Mountain, North Carolina. The basaltic **lava** that welled up through cracks in the basin can also be seen in western North Carolina, near Bakersville in Mitchell County.

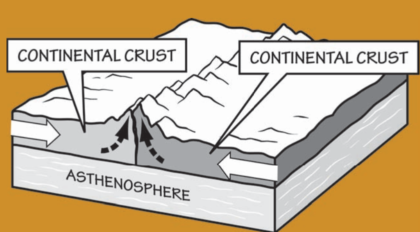
The rift that became the Iapetus Ocean is marked by ancient **sandstone**, which is visible at the top of Pilot Mountain in Surry County, North Carolina. This rifting

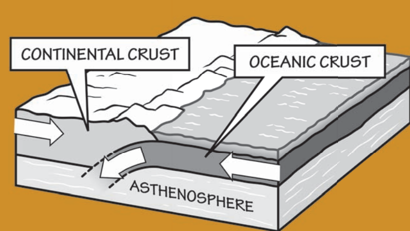


1st Breakup

Continental and Oceanic Crust

The lithosphere includes two types of crust: continental and oceanic. Continental crust is less *dense* but significantly thicker than oceanic crust. The higher density of the oceanic crust means that when continental crust collides with oceanic crust, the denser oceanic crust (made mostly of dense rocks such as basalt) will be dragged (or subducted) under the buoyant continental crust (made mostly of less dense rocks such as granite). Although mountains are created at these oceanic/continental crust collisions due to the compression of the two plates, much taller ranges are produced by continental/continental collisions. When two buoyant continental crusts collide, there is nowhere for the crust to go but up! The modern Himalayas, at the collision site of the Asian and Indian plates, are a good example of very tall mountains formed by a collision between two continental crusts.





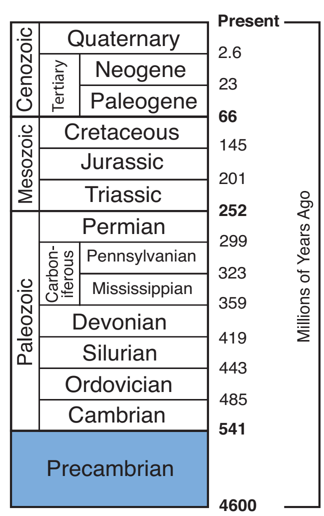
The Iapetus Ocean

In Greek mythology, Iapetus was the son of Uranus, the sky god, and Gaia, the mother of Earth and all the other gods. Geologists use the name Iapetus for the ocean that formed to the south of the ancient continent Laurentia during the Paleozoic. In many textbooks, Iapetus refers to the entire ocean between Laurentia and Gondwana. Some geologists use it in a narrower sense, referring only to the stretch of ocean between Laurentia and the Taconic island arcs prior to the Taconic Orogeny.

lava • *molten rock located on the Earth's surface.*

sandstone • *sedimentary rock formed by cementing together grains of sand.*

density • *a physical property of minerals, describing the mineral's mass per volume.*



1st Breakup

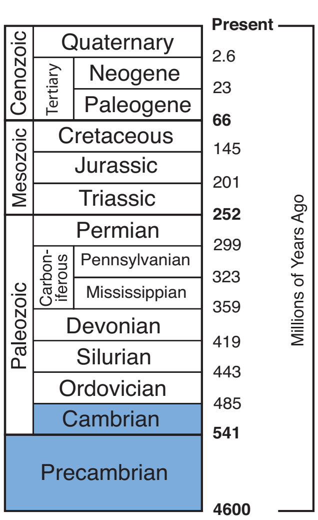
embayment • *a bay or recess in a coastline.*

passive margin • *a tectonically quiet continental edge where crustal collision or rifting is not occurring.*

carbonate rocks • *rocks formed by accumulation of calcium carbonate, often made of the skeletons of aquatic organisms.*

limestone • *a sedimentary rock composed of calcium carbonate ($CaCO_3$).*

inland sea • *a shallow sea covering the central area of a continent during periods of high sea level.*



formed an irregular margin along the edge of Laurentia, consisting of a series of projections or promontories (that are found in what is now Alabama, New York, and the St. Lawrence region of Quebec), and **embayments** (Tennessee, Pennsylvania, Newfoundland). The promontories received little or no sediment during the Precambrian, but the embayments accumulated thick piles of sediment from the eroding continent.

A rift occurs when tectonic plates move away from each other. Magma rises up into the margin, cooling to produce new oceanic crust. The resulting action is similar to two conveyor belts moving away from each other. A failed rift occurs when the existing crust is stretched thin and magma begins to well up, but the plate is never completely broken.

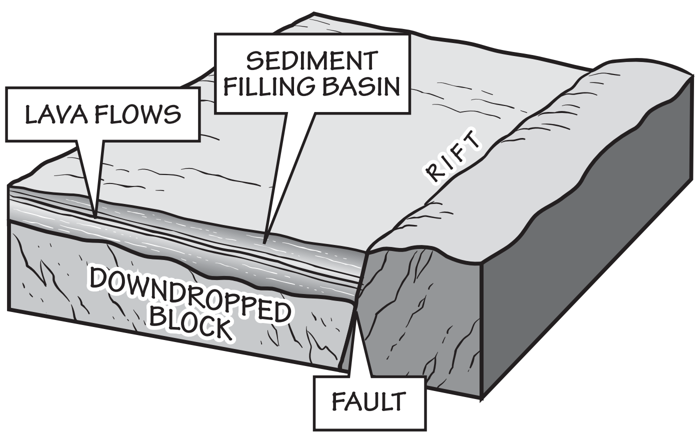


Figure 1.6: A typical rift basin, filled with sediment and lava flows.

During the late Precambrian and early Cambrian, Laurentia was positioned near the equator, and the Southeast was rotated roughly 90° clockwise relative to its current position—today's east coast faced south (*Figure 1.7*). The lack of tectonic activity along the continent's coastline made it a **passive margin**, similar to the Atlantic and Gulf coasts of the US today. As the young Iapetus Ocean widened, global sea levels also rose, flooding much of Laurentia's interior (and that of other continents) with seawater. These relatively shallow epicontinental seas were sites of widespread deposition of **carbonate** sediment derived from the abundant organisms living there (*Figure 1.8*); these sediments formed **limestones,** including those seen today in Kentucky and Tennessee. Sediments continued to erode from either side of the Grenville Mountains into the deeper Iapetus Ocean to the south (presently east) and the shallow **inland sea** to the north (presently west).

See Chapter 2: Rocks to learn more about the environments in which carbonate rocks are found and the organisms that form them.

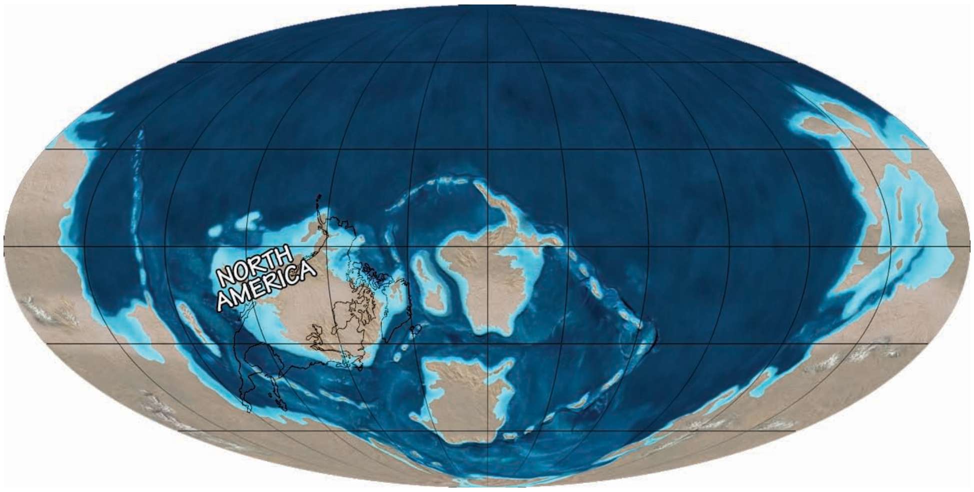


Figure 1.7: Earth during the early Cambrian, around 545 million years ago.

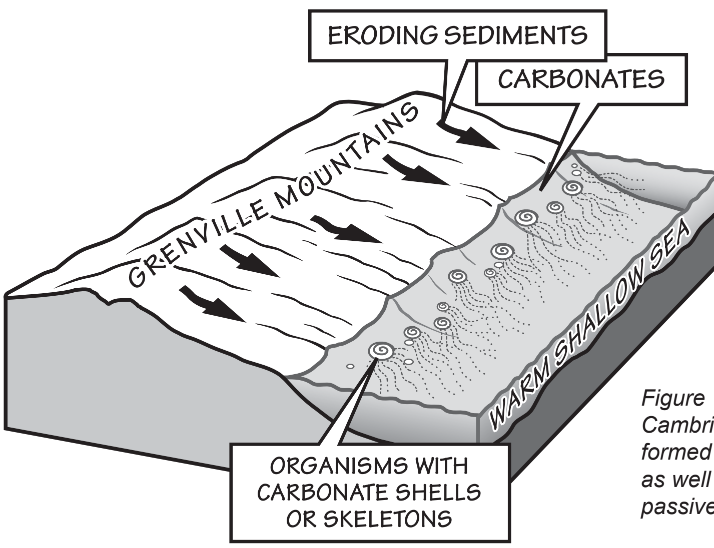


Figure 1.8: During the early Cambrian, carbonate rocks formed in shallow inland seas as well as along North America's passive continental margin.

Around 500 million years ago, the Iapetus Ocean stopped widening and the continents began to move back toward each other. The ocean floor split open to form a **subduction** zone, and the Taconic volcanic island arc was formed as melting and volcanism occurred. These volcanoes apparently occurred on or very close to one or more small pieces of continental crust, perhaps similar to what has taken place on the modern island of Madagascar.

Southeast Mountain Building, Part 2
The Taconic Mountains

As the Iapetus Ocean continued to narrow, the Taconic islands and their associated volcanoes eventually collided with the margin of North America, **accreting** to the continent. The subduction of the oceanic plate beneath the Taconic islands as they collided with North America is recorded by a series

Mtn Building 2

subduction • *the process by which one plate moves under another, sinking into the mantle.*

accretion • *the process by which a body of rock increases in size due to the addition of further sedimentary particles or of large chunks of land.*

Era	Sub-period	Period	Millions of Years Ago
			Present
Cenozoic		Quaternary	2.6
Cenozoic	Tertiary	Neogene	23
Cenozoic	Tertiary	Paleogene	66
Mesozoic		Cretaceous	145
Mesozoic		Jurassic	201
Mesozoic		Triassic	252
Paleozoic		Permian	299
Paleozoic	Carbon-iferous	Pennsylvanian	323
Paleozoic	Carbon-iferous	Mississippian	359
Paleozoic		Devonian	419
Paleozoic		Silurian	443
Paleozoic		Ordovician	485
Paleozoic		Cambrian	541
		Precambrian	4600

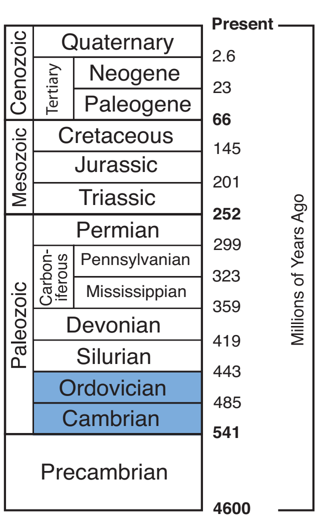
Mtn Building 2

ophiolite • *a section of the Earth's oceanic crust and the underlying upper mantle that has been uplifted and exposed above sea level and often thrust onto continental crustal rocks.*

Taconic Orogeny • *a late Ordovician mountain-building event involving the collision and accretion of a volcanic island arc along the eastern coast of North America.*

uplift • *upward movement of the crust due to compression, subduction, or mountain building.*

mafic • *igneous rocks that contain a group of dark-colored minerals, with relatively high concentrations of magnesium and iron.*



of rocks called **ophiolites**. These rocks, which include deep-sea sediments overlying the crust, the oceanic crust itself, and rock from the upper mantle, were scraped off the descending plate and attached to the continental crust (*Figure 1.9*). This set of collisions caused a new episode of mountain building between around 490 and 460 million years ago, known as the **Taconic Orogeny** (*Figure 1.10*). The pressure of these collisions was so great that large slabs of crust broke free and were pushed up and over the edge of the continent in a process called thrust faulting. This combination of folding, thrusting, **uplift**, and intrusion occurred along the entire margin of North America.

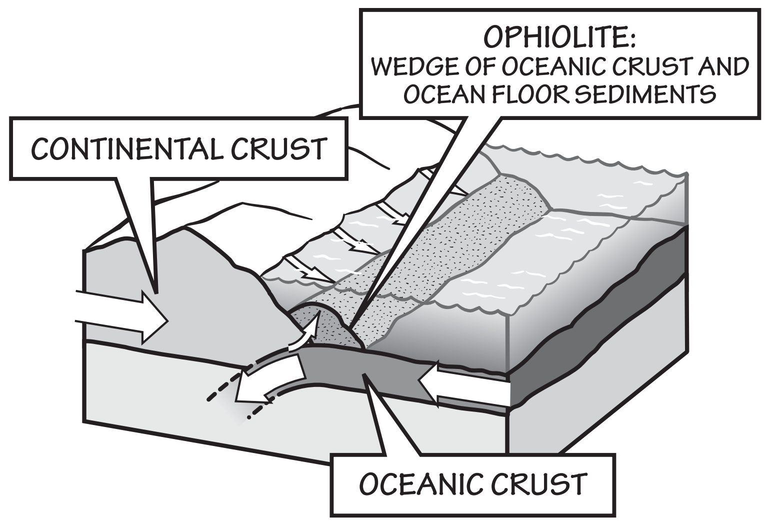


Figure 1.9: The formation of an ophiolite.

Volcanic Island Arcs

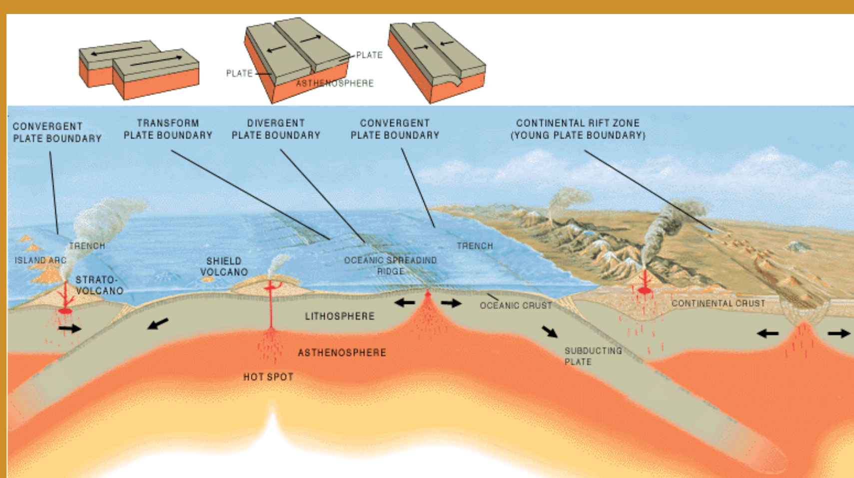
Volcanic islands are common at subduction zones between colliding oceanic plates, where one plate moves (is subducted) beneath the other. They frequently form in curved lines, and are therefore called island arcs. As the plates press together, friction between them generates enough heat and pressure to melt some of the crust. The molten rock rises through the crust and creates volcanoes along the edge of the overlying plate. The Aleutian Islands, Philippine Islands, and Lesser Antilles are all modern examples of volcanic island arcs associated with subduction. Because island arc volcanoes mix the more *mafic* composition of the ocean floor with the more *felsic* composition of overlying sediment derived from continents, they are usually of "intermediate" composition along this spectrum.

Mtn Building 2

Understanding Plate Boundaries

Active plate margins **are the boundaries between two plates of the Earth's crust that are colliding, pulling apart, or moving past each other as they move over the mantle. Some of these plates move as fast as 10 centimeters/year (4 inches/year). The processes of plate movement, spreading, subduction, and mountain building are collectively called plate tectonics.**

When one plate slides beneath another, it is called a ***convergent boundary*** **or subduction zone. When two plates pull apart from each other, it is called a** ***divergent boundary*** **or rift margin. When the plates slip past each other in opposite directions, it is a** ***transform boundary*.**



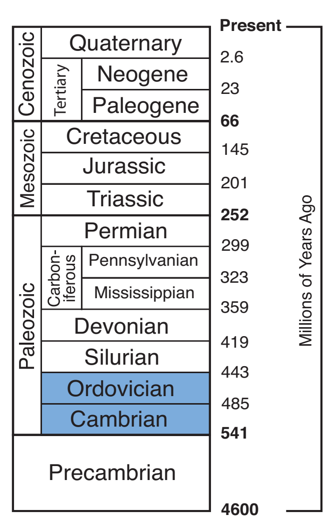
Large chunks of rock like the Taconic islands, which originate in one place and are eventually added to a continent, are called **terranes** (or sometimes "exotic" terranes to emphasize their distant origin). Some terranes are little more than chains of volcanoes; others are small blocks of continental crust that are sometimes called **microcontinents**. Addition (or accretion) of terranes is one of the major ways in which continents grow in size, as they are pressed against the edge of the continent in a process sometimes known as "docking." After accretion, the boundaries between adjacent terranes are marked by major faults or fault zones. In the Southeast, the islands that collided with North America during the Taconic Orogeny are today known as the Piedmont Terrane (*see Figure 1.12*); farther north, in New England, they are called the Taconic Mountains.

felsic • *igneous rocks with high silica content and low iron and magnesium content.*

active plate margin • *the boundary between two plates of the Earth's crust that are colliding, pulling apart, or moving past each other.*

terrane • *a piece of crustal material that has broken off from its parent continent and become attached to another plate.*

microcontinent • *a piece of continental crust, usually rifted away from a larger continent.*



Mtn Building 3

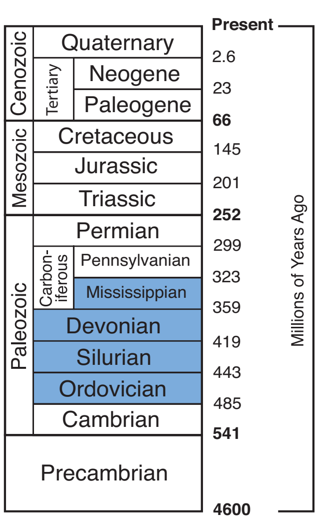
downwarp • *a segment of the Earth's crust that is broadly bent downward.*

Carboniferous • *a geologic time period that extends from 359 to 299 million years ago.*

inland basin • *a depression located inland from the mountains, and formed by the buckling (downwarping) of the Earth's crust.*

Ordovician • *a geologic time period spanning from 485 to 443 million years ago.*

Silurian • *a geologic time period spanning from 443 to 419 million years ago.*



The compression induced by the collision of the Iapetus and Taconic rocks with North America also depressed (**downwarped**) the crust to the west of the Taconic Mountains, creating the **Appalachian Basin.** This basin, actually a connected set of basins that stretched from New York to Tennessee and formed in stages between the Ordovician and **Carboniferous**, was flooded by a broad, shallow inland sea and filled with sediment eroded from the Taconic Mountains. Other **inland basins** also formed from the compressional forces of Taconic mountain building, including the Black Warrior Basin of northwest Alabama and northeast Mississippi.

Geologically "quiet" times in the Southeast, between the rise of great mountains and crushing crusts of colliding plates, were marked by erosion of the highlands and very little plate movement and compression. The Taconic Orogeny ended by the late **Ordovician**, and for many millions of years afterward, the Southeast experienced a time during which erosion from the Taconic highlands and deposition in the inland sea were the main geological events. Huge thicknesses of sedimentary rocks accumulated in and on the margins of the inland sea during the **Silurian**. As sediment weathered from the western side of the Taconic Mountains, **deltas**—wedge-shaped deposits formed when eroded sediment is transported from the mountains and fans out across lower elevations—spread along the shoreline (Figure 1.11). Most of this sediment was concentrated to the north, extending southward only as far as West Virginia and Virginia.

The Mississippi Delta is a modern delta that dumps sediment from the Mississippi River into the Gulf of Mexico.

Southeast Mountain Building, Part 3
The Acadian Mountains

Beginning around 430 million years ago in the mid-Silurian, and ending around 345 million years ago in the early **Mississippian**, another series of continent-continent collisions took place along North America's margin, resulting in the **Acadian Orogeny** (Figure 1.12). It began in the north as **Baltica** (proto-Europe) collided with the northeastern part of North America and proceeded to the south like a closing zipper. More southern collisions involved at least three other terranes that broke off from **Gondwana** when the supercontinent Rodinia broke apart. Rocks from the Carolina Terrane became the southern and central Appalachians, while the **Avalon** and Gander terranes include much of the northern Appalachians (Figure 1.13). To make the story even more complicated, these terranes are themselves the result of the collision of multiple smaller terranes (and are for this reason sometimes called "superterranes"). Two smaller pieces of the Carolina Terrane—the Talladega Slate Belt and the Carolina Slate Belt—are noteworthy for containing fossils that indicate their origin far from North America.

See Chapter 3: Fossils to learn about trilobites found in the Carolina State Belt.

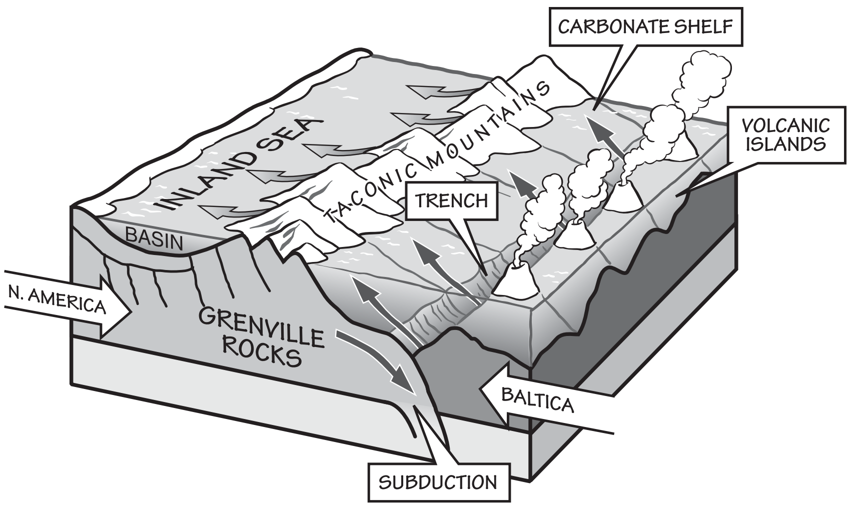


Figure 1.10: Volcanic islands formed where the plates were forced together as the Iapetus Ocean closed. The compression crumpled the crust to form the Taconic Mountains and a shallow inland sea farther to the west.

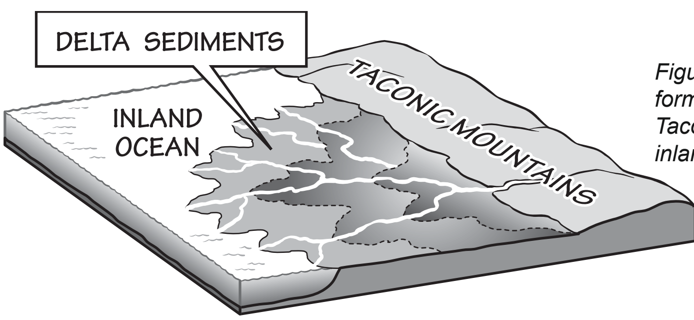


Figure 1.11: Delta deposits formed along the eroding Taconic Mountains into the inland sea.

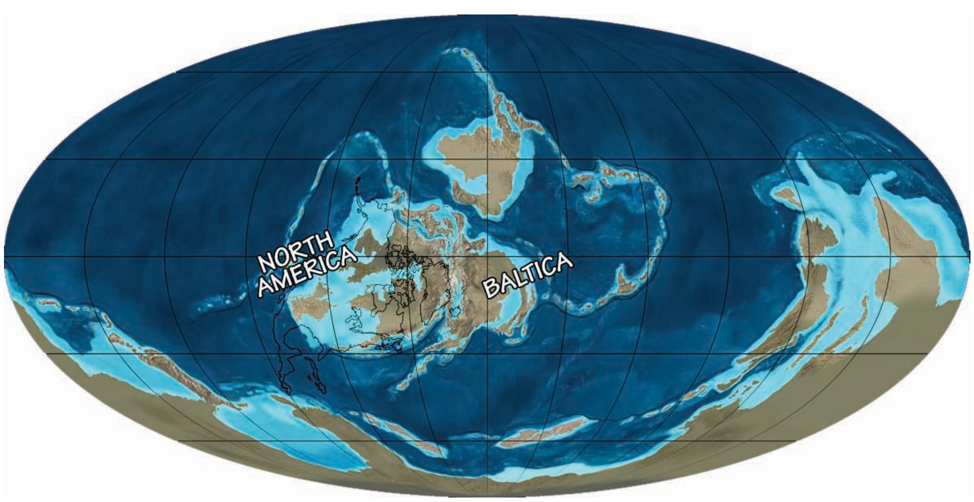


Figure 1.12: Earth during the Silurian, about 430 million years ago.

Mtn Building 3

Mississippian • *a subperiod of the Carboniferous, spanning from 359 to 323 million years ago.*

Acadian Orogeny • *a Devonian mountain-building event involving the collision of the eastern coast of North America and the accreted terrane of Avalon.*

Baltica • *a late-Proterozoic, early-Paleozoic continent that included ancient Europe.*

Gondwana • *the super-continent of the Southern Hemisphere, composed of Africa, Australia, India, and South America.*

Era		Period	Millions of Years Ago
			Present
Cenozoic		Quaternary	2.6
	Tertiary	Neogene	23
		Paleogene	66
Mesozoic		Cretaceous	145
		Jurassic	201
		Triassic	252
Paleozoic		Permian	299
	Carbon-iferous	Pennsylvanian	323
		Mississippian	359
		Devonian	419
		Silurian	443
		Ordovician	485
		Cambrian	541
		Precambrian	4600

Mtn Building 4

Devonian *• a geologic time period spanning from 419 to 359 million years ago.*

Pennsylvanian *• a subperiod of the Carboniferous, spanning from 323 to 299 million years ago.*

Permian *• the geologic time period lasting from 299 to 252 million years ago.*

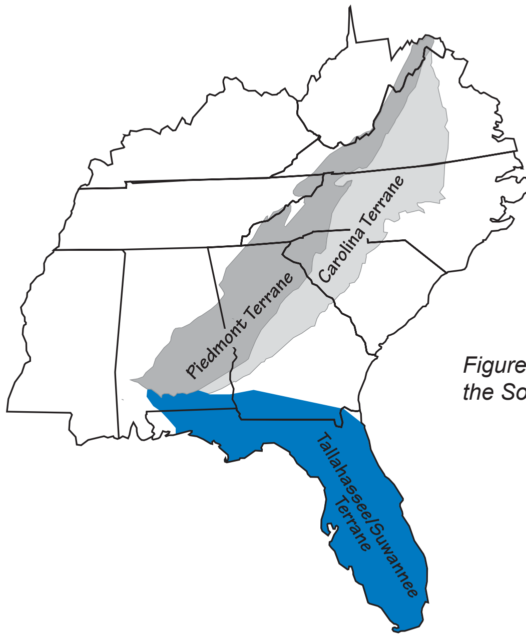


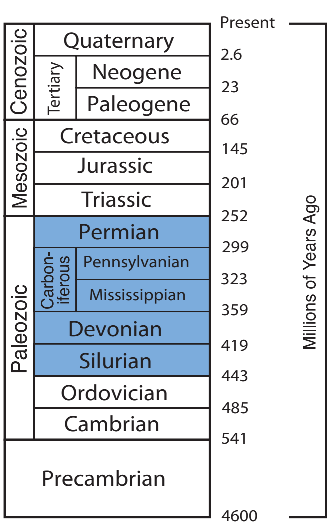
Figure 1.13: Modern locations of exotic terranes in the Southeastern states.

Southeast Mountain Building, Part 4
Pangaea and the Appalachians

The Avalon and Gander terranes collided with what is now New England around 410 million years ago, and the Carolina Terrane was accreted farther south, perhaps 360 million years ago. As with the Taconic Orogeny, these Acadian collisions caused the rocks of North America's eastern margin to be squeezed, folded, metamorphosed, and intruded by magma. During this time, North America gradually moved closer to its present geographic position and rotated toward the north-south alignment we are familiar with today (*Figure 1.14*). At the time of the Acadian mountain building and subsequent erosion during the **Devonian**, the Southeast was located south of the equator, and experienced a tropical climate. Africa, South America, India, Australia, Antarctica, and what is now Florida were combined into the southern supercontinent Gondwana. Most or all of the continental landmasses were gradually moving closer together.

See Chapter 8: Climate to learn how Earth's climate changed when the supercontinents re-arranged.

During the Mississippian period, the Inland Basin region was still flooded with a warm inland sea, in which abundant limestone was deposited. Approximately 300–250 million years ago, through the **Pennsylvanian** and **Permian** periods, a final mountain-building event occurred as Gondwana collided with North America to form the supercontinent Pangaea, creating the central and southern Appalachians (*Figures 1.15 and 1.16*). This mountain-building event is known



as the **Alleghanian Orogeny**, and it is responsible for the Appalachians' basic structure. Sea levels began to fluctuate and ultimately fall, due to a combination of glaciation at the South Pole and the renewed forces of mountain building. Along the margins of this retreating sea, enormous coastal swamps formed from modern Pennsylvania to Alabama. When the vegetation in these swamps died, it fell into stagnant oxygen-poor water. This slowed decomposition, forming huge deposits of **peat**. Sediment covered these deposits, compressing and ultimately metamorphosing them into some of the largest **coal** beds in the world. Together with similar deposits in Western Europe, they give the Carboniferous period its name.

See Chapter 6: Energy for more on the formation of coal in the Southeast.

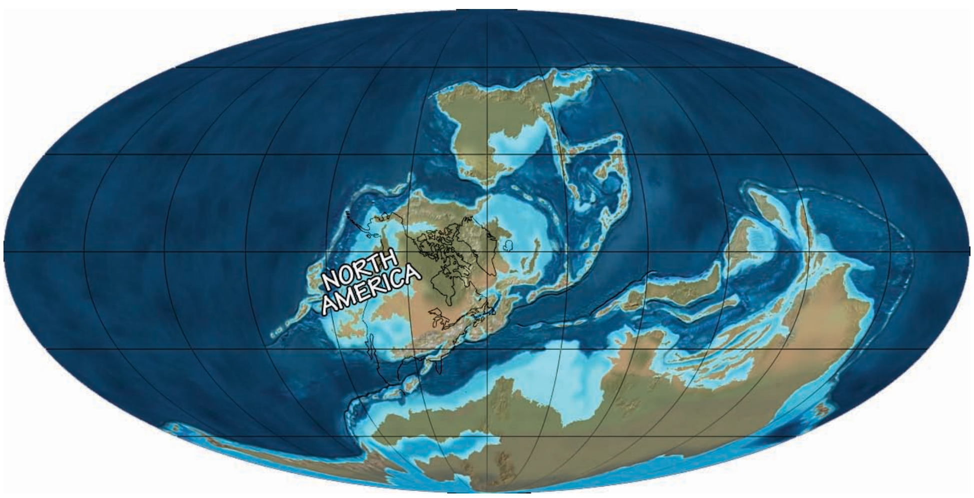


Figure 1.14: Earth during the late Devonian, about 370 million years ago.

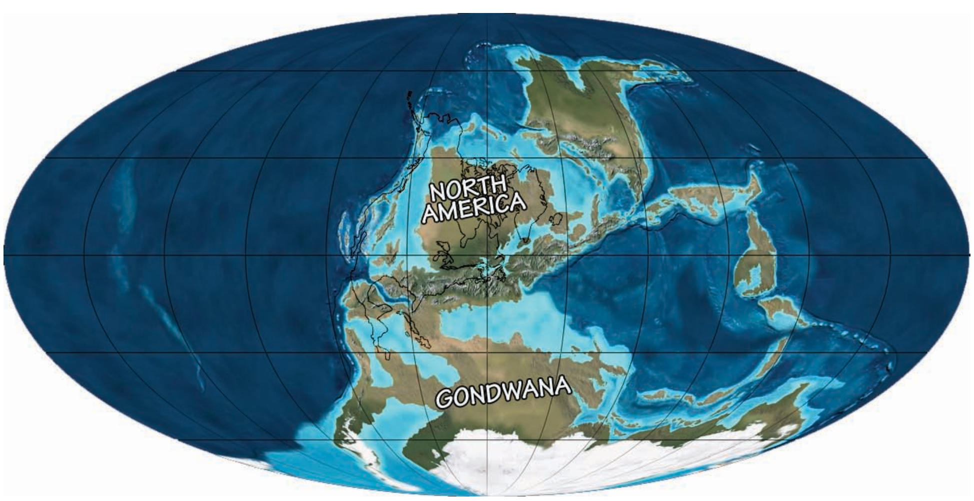
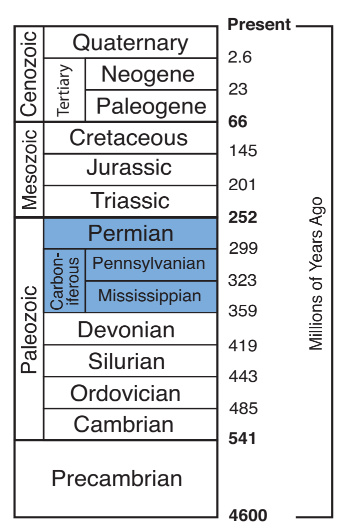


Figure 1.15: Initial formation of Pangaea during the late Carboniferous, around 300 million years ago.

Alleghanian Orogeny • *a Carboniferous to Permian mountain-building event involving the collision of the eastern coast of North America and the northwestern coast of Africa.*

peat • *an accumulation of partially decayed plant matter.*

coal • *a combustible, compact black or dark-brown carbonaceous rock formed by the compaction of layers of partially decomposed vegetation.*



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atmosphere • *a layer of gases surrounding a planet.*

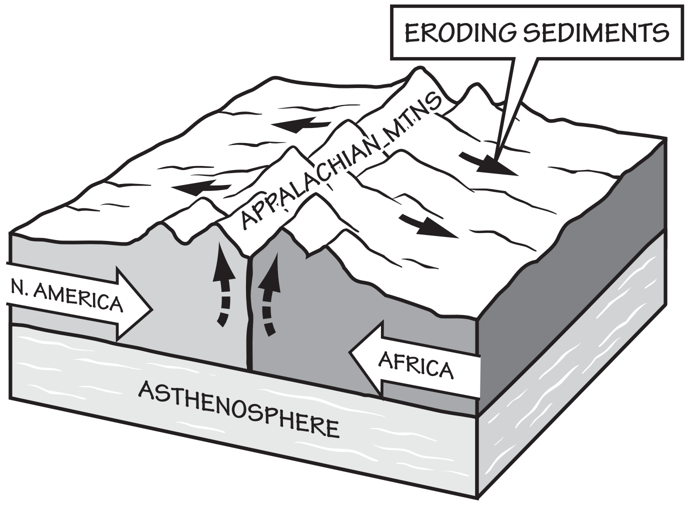


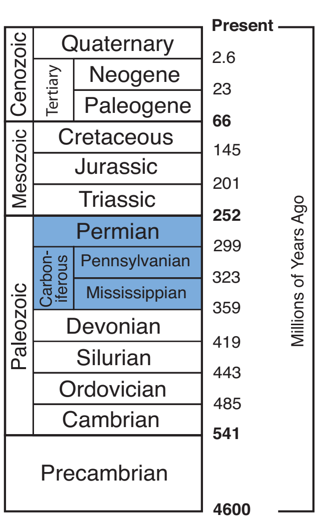
Figure 1.16: North America and Africa (part of Gondwana) collided to form the Appalachian Mountains.

The burial of so much carbon lowered the amount of carbon dioxide (CO_2) in the Earth's **atmosphere**, and abundant plant life raised global oxygen levels. Global temperatures continued to fall, accelerating glaciation in the southern hemisphere and lowering sea level worldwide. Ultimately, the sea retreated completely from the Interior Basin, which is why there is no marine sediment younger than Pennsylvanian in age across this area of the continent.

Like the Acadian Orogeny before it, the Alleghanian began in the north and moved south, closing what remained of the Iapetus Ocean like a zipper. The Alleghanian Orogeny caused the rocks along the eastern margin of North America to compress westward like a collapsing telescope. Slices of crust were thrust westward along enormous faults such as the Brevard Fault Zone, running along the eastern edge of the Blue Ridge from Alabama to the North Carolina-Virginia border (*Figure 1.17*). This event caused the crust to shorten by almost 200 kilometers (120 miles). The resulting Appalachian Mountain chain extends from Alabama to Canada. The South American portion of Gondwana also collided with North America during the early Pennsylvanian, forming the Ouachita Mountains of Arkansas and Texas. These mountains originally extended into Mississippi, but are now buried beneath younger sediments.

The orogeny affected sediment deposited in the inland ocean throughout the Paleozoic era as well as the Iapetus and Avalon rocks that had been added to North America from the Ordovician through the Devonian. Although the Appalachian Mountains were formed over 250 million years ago, they are still around today. Once perhaps as tall and rugged as the Himalayas of India, these mountains have been worn down by the same forces of erosion and weathering that also filled the Appalachian Basin with their sediment.

The geological basement of the modern Florida peninsula was the last major piece of present-day North America to be attached. This basement is composed



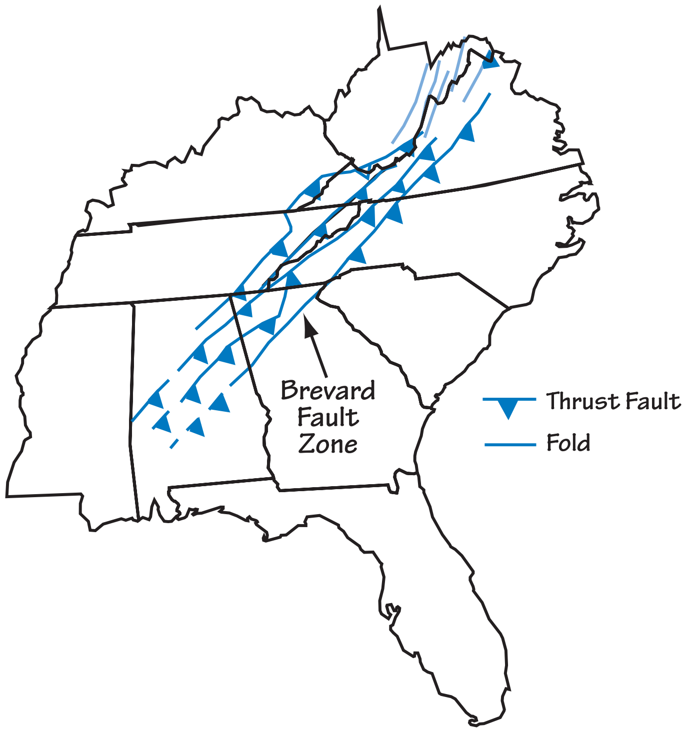


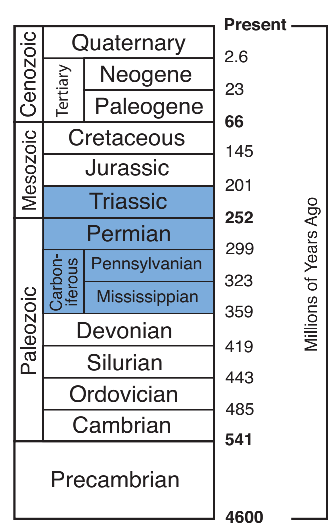
Figure 1.17: Major thrust faults of the Southeast. The Brevard Fault Zone divides the Blue Ridge from the Piedmont. Folds (rather than thrusts) are common in West Virginia, northern Virginia, and farther north.

of two major pieces: the Florida-Bahama Block and the Suwannee Basin Block (also known as the Tallahassee-Suwanee Terrane). Both of these pieces were part of Gondwana when it collided with southeastern North America in the late Paleozoic. They are recognizable today as different from the rest of the continent due to the distinctive rocks and fossils they contain. We know about Florida's ancient basement only from drill cores and other remote geophysical methods, as no surface rock in Florida is older than the Cenozoic.

The Second Breakup

Pangaea Comes Apart

Pangaea lasted less than 100 million years, before Earth's dynamic crust began to break it apart. Tension slowly began to pull North America away from the other merged continents. Rifts once again developed in the middle of the supercontinent, eventually leading to its breakup. These rifts occurred along a series of cracks in the Earth's crust roughly parallel to the present eastern coastline of North America. Blocks of crust slid down the faults on the rift margins to form rift basins bounded by tall cliffs. Some rift basins are exposed at the surface in Virginia and North Carolina; younger sediment buried others throughout the Southeastern states (*Figure 1.18*). Deposits of ash and lava flows originating from volcanoes in the rift area alternate with sandstone



Geologic History

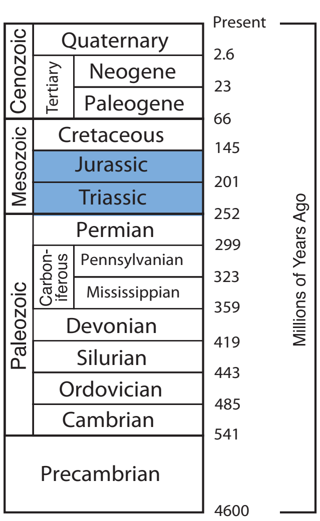
Mtn Building 4

shale • *a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.*

Newark Supergroup • *a sequence of nonmarine sedimentary rocks that accumulated along what is now eastern North America in the late Triassic to early Jurassic.*

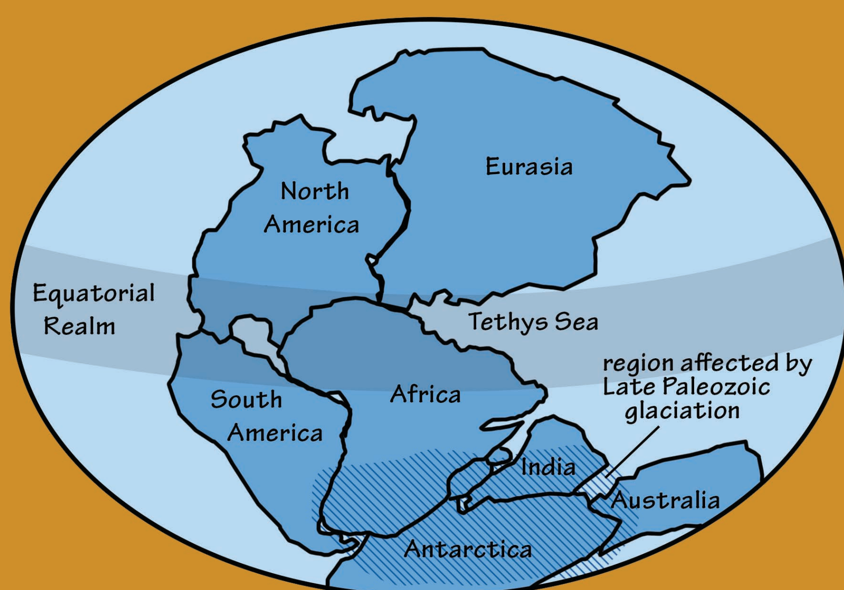
salt • *a mineral composed primarily of sodium chloride (NaCl).*

petroleum • *a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface.*



Evidence for Pangaea

How do we know that Pangaea existed 250 million years ago? Long before the discovery of plate tectonics in the 1960s and early 1970s, fossils and mountain belts provided evidence that the continents had not always been in their current positions. For example, the Permian-aged fossil plant *Glossopteris* had seeds too heavy to be blown across an ocean. Yet *Glossopteris* fossils are found in South America, Africa, Australia, India, and Antarctica! The mountain belts along the margins of North America, Africa, and Europe line up as well and have similar rock types, an indication that the continents at one time were joined as Pangaea. Despite the discovery of *Glossopteris* and other geologic evidence, the theory of continental drift was not accepted for decades, until the mechanisms of continental movement were discovered and reformulated under the modern theory of plate tectonics. The super-continent Pangaea existed for approximately 100 million years, reaching its largest size during the Triassic period. During the Jurassic, the landmass began to fragment into the modern continents, which slowly moved toward their present-day positions over the following 150 million years.



Pangaea during the late Paleozoic era

and **shale** to fill the basins. These flat-lying rock layers were eventually faulted again and tilted, exposing the edges of sedimentary rock and cooled lava. In many instances, the hardened lava was more resistant to erosion than the sedimentary rock was, so ridges of cooled lava have been worn into topographic highs. These late **Triassic** and early **Jurassic** rocks are collectively called the **Newark Supergroup**.

During the Jurassic, the final break between North America, Gondwana, and Baltica occurred along what is now the Mid-Atlantic Ridge. Pangaea gradually fragmented into the modern continents, each slowly moving into their present positions (*Figure 1.19*). The Atlantic Ocean began to widen as Africa separated from North America, and the Gulf of Mexico opened up as South America pulled away. The east coast of North America no longer experienced the strong tectonic activity associated with the compression and rifting of a plate margin; it once again became a passive margin.

In the early stages of its formation, the Gulf of Mexico was the site of abundant **salt** formation, as seawater from the first tentative arms of the ocean evaporated. Eventually, this Jurassic salt was deeply buried beneath sediments carried into the Gulf by rivers, and would later become important in the trapping of **petroleum** and **natural gas** beneath the modern Gulf.

Beginning 95 million years ago, North America passed over a **hot spot** in the mantle. The rising magma uplifted a portion of the Ouachita-Appalachian Mountains, creating an arch and causing the range to be preferentially weathered. After the continent passed over the hot spot, the crust there had thinned significantly, and it began to cool and **subside**, eventually forming a basin. As the ocean flooded the area between the Interior Highlands and the Appalachians, what is now the **Mississippi Embayment** was created. The Embayment area today extends from the confluence of the Ohio and Mississippi Rivers in the north, to the Gulf of Mexico in the south. This is the origin of the relatively low, flat area that now separates the Appalachian and Ouachita mountain ranges.

Building the Coastal Plain

The late **Cretaceous** period was marked by very high sea levels worldwide, in part due to the significant increase in **plate tectonic** activity that accompanied the breakup of Pangaea. When the continents began to move apart, they were separated by oceanic crust that formed at deep-sea ridges like the Mid-Atlantic Ridge, where new oceanic crust continues to form today. The subsequent displacement of ocean water contributed to a higher global sea level. Spreading eventually slowed and the ridges subsided, allowing sea level to fall. Despite minimal tectonic activity throughout the last 140 million years, the face of the Southeast has changed significantly due to erosion, deposition, sea level fluctuations, and the **ice age**.

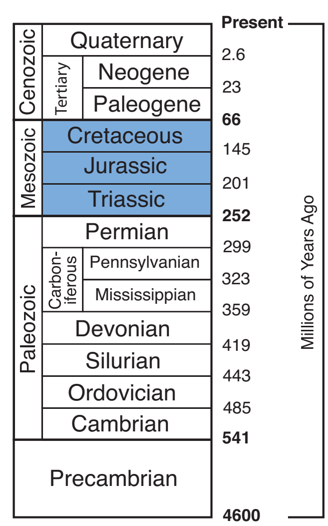
Because the North American continent is still drifting away from the Mid-Atlantic Ridge, the eastern margin of North America transitioned to a passive

natural gas • *a hydrocarbon gas mixture composed primarily of methane (CH_4), but also small quantites of hydrocarbons such as ethane and propane.*

subsidence • *the sinking of an area of the land surface.*

Mississippi Embayment • *a topographically low-lying basin in the south-central United States, stretching from Illinois to Louisiana.*

plate tectonics • *the process by which the plates of the Earth's crust move and interact with one another at their boundaries.*



1 Geologic History

Coastal Plain

stratigraphy • *the branch of geology specifically concerned with the arrangement and age of rock units.*

Paleogene • *the geologic time period extending from 66 to 23 million years ago.*

Tertiary • *an unoffical but still commonly used term for the time period spanning from 66 million to 2.5 million years ago, including the Paleogene, Neogene, and part of the Pleistocene.*

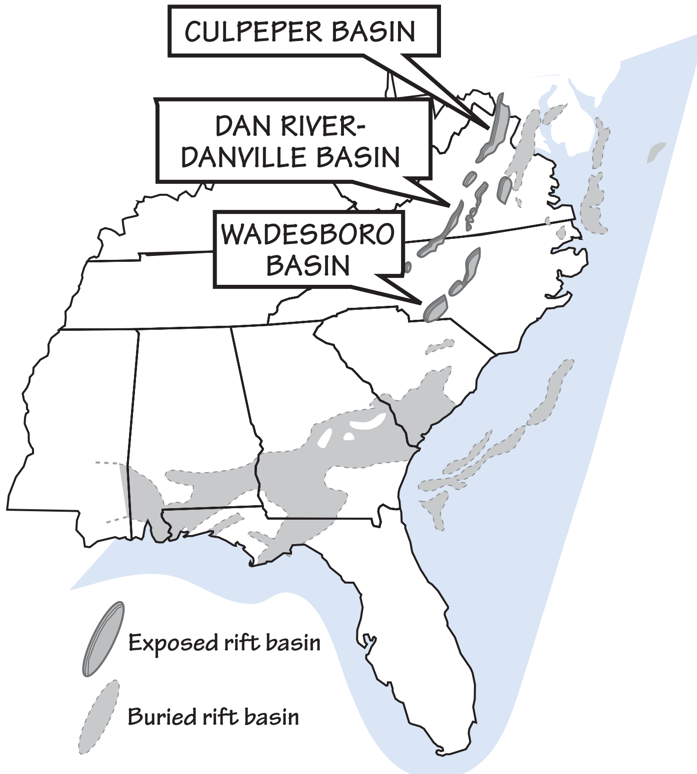


Figure 1.18: The Triassic-Jurassic Rift Basins of the Southeast formed as North America broke away from Pangaea. Many basins are buried by younger sediment and are located on the continental shelf as well as on land.

Era		Period	Millions of Years Ago
			Present
Cenozoic		Quaternary	2.6
	Tertiary	Neogene	23
	Tertiary	Paleogene	**66**
Mesozoic		Cretaceous	145
		Jurassic	201
		Triassic	**252**
Paleozoic		Permian	299
	Carbon-iferous	Pennsylvanian	323
	Carbon-iferous	Mississippian	359
		Devonian	419
		Silurian	443
		Ordovician	485
		Cambrian	**541**
		Precambrian	**4600**

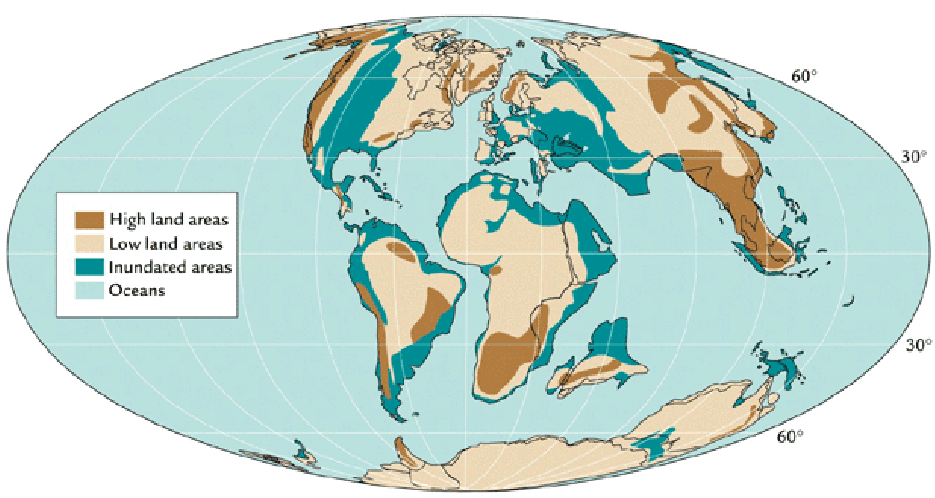


Figure 1.19: Landmasses following the breakup of Pangaea. (See TFG website for full-color version.)

continental margin. Rivers and streams transported sediment from the mountains to the coast, forming successive layers that fanned out across the gently sloping continental shelf and built up the Atlantic and Gulf Coastal plains. The Fall Line, a break between the harder inland rock and the softer sediments of the coast, marks the boundary between the Coastal Plain and the Blue Ridge and Piedmont region.

See Chapter 4: Topography to learn more about the Fall Line.

Just like the breakup of Rodinia, the rifting and breakup of Pangaea left an irregular continental margin on eastern North America, marked by higher promontories jutting eastward into the Atlantic, and lower embayments that the ocean filled to the west. The embayments became sites of deposition for thick piles of eroded sediments, and each embayment has a separate **stratigraphic** sequence. Geologists build a larger knowledge of geologic history in the Coastal Plain by connecting these sequences with each other, correlating the different sedimentary layers through the characteristics of the fossils in each one.

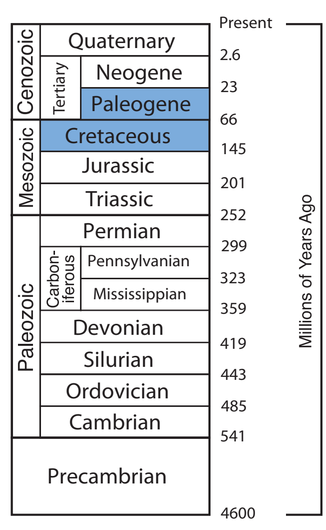
The Cretaceous-**Paleogene** (K-Pg) boundary (previously known as the Cretaceous-**Tertiary** [K-T] boundary) marks one of the most significant physical and biological events in Earth history. The boundary marks the contact between the Mesozoic and Cenozoic eras at around 65 million years ago, representing a time during which a large proportion (perhaps 50–70%) of all species of animals and plants (both marine and terrestrial, from microscopic one-celled organisms to massive dinosaurs) abruptly became extinct. Most geologists and paleontologists think these extinctions resulted from the impact of a large comet or asteroid, perhaps associated with an impact crater in the subsurface of Mexico's Yucatan Peninsula. There is also evidence for the occurrence of extensive volcanism at the K-Pg boundary, indicated by large basaltic lava flows in India called the Deccan Traps. The end-Cretaceous event greatly altered the history of life, and these changes are clearly visible in the Southeast's fossil record. The boundary itself is rarely preserved in the geologic record, due to an incomplete sedimentary record and widespread erosion.

One of the rift basins that developed as Pangaea broke up in the early Mesozoic extended from what is now the northeastern corner of the Gulf of Mexico to the Atlantic coast of Georgia. This basin, which geologists call the Gulf Trough (or the Suwanee Straits), had a major impact on Florida's Cenozoic history. During the Paleogene, it separated the eroding Appalachians from the growing carbonate bank to the south. The Trough diverted sediment from the Appalachians, which would otherwise have covered the Florida carbonate bank. As the Trough eventually filled with sediment, the Florida Platform was inundated with material from the mainland, but not before a huge amount of limestone had already formed there. Florida's modern peninsula is the above-water section of the much larger Florida Platform, made mostly of limestone and coated with a relatively thin layer of **sand** (*Figure 1.20*). Today, the main sites of carbonate deposition in the Southeast are the southern tip of Florida and the Florida Keys, where **reefs** still grow thanks to warm temperatures and a low influx of **siliciclastic** sediment.

sand *• rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

reef *• a feature lying beneath the surface of the water, which is a buildup of sediment or other material built by organisms, and which has positive relief from the sea floor.*

siliciclastic *• pertaining to rocks that are mostly or entirely made of silicon-bearing clastic grains weathered from silicate rocks.*



Quaternary

Pleistocene • *a subset of the Quaternary, lasting from 2.5 million to about 11,700 years ago.*

Holocene • *the most recent portion of the Quaternary, beginning about 11,700 years ago and continuing to the present.*

interglacial • *a period of geologic time between two successive glacial stages.*

terrace • *a flat or gently sloped embankment or ridge occurring on a hillside, and often along the margin of (or slightly above) a body of water, representing a previous water level.*

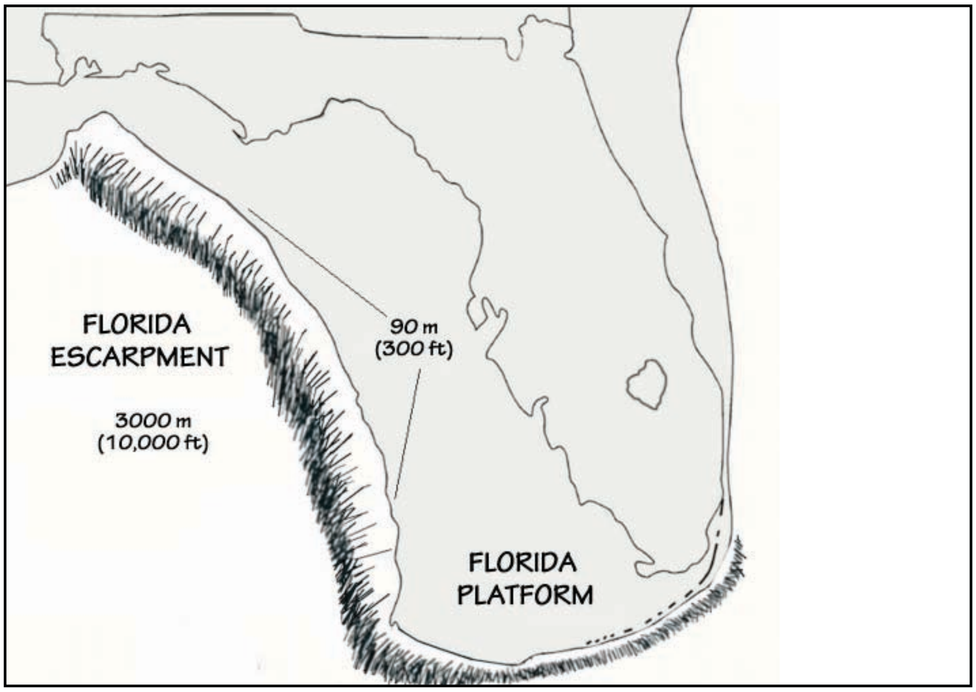
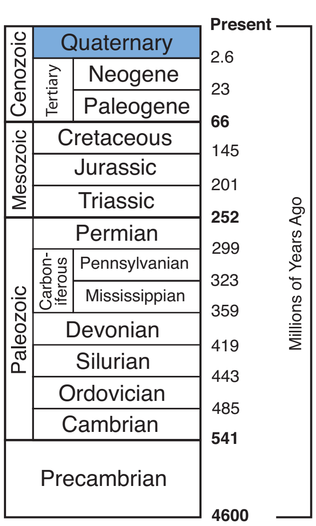


Figure 1.20: The extent of the Florida Platform and surrounding water depths.

The Quaternary
Mountains of Ice

At the start of the **Quaternary** period, about 2.5 million years ago, continental ice sheets began to form in northernmost Canada. Throughout this period, the northern half of North America has been periodically covered by continental glaciers that originated in northern Canada (*Figure 1.21*). The Quaternary period is divided into two epochs: the **Pleistocene** and **Holocene**. During the Pleistocene, ice sheets advanced south and retreated north several dozen times, reaching their last maximum extent 25,000–18,000 years ago. The Holocene epoch is the most recent (and current) period of retreat, and is referred to as an **interglacial** interval. The beginning of the Holocene is considered to be 11,700 years ago, or about 9700 BCE.

The Pleistocene ice sheets did not extend into the Southeast. Here, the predominant effects of the ice age were the rise and fall of sea level, subsequent erosion and deposition, changes in weather and the distribution of plant and animal species, and changes in drainage patterns. At the peak of the last glacial advance (around 22,000 years ago) sea level was over 100 meters (330 feet) below its current level (*Figure 1.22*). Widely fluctuating sea levels drastically affected the erosion and deposition of sediment on the Coastal Plain, creating scarps (such as the Orangeburg Scarp in South Carolina) and river **terraces** as well as steepening stream gradients, which resulted in more rapid erosion of the streambeds. Of all the states in the Southeast, sea level changes have most



Quaternary

Figure 1.21: Extent of glaciation over North America during the last glacial maximum.

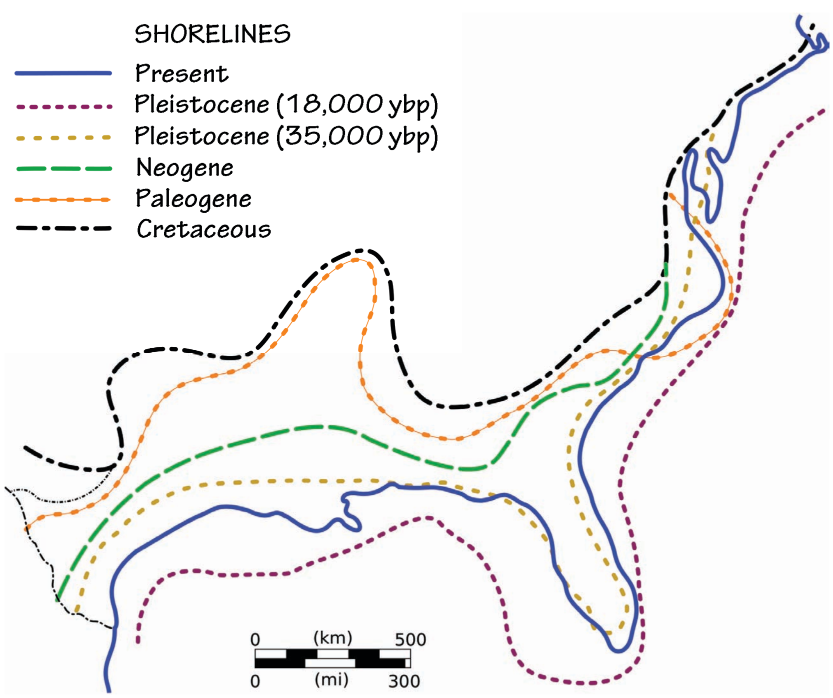
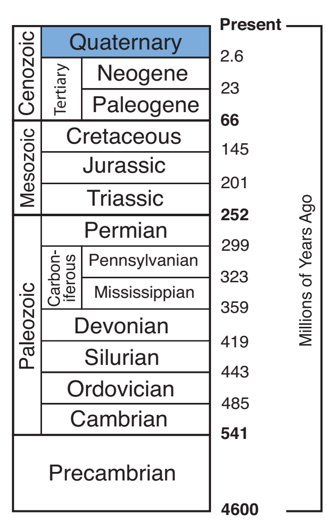


Figure 1.22: Shoreline positions along the Coastal Plain during the past 70 million years. The shoreline reflects the regression that resulted from the last significant glacial advance of the modern ice age.



Quaternary

climate change • *See global warming: the current increase in the average temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere.*

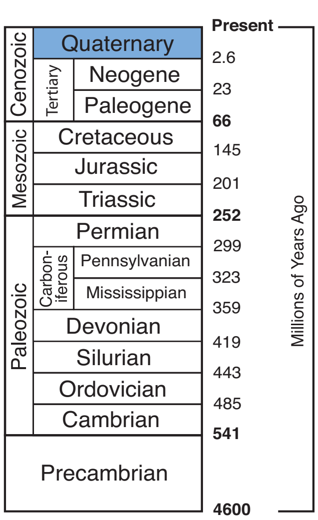
dramatically affected the shape and sedimentary deposits of Florida. When glaciation was at its maximum during the Pleistocene, and sea levels were at their lowest, the peninsula was almost 480 kilometers (300 miles) across at its widest.

The ice age continues today, but the Earth is in an interglacial stage, since the ice sheets have retreated for now. The current interglacial period has slowed both erosional and depositional processes in the Southeast—this, and a higher, more stable sea level, allowed coastal features such as barrier islands and lagoons to form, resulting in the landscape we know today. The glacial-interglacial cycling of ice ages indicates that the world will return to a glacial stage in the future, unless the impacts of human-induced **climate change** radically shift these natural cycles.

See Chapter 9: Climate to learn more about how climate change affects the environment.

Why was there an ice age?

What led to the formation of large continental glaciers in the Northern Hemisphere between 3.5 and 2.5 million years ago? Movement of the Earth's tectonic plates may have been a direct or indirect cause of the glaciation. As plates shifted, continents moved together and apart, changing the size and shape of the ocean basins, and altering ocean currents that transported heat from the equator to the poles. Sufficient precipitation in northern Asia and North America also enabled continental glaciers to grow and flow outward. The rise of the Himalayas exposed new rock that trapped carbon dioxide through chemical weathering; in turn, the decreased levels of carbon dioxide led to a global cooling. Finally, and surprisingly, the formation of the Central American Isthmus, which connects North and South America in what is now Panama, likely had a major effect on climate. Ocean currents that had once flowed east to west through the Central American Seaway were now diverted northward into the Gulf of Mexico and ultimately into the Gulf Stream in the western Atlantic. This strengthened Gulf Stream transported more moisture to high northern latitudes, causing more snow, which eventually formed glaciers.



Geologic History 1

Resources

Resources

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Chapter 2:
Rocks of the Southeastern US

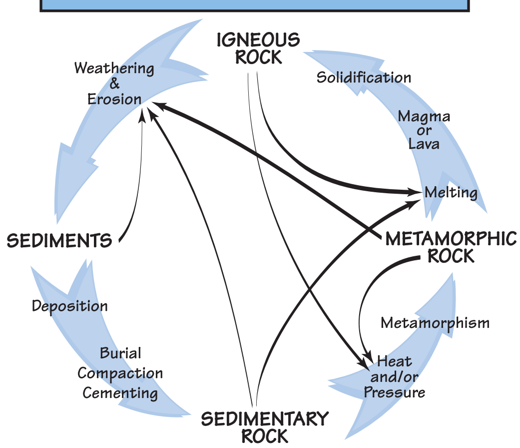
The amazing diversity of rocks in the Southeast records over a billion years of history—from 1.8-billion-year-old **Precambrian gneisses** to sedimentary deposits from the most recent **ice age**. Colliding **plates**, **rifting**, **inland seas**, deposition, **erosion**, igneous and metamorphic activity, and recent glacial processes are all part of this story. The Southeast's different rock types influence its **topography** and tell us where to look for certain **fossils** or natural resources. Each type of rock forms in a particular environment under particular conditions (*Figure 2.1*).

A rock is a naturally occurring solid substance composed of one or more **minerals**. Broadly speaking, there are three types of rock: sedimentary, igneous, and metamorphic. The rock cycle describes the many processes that produce rocks, while also illustrating differences between the rock types. One type of rock may be transformed into either of the other types, often with the

Igneous Rocks of the Southeast

anorthosite	gabbro
basalt	granite
diabase	pegmatite
diorite	peridotite
feldspar	rhyolite

Unconsolidated Sediments of the Southeast
clay
gravel
sand
silt
mud



Metamorphic Rocks of the Southeast
gneiss
greenstone
marble
phyllite
quartzite
schist
serpentinite
slate

Sedimentary Rocks of the Southeast

chalk	chert
conglomerate	coquina
dolostone	limestone
marl	sandstone
siltstone	shale

Figure 2.1: The rock cycle shows the relationships among the three basic types of rock.

Precambrian • *a geologic time interval that spans from the formation of Earth (4.6 billion years ago) to the beginning of the Cambrian (541 million years ago).*

gneiss • *a metamorphic rock that may form from granite or layered sedimentary rock such as sandstone or siltstone.*

ice age • *a period of global cooling of the Earth's surface and atmosphere, resulting in the presence or expansion of ice sheets and alpine glaciers.*

plates • *large, rigid pieces of the Earth's crust and upper mantle, which move and interact with one another at their boundaries.*

rift • *a break or crack in the crust that can be caused by tensional stress as a landmass breaks apart into separate plates.*

erosion • *the transport of weathered materials.*

CHAPTER AUTHORS

Jane A. Picconi
Charles C. Smith

help of other parts of the Earth **system**, such as **plate tectonics**, the water cycle, and biological processes, to name a few.

Sedimentary rock is formed by the **lithification** of sediments (e.g., unconsolidated mineral and organic particles created through the **weathering** of other materials, such as rock and organic matter). Typically, sediments are created in an environment where erosion is a dominant force, and they are transported by **wind**, water, or ice to a depositional environment. For example, a rushing river can wear away the rock it is flowing over, and it also has enough energy to transport the resulting sediment to a lake. The water slows down, losing energy, and deposits the sediment on the bottom of the lake.

Lithification of sediments occurs in several ways. As sediments build up and lower layers are buried more deeply, they may become permeated by water. Minerals dissolved in the water are precipitated, filling the spaces between particles and **cementing** them together. This cementation helps to form

Review

system • *a set of connected things or parts forming a complex whole.*

plate tectonics • *the process by which the plates of the Earth's crust move and interact with one another at their boundaries.*

lithification • *the process of creating sedimentary rock through the compaction or sementation of soft sediment.*

weathering • *the breakdown of rocks by physical or chemical means.*

wind • *the movement of air from areas of high pressure to areas of low pressure.*

cementation • *the precipitation of minerals that binds together particles of rock, bones, etc., to form a solid mass of sedimentary rock.*

shale • *a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.*

Sedimentary Rock Classification

Sedimentary rocks are classified by their sediment size or their mineral content, and each one reveals the story of the depositional environment where its sediments accumulated and were eventually lithified.

Sediment size	Sedimentary rock	Environment of deposition
gravel	conglomerate	river beds, mountains
sand	sandstone	beaches, river sand bars, sand dunes
sand, silt, clay	greywacke	continental shelf
silt	siltstone	quiet water
clay	shale	very quiet water, lakes, swamps, shallow oceans

Mineral Content	Sedimentary rock	Environment of deposition
calcium carbonate skeletons of marine organisms	limestone	tropical reefs, beaches, warm shallow seas
precipitated calcium carbonate	travertine, tufa	hot springs, playas (dry lake beds), drying seas
gypsum	rock gypsum	playas, drying seas
halite	rock salt	playas, drying seas

many common sedimentary rocks, such as **shale**, **sandstone**, and most **conglomerates**. The evaporation of water may also form sedimentary rocks by leaving behind evaporites (previously dissolved minerals) such as **salt**. Deposits of **calcium carbonate**, usually created through the accumulation of calcium carbonate skeletal material (such as clams and corals), form the sedimentary rocks **limestone** and **dolostone**.

Igneous rocks form from the cooling of **magma** (molten rock underground) or **lava** (molten rock at the Earth's surface). When magma cools slowly underground, it has time to produce large crystals that are visible to the naked eye. Rocks that form in this manner, such as **granite**, are called **plutonic**. When magma comes to the surface (as lava), it cools quickly so that individual crystals are not visible, resulting in a **volcanic** rock such as **basalt**. In some circumstances, lava may cool so quickly that crystals do not form at all, creating a **glassy rock** such as **obsidian**. Smaller fragmental rocks that cool quickly at the surface form during explosive eruptions; these are called **pyroclastic rocks**, and they are composed of a variety of different volcanic ejecta.

Every rock is capable of being melted, weathered, or changed by **heat** and pressure. Any rock that has been subjected to intense heat and pressure can **recrystallize** into a **metamorphic rock**. This process destroys features in the

Igneous Rock Classification

Igneous rocks differ not only in their cooling rates and subsequent crystal sizes, but also in their chemical compositions. Rocks found in oceanic crust, such as basalt and gabbro, generally come from either mantle magma or melting oceanic crust at a subduction zone. These dense, dark rocks are called *mafic*; they are low in silica and high in iron and magnesium. Rocks found in continental crust, such as granite, are typically formed from crust that has melted from the pressure of overlying rock or friction from colliding plates. These light-colored rocks are high in silica content and low in iron and magnesium; they are less dense than oceanic crust and are called *felsic*.

Crystal size	Felsic	Intermediate	Mafic	Ultramafic
large (plutonic)	granite	diorite	gabbro	peridotite
small (volcanic)	rhyolite	andesite	basalt	--
none (glassy)	obsidian, tuff, pumice	obsidian	obsidian	--

Review

sandstone • *sedimentary rock formed by cementing together grains of sand.*

conglomerate • *a sedimentary rock composed of multiple large and rounded fragments that have been cemented together in a fine-grained matrix.*

salt • *a mineral composed primarily of sodium chloride (NaCl).*

calcium carbonate • *a chemical compound with the formula $CaCO_3$, commonly found in rocks in the mineral forms calcite and aragonite, as well as the shells and skeletons of marine organisms.*

limestone • *a sedimentary rock composed of calcium carbonate ($CaCO_3$).*

dolostone • *a rock primarily composed of dolomite, a carbonate mineral.*

granite • *a common and widely occurring type of igneous rock.*

Review

compression • *flattening or squeezing as a result of forces acting on an object from all or most directions.*

protolith • *the original parent rock from which a metamorphosed rock is formed.*

crust • *the uppermost, rigid outer layer of the Earth.*

intrusive rock • *a plutonic igneous rock formed when magma from within the Earth's crust escapes into spaces in the overlying strata.*

rock that would have revealed its previous history, transforming it into an entirely new form as the minerals within realign. The pressure to transform a rock may come from burial by sediment or from **compression** due to plate movements, while the heat may come from very deep burial or from contact with magma.

Metamorphic Rock Classification

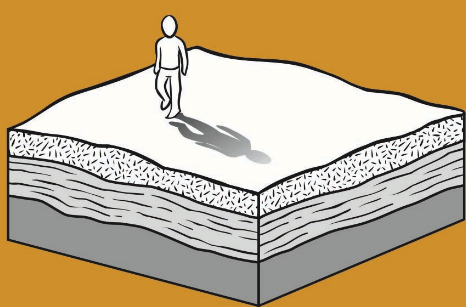
Metamorphic rocks are classified differently depending on the *protolith* (parent rock) they are made from. The following chart shows common rocks and the metamorphic rocks that they can become.

Parent Rock	Metamorphic Rocks
shale	slate, phyllite, schist, gneiss (in order of increasing heat and pressure)
granite	gneiss
sandstone	quartzite
limestone	marble
peridotite	serpentinite

As you read through this chapter, keep in mind that once you understand the geologic events that have affected a given region, you should be able to predict the type of rocks found in that area. For example, when plates collide, compression and friction melt the **crust**. The rising magma forms igneous **intrusions** that crystallize below the surface, producing large-grained igneous rocks such as granite. Rising magma may also break through the surface in the form of volcanoes, creating volcanic rocks such as basalt. Tectonic collision leads to increased heat and pressure, buckling the crust and creating metamorphic rocks. Basins adjacent to mountains fill with transported sediment, producing thick sequences of sedimentary rock. The rocks and sediments exposed at the surface today tell us an important story about the environments in which they were deposited or formed.

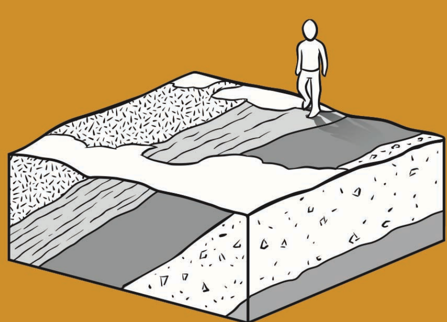
Why do we see different kinds of rocks at the surface?

As you walk across the surface of the Earth, you will observe an amazing variety of rock types. If all rocks were flat-lying layers and there was no erosion, then we would only see one type of rock exposed on the surface. Often, however, rocks have been worn away (eroded), and the underlying layers are now exposed at the surface. Layers of rock may also be tilted, folded, or faulted to reveal the underlying rocks at the surface.



When rocks are flat-lying layers and there is no erosion, folding, or faulting, the person walking across the surface sees only one rock type.

When rocks are worn away (often by streams), the person walking across the surface sees the underlying layers of rock exposed.



When rocks are folded or tilted, the person walking across the surface sees several layers of rock exposed.

2 Rocks

Region 1

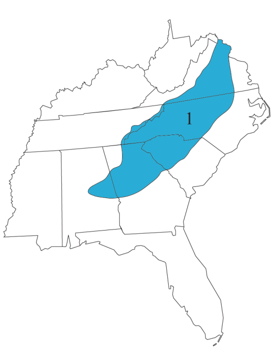
physiography • *a subfield of geography that studies the Earth's physical processes and patterns.*

orogeny • *a mountain-building event generally caused by colliding plates and compression of the edge of the continents.*

Paleozoic • *a geologic time interval that extends from 541 to 252 million years ago.*

fault • *a fracture in the Earth's crust in which the rock on one side of the fracture moves measurably in relation to the rock on the other side.*

shearing • *the process by which compressive stress causes the fracturing and faulting of brittle rocks.*



Rocks of the Blue Ridge & Piedmont
Region 1

The Blue Ridge and Piedmont are distinct **physiographic** areas, but they share similar types of crystalline igneous and metamorphic rocks. This region was at the center of several **orogenic** events that occurred throughout the Precambrian and **Paleozoic**, and many of the rocks found here were metamorphosed by the compressive forces of mountain building. The core of the Blue Ridge mountain range and the Inner Piedmont are the most highly metamorphosed, having been located nearly at the center of the continental collisions; the outer Piedmont is more variably metamorphosed. During the Paleozoic, continental collision compressed the Blue Ridge and Piedmont region further, causing folds, **faults**, intrusion by magma, **shearing**, and **uplift**. The region was pushed over 160 kilometers (100 miles) west, telescoping into a series of folded, thrusted crustal sheets that carried older rocks atop younger rocks, overturning the **stratigraphic** sequence. The Piedmont was thrust over the Blue Ridge, and the Blue Ridge was thrust over the rocks that lie farther west (*Figure 2.2*). The Brevard Fault Zone, one of the thrust faults that formed during this time period, is today considered to mark the border between the Piedmont and Blue Ridge areas (*Figure 2.3*). Along this 600-kilometer-long (370-mile-long) zone, which stretches from Alabama to Virginia, the rocks were crushed and ground by the tremendous pressure of thrusting along the fault zone, creating **cataclastic** gneisses, **schists**, and phyllonite.

See Chapter 1: Geologic History to learn more about rifting, mountain building, continental collision, and early supercontinents.

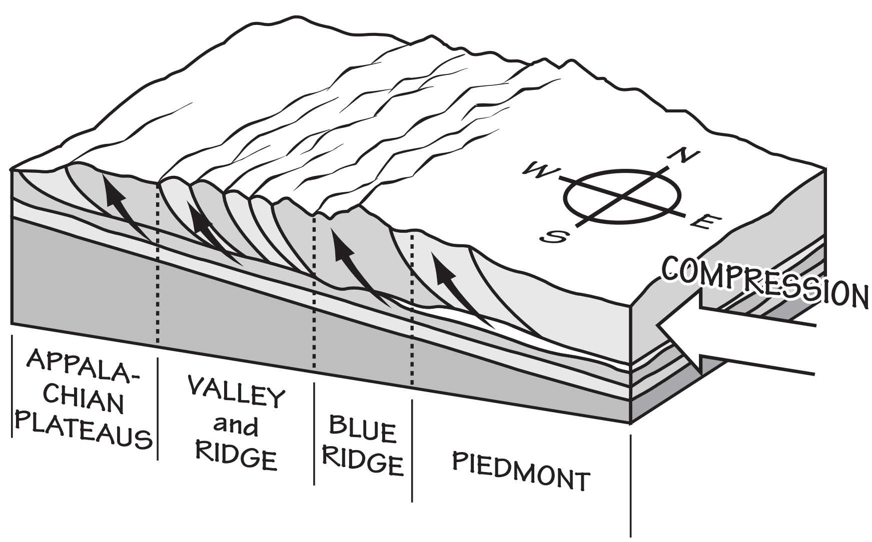


Figure 2.2: The crust of the Blue Ridge and Piedmont was "telescoped" by the compressional forces of Paleozoic mountain building. Slices of crust were thrust over top of each other, stacking like a deck of cards.

Region 1

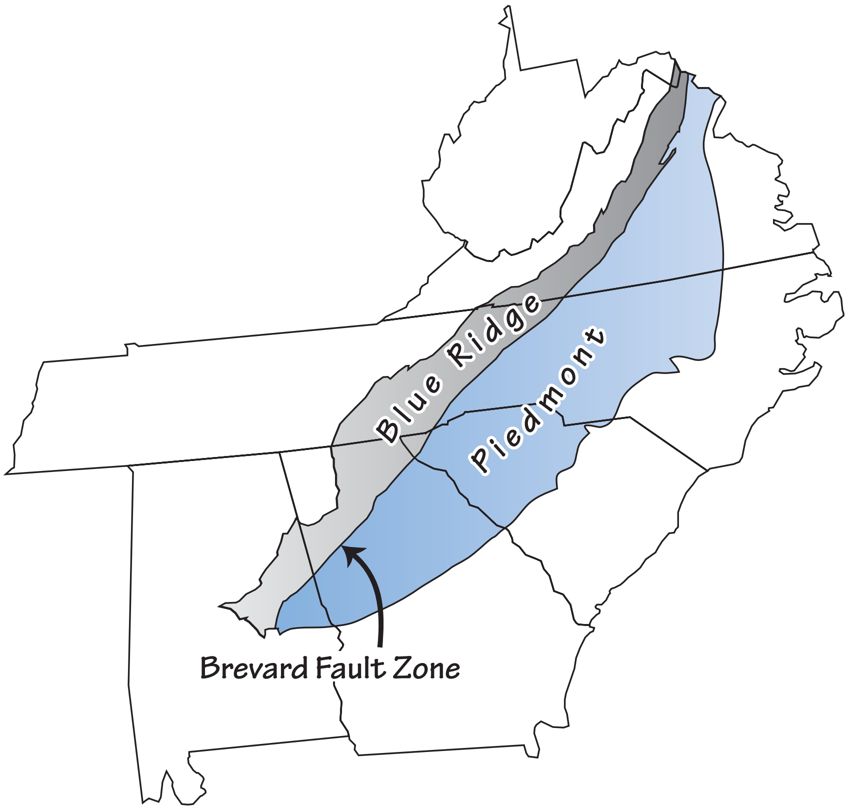


Figure 2.3: The Blue Ridge and Piedmont physiographic regions, as divided by the Brevard Fault Zone.

Superposition and Overthrust

Unless rock layers are overturned, older rocks are found at the bottom and younger rocks are found at the top of a sedimentary sequence. This is known as the *Law of Superposition*. The exception to this rule only happens when folding overturns rocks, or when older rocks are thrust on top of younger ones.

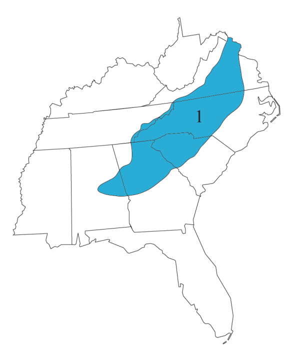
How do geologists figure out whether the youngest rock is on top? If the rock has been overturned in a giant fold, clues such as mud cracks or fossils on the bottom of a sedimentary layer may suggest the rock is upside down. Thrust faults may contain fossils or unique rock components out of the order in which they normally occur in every other known locality. It is often necessary to determine which layers are older by looking at the overall structural geology of a region, or using radiometric dating.

uplift • *upward movement of the crust due to compression, subduction, or mountain building.*

stratigraphy • *the branch of geology specifically concerned with the arrangement and age of rock units.*

cataclastic • *pertaining to rocks made up of cemented fragments that originated from the mechanical breakdown of rock associated with plate tectonics.*

schist • *a medium grade metamorphic rock with sheet-like crystals flattened in one plane.*



2 Rocks

Region 1

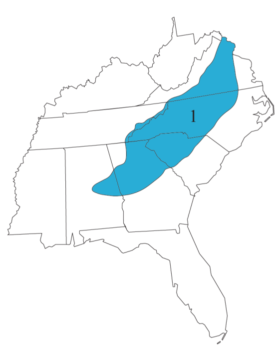
Grenville Orogeny • *a mountain-building event, about 1.3 to 1 billion years ago, that played a role in the formation of the supercontinent Rodinia.*

Rodinia • *a supercontinent that contained most or all of Earth's landmass, between 1.1 billion and 750 million years ago, during the Precambrian.*

quartzite • *a hard metamorphic rock that was originally sandstone.*

marble • *a metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite.*

chemical reaction • *a process that involves changes in the structure and energy content of atoms, molecules, or ions but not their nuclei.*



The Blue Ridge is dominated by rocks of Precambrian origin, including highly metamorphosed igneous and sedimentary rocks formed more than a billion years ago during the **Grenville Orogeny**—a mountain building event associated with the assembly of the supercontinent **Rodinia**. These Precambrian rocks are the oldest materials found at the surface in the Southeast, ranging from 1.8- to 1.1-billion-year-old gneisses along Virginia's Blue Ridge Mountains and North Carolina's Roan Mountain Highlands to 1-billion-year-old gneisses in the Georgia and Alabama Piedmont. Grenville-aged rocks were originally sandstone, shale, and limestone deposited in a zone called the Grenville Series (also called the Grenville Belt), a warm, shallow ocean along the eastern margin of proto-North America. During the formation of Rodinia, the Grenville Series sediments were squeezed and pushed up onto the continental margin, forming the Grenville Mountains. The intensity of compression metamorphosed the sedimentary rocks; sandstone became **quartzite**, gneiss, or schist, limestone became **marble**, and shale became gneiss and schist.

A gneiss is a very highly metamorphosed rock with alternating bands of dark and light minerals. The dark bands are mafic and higher in magnesium and iron, while the lighter bands are felsic and higher in silicates. These bands may form because extreme temperature and pressure cause a *chemical reaction* that forces the different elements into separate layers. Banding may also occur when a set of varied protoliths are subjected to extreme shearing and sliding forces, causing them to stretch into stacked sheets.

During the Grenville Orogeny, friction between the converging plates pushed magma into the overlying crust. Some magma rose high enough to intrude through the overlying sedimentary rocks, but it remained well below the surface. These amorphous intrusions eventually cooled and crystallized (*Figure 2.4*), forming igneous plutons of granite, **anorthosite**, and, less commonly, **gabbro**. As the Grenville Orogeny continued, the cooled plutons and sedimentary rocks of the Grenville Series were later covered by as much as 30 kilometers (19 miles) of sediment! High pressures and temperatures associated with the weight of the overlying material caused further metamorphism of the buried rocks. Today, these resistant igneous and metamorphic rocks can be seen at Old Rag Mountain in Virginia, Blowing Rock in North Carolina, and Red Top Mountain in Georgia (*Figures 2.5 and 2.6*), where they have been exposed by erosion.

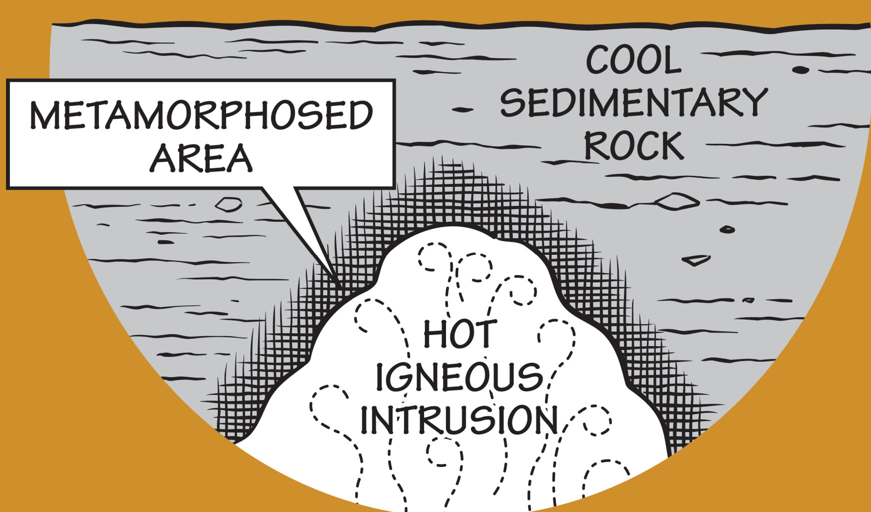
A pluton is a large body of igneous rock that formed under the Earth's surface through the slow crystallization of magma. The term comes from Pluto, Roman god of the underworld.

Region 1

What happens to a rock when it is metamorphosed?

When rocks are subjected to high enough temperatures or pressures, their characteristics begin to change. The weight of overlying rock can cause minerals to realign perpendicularly to the direction of pressure, layering them in a pattern called *foliation*, as exemplified in gneiss and schist. Recrystallization, as seen in marble and quartzite, results as rock is heated to high temperatures, and individual grains reform as interlocking crystals, making the resulting metamorphic rock much harder than its parent rock.

Contact metamorphism describes a metamorphic rock that has been altered by direct contact with magma. Changes that occur due to contact metamorphism are greatest at the point of contact. The farther away the rock is from the point of contact, the less pronounced the change.

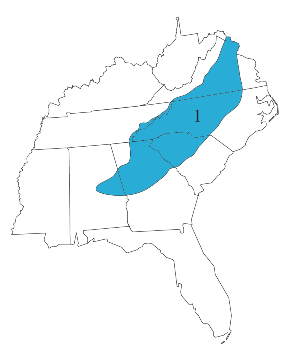


Regional or *dynamic metamorphism* describes a metamorphic rock that has been altered due to deep burial and great pressure. This type of metamorphic rock tends to occur in long belts. Different types of metamorphic rock are created depending on the gradients of heat and pressure applied.

anorthosite • *a plutonic igneous rock made mostly of plagioclase feldspar.*

gabbro • *a coarse-grained, mafic and intrusive igneous rock.*

foliation • *the arrangement of the constituents of a rock in leaflike layers.*



Region 1

Alleghanian Orogeny *• a Carboniferous to Permian mountain-building event involving the collision of the eastern coast of North America and the northwestern coast of Africa.*

anticline *• a layer of rock folded (bent) along an axis, concave side down (i.e., in an upside down "u" or "v" shape).*

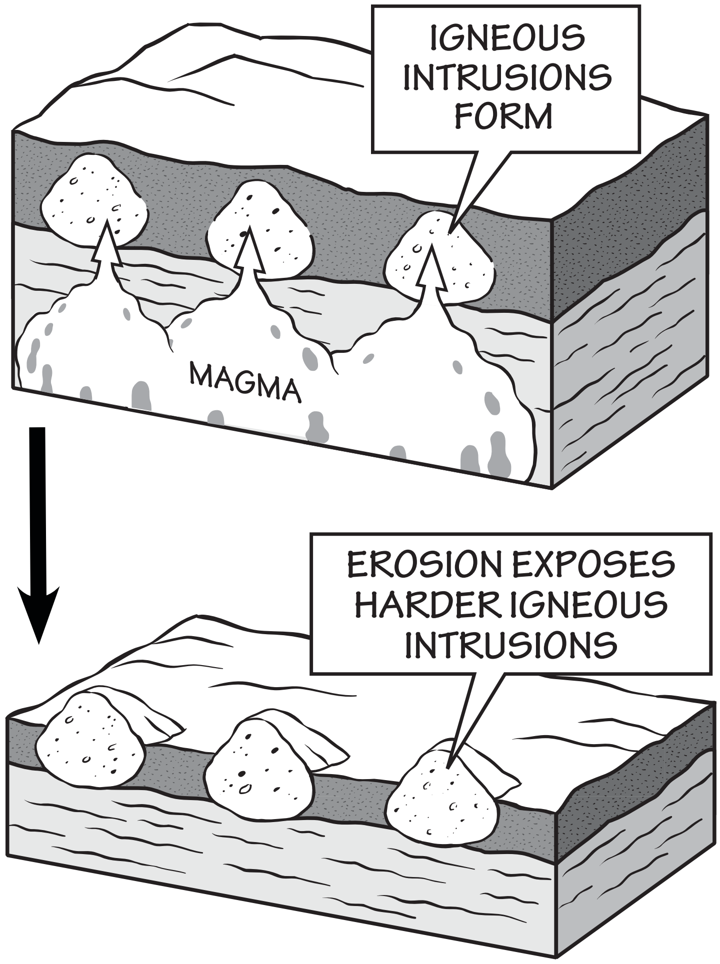


Figure 2.4: Igneous intrusions form when cooling magma is trapped beneath the surface. These rocks, which are more resistant than the surrounding material, can later be exposed at the surface through the process of erosion.

Grenville-aged rocks are present in many other parts of the Southeast besides the Blue Ridge, but they are often deeply buried by younger overlying sedimentary rocks. Precambrian rocks are visible at the surface in the Blue Ridge and Piedmont region only because of the intense thrusting and deformation that occurred during Paleozoic mountain building events (especially the **Alleghanian Orogeny**), uplifting layers of rock that were once buried beneath many kilometers (miles) of crust. The rocks of the Blue Ridge were compressed into a giant **anticline**, or upward fold, that has become the "backbone" of the Appalachian range, preventing the mountains from being worn completely flat. Softer sedimentary rocks were eroded away at the peak of the fold, exposing the resistant Precambrian rocks at its center.

See Chapter 4: Topography to learn about anticlines and the Appalachian anticlinorium.

Precambrian rock can also be seen throughout the region where "windows" in overthrust layers have eroded, exposing

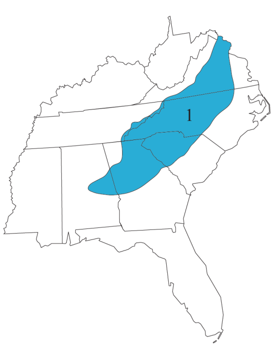
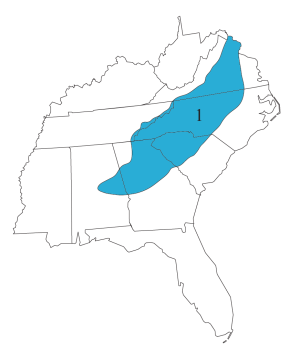


Figure 2.5: The Blowing Rock, an immense 1.05-billion-year-old cliff of gneiss that stands 1200 meters (4000 feet) above sea level in the Blue Ridge Mountains of North Carolina. The rock was named for an updraft of air funneled toward the cliff by the Johns River Gorge below.

Figure 2.6: Weathered Precambrian rocks at Red Top Mountain State Park, Georgia. The mountain takes its name from the red color of its iron-rich granite and gneiss.

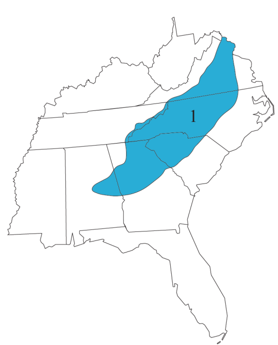


Region 1

rift basin *• a topographic depression caused by subsidence within a rift.*

Cambrian *• a geologic time period lasting from 541 to 485 million years ago.*

phyllite *• a metamorphic rock that is intermediate in grade between slate and schist.*



the ancient bedrock (*Figure 2.7*). One such example is Grandfather Mountain near Linville, North Carolina. This 750-million-year-old mass of **rift basin** conglomerate was covered by a 1-billion-year-old block of crust during the Alleghanian Orogeny, then metamorphosed by the pressure of thrust faulting. A window later eroded in the overlying thrust sheet, revealing the rock that we see at Grandfather Mountain today (*Figure 2.8*). There are several such geologic windows in the Southeastern states (*Figure 2.9*), although not all of them expose Precambrian Grenville rock.

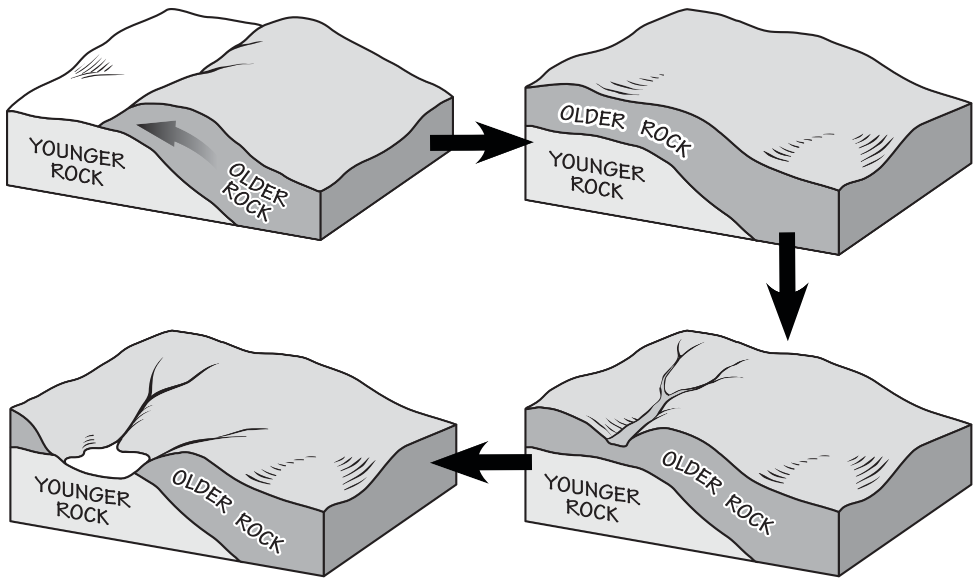


Figure 2.7: The development stages of a window. Older rock is thrust over younger rock. Erosion begins through the older rock, eventually exposing the underlying younger rock.

Beginning around 570 million years ago during the late Precambrian and early **Cambrian**, North America began to rift apart. As the rifts enlarged, many became basins that eventually filled with sediment eroded from the Grenville Mountains. Remnants of these ancient rift basins can found in the rocks at Mt. Rogers in Virginia, Reelfoot Lake in Tennessee, Grandfather Mountain in North Carolina, and outcroppings near Lynchburg, Virginia. The last sediments to fill the rift basins, known as the Chilhowee Group, were deposited in the early Cambrian (*Figure 2.10*). Over time, the rift basin sediment was compacted and cemented together to become conglomerate, sandstone, siltstone, and shale. These rocks were metamorphosed to slate, **phyllite**, and quartzite during later orogenic events, and they are often referred to as "metasedimentary" due to the fact that their sedimentary structures are often well preserved (*see Figure 2.8*).

Figure 2.8: The surface of Split Rock, a large weathered boulder at Grandfather Mountain, reveals large pebbles typical of meta-conglomerates.

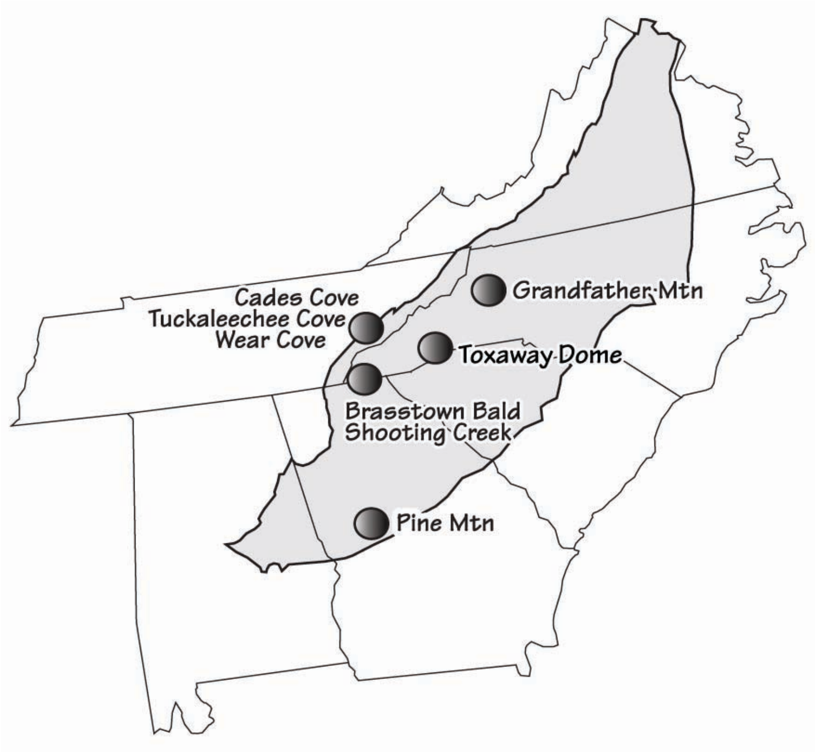
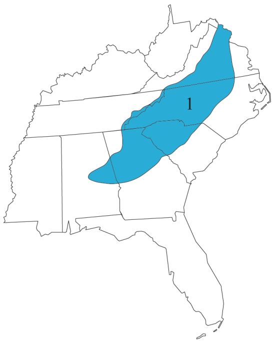


Figure 2.9: Outstanding geologic windows of the Southeast.



Region 1

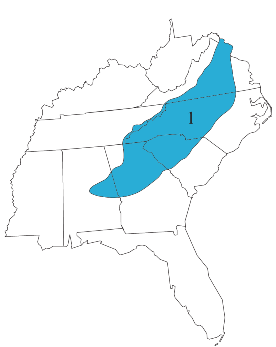
***Iapetus Ocean** • the proto-Atlantic Ocean, located against the eastern coast of North America's ancestral landmass before Pangaea formed.*

***fracture** • a physical property of minerals, formed when a mineral crystal breaks.*

***color (mineral)** • a physical property determined by the presence and intensity of certain elements within the mineral.*

***columnar joint** • five- or six-sided columns that form as cooling lava contracts and cracks.*

***breccia** • a pyroclastic rock composed of volcanic fragments from an explosive eruption.*



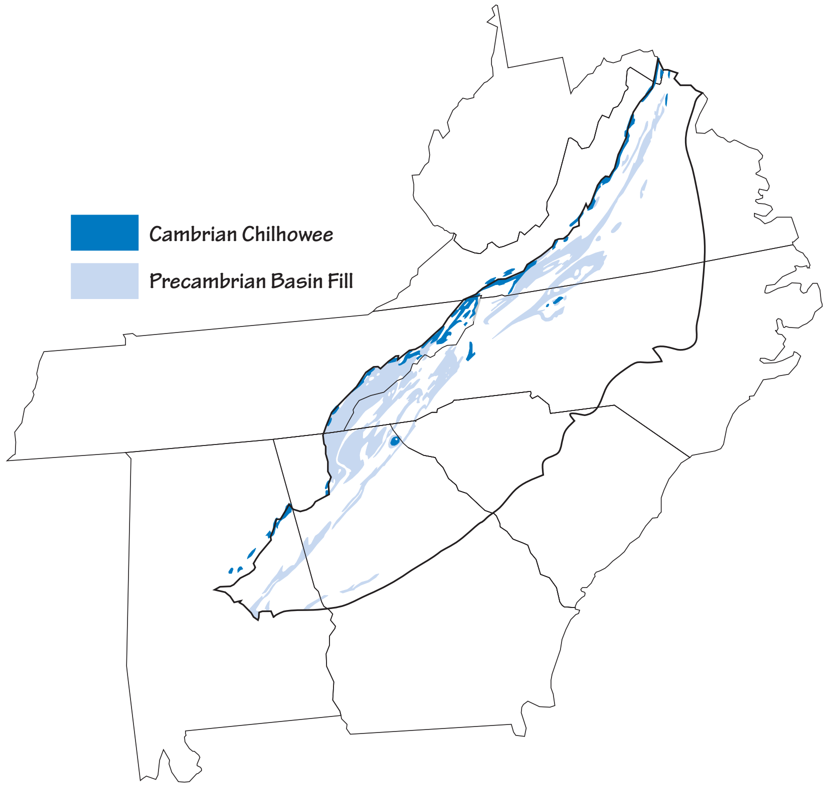


Figure 2.10: Late Precambrian and early Cambrian (Chilhowee Group) rocks of the Blue Ridge and Piedmont region.

As a result of continental rifting and the widening of the **Iapetus Ocean**, volcanic activity was common along the margin of North America during the late Precambrian and early Cambrian. Rifts and **fractures** in the crust made pathways for emerging lava that poured out across the surface for a period of several million years, covering over 10,300 square kilometers (4000 square miles) of land and cooling to form basalt. The Catoctin Basalt underlies Maryland's Catoctin Mountains and caps many of the peaks in easternmost West Virginia as well as Virginia's Shenandoah Mountains. This basalt, originally a dark-**colored** volcanic rock, was highly metamorphosed during the formation of the Appalachian Mountains, and became a fine-grained dark green to light grey greenstone. Although most Shenandoah greenstones are found as boulders or jagged cliffs, the cooling basalt occasionally contracted to form polygonal structures called **columnar joints** (*Figure 2.11*). Areas where new lava flows advanced over older ones are often marked by **breccia**, a chaotic layer of cemented sediments and rock fragments (*Figure 2.12*).

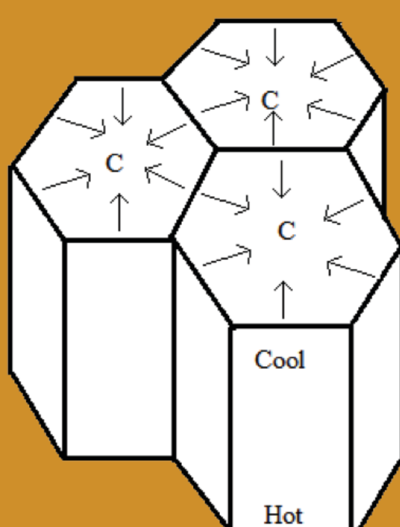
Mt. Rogers is named after William Barton Rogers, Virginia's first state geologist, who was famous for his studies of Appalachian Mountain geology.

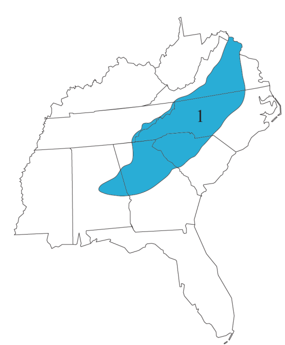
At Mt. Rogers in southwestern Virginia, there is evidence of an explosive rift-related Precambrian volcano that formed around 750 million years ago. The lava from this volcano eventually cooled

Figure 2.11: Columnar jointing in the greenstones of Compton Peak, Shenandoah National Park, Virginia.

Columnar Jointing

As a lava flow cools, it contracts, and the resulting force may cause the rock to crack. These cracks continue down to the bottom of the flow, resulting in five- or six-sided columns. Columnar joints are not restricted to basalt flows and can form in ashflow tuffs as well as shallow intrusions. The columns are generally vertical, but may also be slightly curved.





Region 1

rhyolitic • *a felsic volcanic rock high in abundance of quartz and feldspar.*

glacier • *a body of dense ice on land that does not melt away annually and has sufficient mass to move under its own weight.*

volcanic island • *one of a string of islands created when molten rock rises upward through oceanic crust.*

terrane • *a piece of crustal material that has broken off from its parent continent and become attached to another plate.*

Figure 2.12: A meta-volcanic breccia from the Catoctin Formation, composed largely of angular greenstone fragments.

to form **rhyolite** sections as much as 750 meters (2500 feet) thick in some areas. Beneath these volcanic flows, exposures of diamictite in the Konnarock Formation record evidence of the Neoproterozoic "Snowball Earth" **glaciations** that occurred between 759 and 543 million years ago (*Figure 2.13*).

See Chapter 8: Climate to learn more about Snowball Earth and other early glacial periods.

The rocks of the Blue Ridge form the spine of the Appalachian Mountain Range and the western part of its core, whereas the rocks of the Piedmont form the foothills of these mountains and include the eastern part of the Appalachians. Most ancient rocks in the Blue Ridge are related to major Precambrian and Cambrian tectonic events, from the Grenville Orogeny to Cambrian rifting. However, most Piedmont rocks actually formed somewhere other than North America and were attached to the continent in a patchwork of **volcanic islands**, fragments of land (exotic **terranes**), and former ocean-bottom sediments.

Terranes are fragments of crustal material that have been broken off from one plate and accreted to a different piece of crust through tectonic forces. Each fragment in a large grouping of accreted terranes shows a distinct geologic history.

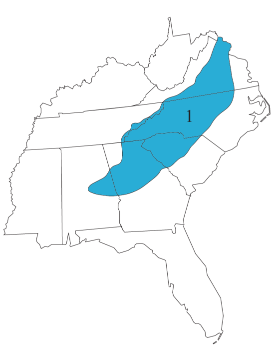


Figure 2.13: Diamictite from the Konnarock Formation at Mt. Rogers, Virginia. This poorly sorted sedimentary rock is believed to be tillite, lithified glacial debris from a major glaciation during the Proterozoic.

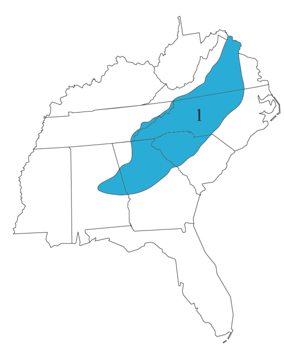
Avalon • *an early Paleozoic microcontinent offshore of what is now the eastern coast of North America.*

carbonate rocks • *rocks formed by accumulation of calcium carbonate, often made of the skeletons of aquatic organisms.*

subduction • *the process by which one plate moves under another, sinking into the mantle.*

Many Piedmont rocks are metamorphosed to varying degrees, and it is difficult to determine their exact origin or age of formation. Nevertheless, they are separated into two basic divisions, the Iapetus rocks and the **Avalon** rocks, based on their inferred origins.

The Iapetus rocks (also known as the Inner Piedmont) include sediments deposited in the ancient Iapetus Ocean, which continued to widen throughout the Cambrian. These sedimentary rocks were once part of a wide **carbonate** bank that formed along the continental margin after eroded sediment dwindled from the nearly worn-down Grenville Mountains. During this time, the Southeast (and most of proto-North America) was entirely underwater. Sandstone and shale were the dominant rocks generated from eroding sediments in the continental highlands, and limestone formed from carbonate sediments and shelled organisms living in the ocean. However, between 500 and 460 million years ago, the direction of plate movement shifted. The Iapetus Ocean began to close as the continental plates once again moved toward each other, and the Taconic volcanic island arc developed at the **subduction** zone where the plates came together. As these islands approached North America, compression metamorphosed the limestone, sandstone, and shale, forming marble, quartzite, slate, phyllite, and schist. The Murphy Marble, which stretches across northern Georgia into North Carolina, dates from the Taconic Orogeny, where it was metamorphosed from limestone formed at the bottom of the Iapetus Ocean (*Figure 2.14*). Marble is also quarried extensively from the Piedmont Uplands in Alabama, where it is the official state rock.



Ordovician • *a geologic time period spanning from 485 to 443 million years ago.*

diabase • *a dark-gray to black, medium-grained, intrusive igneous rock consisting mainly of labradorite and pyroxene.*

suture • *the area where two continental plates have joined together through continental collision.*

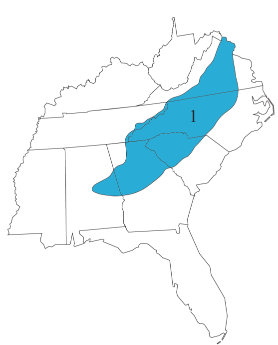
mantle • *the layer of the Earth between the crust and core.*

chert • *a sedimentary rock composed of microcrystaline quartz.*

Figure 2.14: Murphy Marble, collected from a quarry near Tate, Georgia. Specimen is 7.6 centimeters (3 inches) wide.

Evidence of the Taconic island arc's collision with North America can be seen throughout the Piedmont, where **Ordovician**-aged metamorphosed sedimentary rock from the volcanic islands is interlayered with metamorphosed volcanic rocks such as slate (originally ash) and greenstone (originally basalt) (*Figure 2.15*). The Hillabee Greenstone in Alabama is one such remnant of the Taconic island arc. Igneous intrusions resulting from the collision (e.g., granite, gabbro, and **diabase**) are located along the **suture** zone where the Taconic volcanic islands and ocean bottom sediments collided with the margin of North America (*Figure 2.16*), forming the Taconic Mountains.

Small exposures of dark rocks called **ophiolites** are found along the Taconic suture zone, stretching from northern Georgia to southwestern Virginia. These rocks are composed of former deep-sea sediment, oceanic crust, and upper **mantle** material. Ophiolites appear when a subducting oceanic plate fractures, leaving behind a slice of oceanic crust on land, and they are among the only places where mantle rock can be seen on the Earth's surface. The resulting rock sequences (*Figure 2.17*) are some of the most helpful tools we have for studying oceanic crust. An ophiolite sequence includes sedimentary rock from the deep sea, such as **chert**, underlain by **pillow basalts** that were **extruded** into the water at a mid-ocean ridge. Below the pillow basalts are intrusions of basalt known as sheeted **dikes**, formed as the mid-ocean ridge pulled apart. Below the basalt is gabbro, the plutonic version of basalt, and finally **peridotite**, the rock that composes the Earth's upper mantle. Peridotite is commonly altered slightly through metamorphism into a greenish rock called **serpentinite**.



Understanding Volcanism

Most volcanic eruptions occur along tectonic plate boundaries. At *divergent boundaries*, the mantle wells up where two plates pull apart, creating new crust. Mid-ocean ridges are the most common type of divergent boundary and are characterized by the eruption of bulbous pillow-shaped basalt lavas and hydrothermal fluids. Conversely, convergent plate boundaries destroy old *lithosphere* at subduction zones, where the ocean floor descends into the mantle. Volcanism here results from the subduction of seawater and seafloor sediments that descend into the mantle with the subducting slab, which lowers the melting temperature of mantle rocks enough to generate magma. Explosive eruptions characterize subduction zone volcanism and create arrays of cone-shaped *stratovolcanoes* that mark the position of the convergent boundary.

Volcanism can also occur at a *hot spot*, where superheated magma plumes well up from a point directly underneath the plate. Large shield volcanoes are produced as a direct result. The mechanics of hot spot volcanism are still largely unknown.

Prior to eruption, magma ascends from the mantle to a relatively shallow (1–10 kilometers [0.5–6 miles] deep) magma chamber. Upward movement reduces the pressure on the magma until it is low enough to permit dissolved gas to *exsolve* (come out of solution and form bubbles). All eruptions are driven by the exsolution of dissolved gas. As the gas forms bubbles, it expands in volume and forces the magma out of the vent/chamber system onto the surface. The combination of magma viscosity and gas content can produce a range of eruptive styles, from gentle, effusive eruptions to violent explosions.

The Avalon rocks (also known as the Outer Piedmont) were **accreted** to the margin of North America during the late **Devonian**. These rocks include the Avalon **microcontinent** (made up of volcanic sediment, sandstone, mudstone, and intrusions) and the surrounding ocean basin sediment (made up of mud,

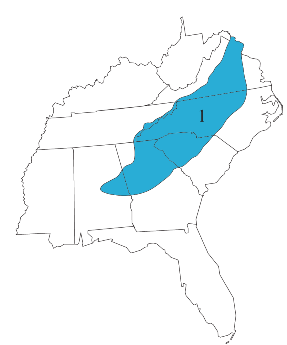
pillow basalt • *basaltic lava that forms in a characteristic "pillow" shape due to its extrusion underwater.*

extrusion • *an igneous rock formed by the cooling of lava after magma escapes onto the surface of the Earth through volcanic craters and cracks in the Earth's crust.*

dike • *a sheet of intrusive igneous or sedimentary rock that fills a crack cutting across a pre-existing rock body.*

peridotite • *a coarse-grained plutonic rock containing minerals, such as olivine, which make up the Earth's mantle.*

serpentinite • *a metamorphic rock formed when peridotite from a subducting plate reacts with water, producing a light, slippery, green rock.*



Region 1

sand • *rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

gold • *a soft, yellow, corrosion-resistant element (Au), which is the most malleable and ductile metal on Earth.*

pegmatite • *a very coarse-grained igneous rock that formed below the surface.*

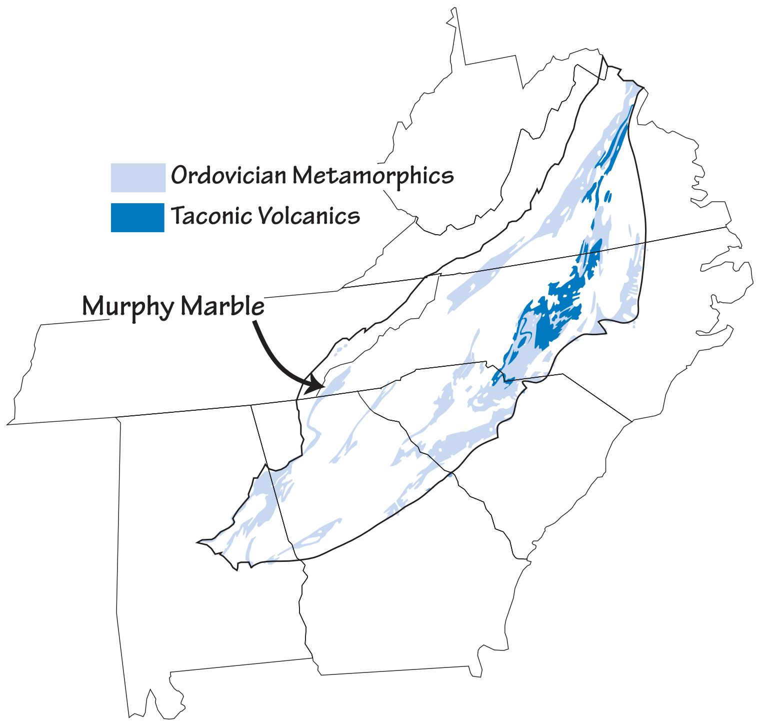


Figure 2.15: Metamorphic and volcanic rocks related to compression and accretion during the Taconic Orogeny.

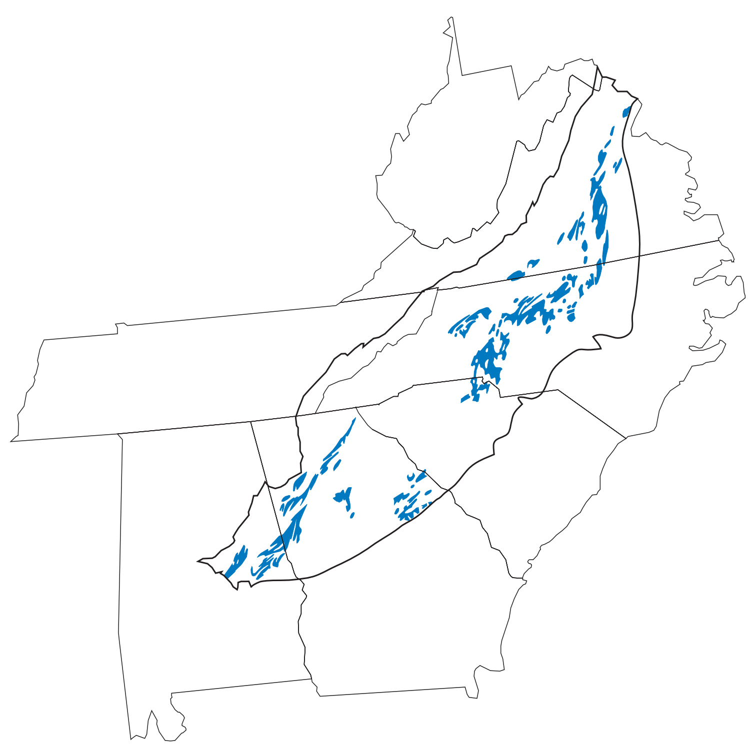
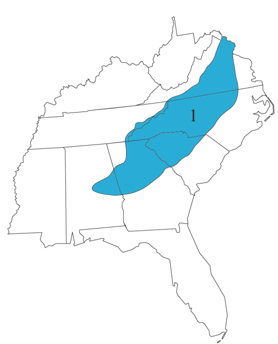


Figure 2.16: Granite intrusions related to the Taconic Orogeny.



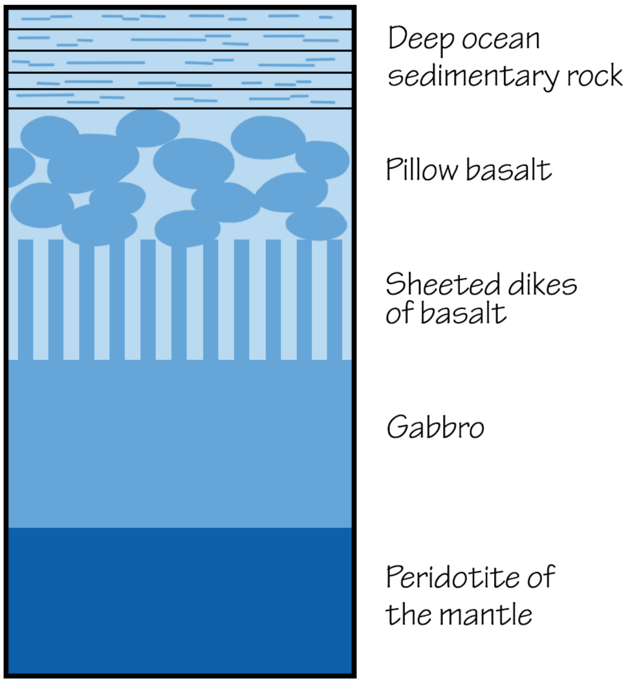


Figure 2.17: Structure of an ophiolite.

ash, and **sand**) on either side of the microcontinent. During the microcontinent's collision with North America, the Avalon rocks underwent varying degrees of metamorphism based on their distance from the center of the collision. Marine sediments became argillite, slate, gneiss, schist, phyllite, and quartzite; preexisting intrusions were metamorphosed to amphibolite, greenstone, serpentinite, metagabbro, and metabasalt. The Carolina Slate Belt, a weak to moderately metamorphosed section of Avalon rocks, stretches over 970 kilometers (600 miles) from Georgia to Virginia. Located in the Outer Piedmont, the belt includes argillite, slate, schist, and phyllite and contains significant **gold** deposits *(Figure 2.18)*. The collision of Avalon with North America also resulted in igneous intrusions throughout the Piedmont, similar to earlier intrusions formed during the Ordovician. Some of these intrusions formed **pegmatites**.

See Chapter 5: Mineral Resources for more information about the Southeast's gold and other precious metals.

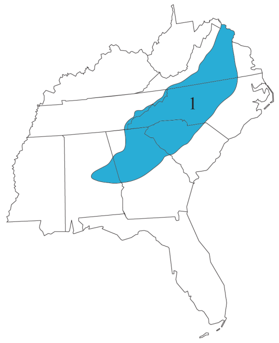
Africa collided with North America during the Alleghanian Orogeny of the late **Pennsylvanian** and **Permian**, uplifting the Appalachian Mountains and resulting in the formation of the supercontinent **Pangaea**. The collision resulted in intense metamorphism of the Blue Ridge and Inner Piedmont, moderate metamorphism in the Outer Piedmont, westward thrusting of the crust, and igneous intrusions throughout the Blue Ridge and Piedmont region. Stone Mountain in Georgia is a granitic and **feldspar**-rich pluton that formed deep below the Earth's surface during the Alleghanian Orogeny, and was later exposed by erosion (*Figure 2.19*). Arabia Mountain and Panola Mountain, two smaller

Pennsylvanian • *a subperiod of the Carboniferous, spanning from 323 to 299 million years ago.*

Permian • *the geologic time period lasting from 299 to 252 million years ago.*

Pangaea • *supercontinent, meaning "all Earth," which formed over 300 million years ago and lasted for almost 150 million years.*

feldspar • *an extremely common group of rock-forming minerals found in igneous, metamorphic and sedimentary rocks.*



Region 1

Triassic • *a geologic time period that spans from 252 to 201 million years ago.*

Jurassic • *the geologic time period lasting from 201 to 145 million years ago.*

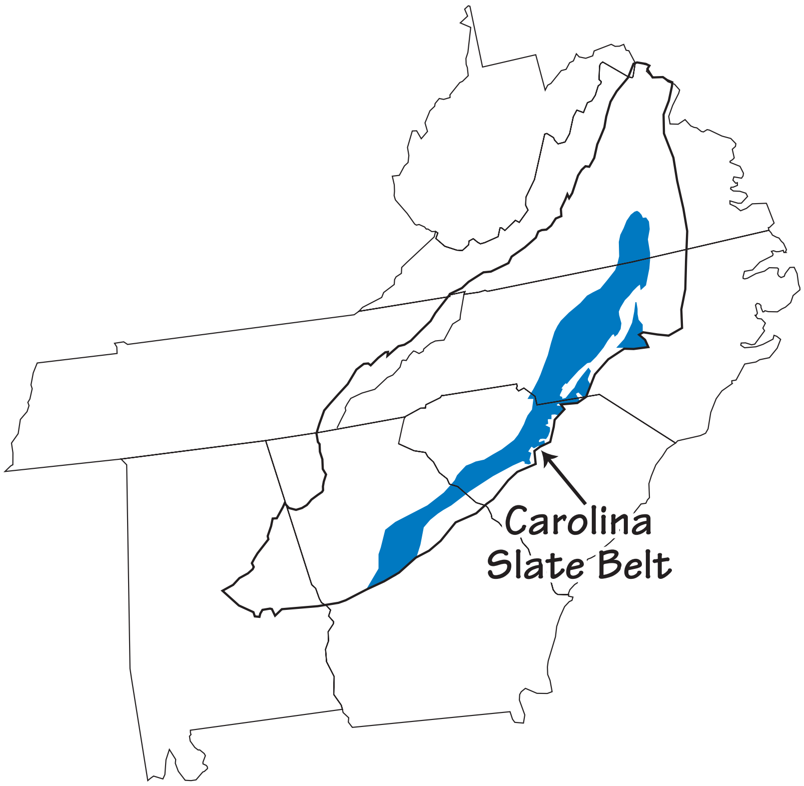
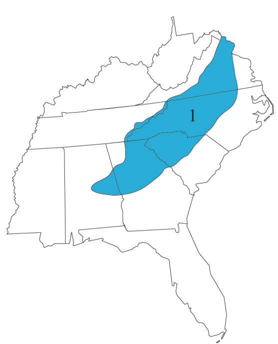


Figure 2.18: Extent of the Carolina Slate Belt.

granite outcroppings east of Stone Mountain in DeKalb County, were formed during the same intrusive event. Stone Mountain is 8 kilometers (5 miles) in circumference, and continues underground for up to 14 kilometers (9 miles) at its deepest point. Granite from the mountain was quarried extensively from the 1830s through the early 1900s, and the stone was shipped worldwide for use in buildings and structures as far ranging as the locks in the Panama Canal, the federal gold depository at Fort Knox, and the Imperial Hotel in Tokyo. Today, the mountain is famous not only for its geology but for the enormous bas-relief carving on its north face (*Figure 2.20*).

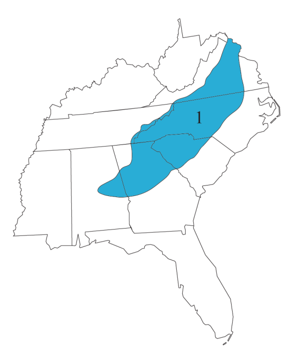
See Chapter 1: Geologic History for more information about Pangaea.



During the late **Triassic** and early **Jurassic**, Pangaea broke apart. Rifts formed in the crust along the margin of North America (as well as along the margins of Africa and western Europe), and blocks of crust slid down fault planes to form rift basins of varying size. The basins were periodically filled with water, forming shallow lakes in which were deposited thin, dark layers of poorly sorted sediment that solidified into red-colored sandstone and shale. Magma pushed up through fractures in the rifted crust, pouring out on the surface of the basin as lava or cooling and crystallizing below ground as igneous intrusions. The Southeast's

Figure 2.19: An aerial view of Stone Mountain, DeKalb County, Georgia.

Figure 2.20: The carving of Jefferson Davis, Robert E. Lee, and Thomas "Stonewall" Jackson on the north face of Stone Mountain is the world's largest bas-relief sculpture, spanning a total surface area of 1.2 hectares (3 acres), or about two and a half football fields. The carving was commissioned in 1916, but not completed until 1972.



2

Rocks

Region 1

Newark Supergroup *• a sequence of nonmarine sedimentary rocks that accumulated along what is now eastern North America in the late Triassic to early Jurassic.*

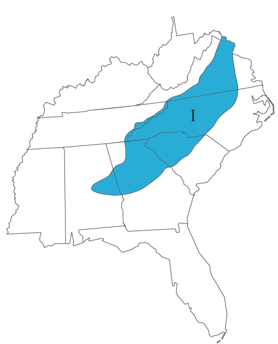
Triassic- and Jurassic-aged rift basin deposits are part of a sequence of rocks known as the **Newark Supergroup**, which can reach thicknesses of up to six kilometers (four miles). They are found at the surface in Virginia and North Carolina, where they expose characteristic reddish-brown sedimentary rock and igneous basalt or diabase, also known locally as "traprock." There is also a very small, poorly exposed basin at the surface in South Carolina called the Crowburg Basin. While there are many other rift basins in eastern North America, most are now buried by younger sediment.

Diabase dikes that formed during the Triassic and Jurassic rifting period are found not only in the region's rift basins, but also throughout the Piedmont. North and South Carolina claim the largest diabase dike in the eastern United States, "the Great Diabase Dike," which extends across the border between the two states for 35 miles. The dike is more than 300 meters (1000 feet) wide in sections. Diabase from this dike is exposed near Forty Acre Rock in Lancaster County, South Carolina, a large exposure of granite that was emplaced during the Alleghanian Orogeny.

Colors of Sedimentary Rocks
What do they tell us about the environment?

The color of a rock can be an important indicator of the environment in which it formed. The red-brown color so common in the rift basins of the Southeast results from oxidized (rusted) iron within the rock. This is most common in sediments deposited in a seasonally hot and dry climate on land, where the iron could be exposed to the air. Red sedimentary rock is also found in the Silurian rocks of the Inland Basin region, reflecting a time when ocean floor sediments were exposed above water. Red clays may also form in well-oxygenated, deep marine conditions. In some marine environments, however, where iron is reduced rather than oxidized, rocks may take on a greenish hue. Likewise, some greenish sedimentary rocks may indicate the presence of the mineral glauconite, which is found only in marine environments.

In contrast, many shales are gray or black in color, reflecting the abundance of carbon-rich organic material that can accumulate in quiet-water settings. The darker the shale, the more organic material that is preserved within. Shales are most commonly formed in quiet waters where tiny particles have time to settle out onto the sea or lake floor.



Rocks of the Inland Basin
Region 2

Region 2

The Inland Basin is a large geophysical province that extends over much of the central and Southeastern US. Inland from the mountain-building events that occurred throughout the Paleozoic, the Earth's crust was buckled (**downwarped**) into a series of depressions called "basins" that give the region its name (*Figure 2.21*). There are two major basins in the Inland Basin region—the Appalachian and Illinois basins—separated by the **Cincinnati Arch** and its branches. Other, smaller basins have existed throughout the region at various times through geologic history. One notable area of deposition is the Black Warrior Basin of northern Alabama and Mississippi (at the southern tip of the **Appalachian Basin**), which is a particularly important area for **fossil fuel** production.

See Chapter 6: Energy for more about fossil fuel production in the Southeast.

__downwarp__ • a segment of the Earth's crust that is broadly bent downward.

__Cincinnati Arch__ • an uplifted region that existed between the Illinois Basin, the Michigan Basin, and the Appalachian Basin during the late Ordovician and Devonian.

__Appalachian Basin__ • an inland basin, formed by the Taconic and Acadian mountain-building events.

__fossil fuels__ • fuel for human use that is made from the remains of ancient biomass.

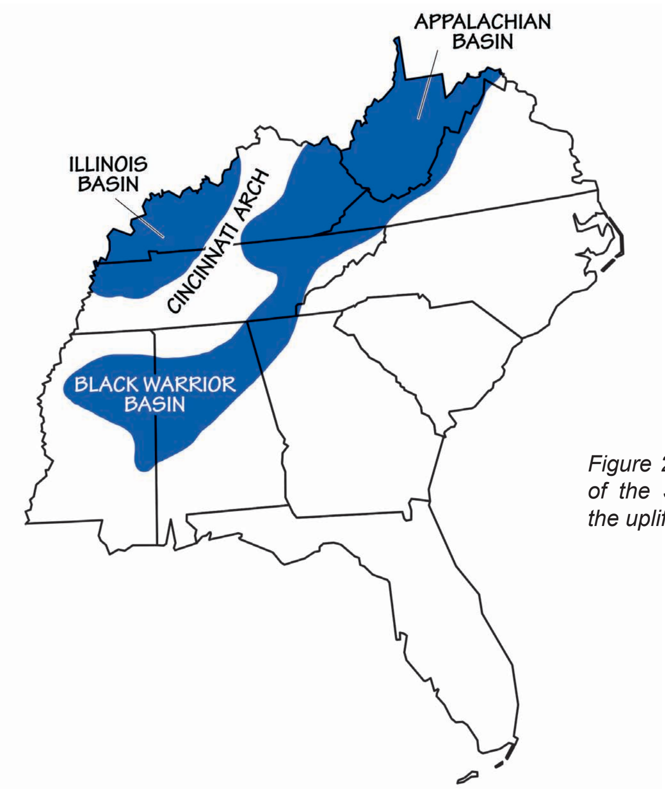
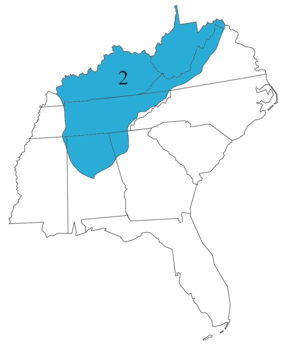


Figure 2.21: Sedimentary basins of the Southeast, separated by the uplifted Cincinnati Arch.



Since the Inland Basin was not at the center of the tectonic collisions that occurred during the Paleozoic, there are almost no igneous intrusions exposed at the surface, and the rocks here were not metamorphosed as they were in the Blue Ridge and Piedmont region. The easternmost section of this region, however, called the Valley and Ridge, was squeezed into tight folds during the Taconic,

Region 2

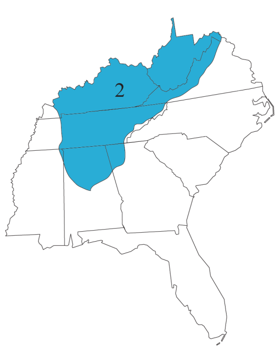
relief • *the change in elevation over a distance.*

subsidence • *the sinking of an area of the land surface.*

geologic time scale • *a standard timeline used to describe the age of rocks and fossils, and the events that formed them.*

unconformity • *the relation between adjacent rock strata for which the time of deposition was separated by a period of nondeposition or erosion.*

dolomite • *a carbonate mineral, consisting of calcium magnesium carbonate ($CaMg(CO_3)_2$).*



Acadian, and Alleghanian orogenies. The Appalachian Plateau, the central section of the Inland Basin, was broadly folded as the effects of mountain building decreased to the west (away from the collision). In contrast, the westernmost section of the Inland Basin, known as the Interior Low Plateaus, was minimally affected by orogenesis during the Paleozoic.

See Chapter 4: Topography to learn about physiographic regions.

The Inland Basin is dominated by sedimentary rock thanks to its low topographic **relief**; basins are naturally excellent places for the preservation of thick sediment layers because they easily collect sediment and often **subside** from its weight. The rocks of the Inland Basin, including conglomerate, sandstone, siltstone, shale, limestone, and dolostone, reveal the changing depositional environments of the inland sea as it advanced and retreated repeatedly throughout **geologic time**.

Inland sea may sound like a contradiction in terms, but there is a very simple, yet important, distinction that differentiates it from other seas: an inland sea is located on continental crust, while other seas are located on oceanic crust. An inland sea may or may not be connected to the ocean. For example, Hudson Bay is on the North American plate and connects to the Atlantic and Arctic oceans, while the Caspian Sea is on the European plate but does not drain into any ocean at all.

Following the Precambrian Grenville Orogeny, global sea level began to rise, until most of North America was covered by a shallow inland sea. A period of erosion gradually wore down the Grenville Mountains, and their weathered sediments were carried westward and deposited into the Inland Basin. As the sea widened, sand and mud were deposited near shore, while organically derived carbonates including limestone and dolostone formed in deeper water. Gradually, the amount of sediment settling into the basin declined as the mountains were weathered down. Sea level remained high through the Ordovician, but the reduced sediment supply resulted in the formation of more limestone and dolostone, which are common in warm, shallow, sediment-starved seas. These widespread carbonate rocks are thousands of meters (feet) thick in Kentucky and Tennessee (*Figures 2.22 and 2.23*).

As sea level dropped later in the Ordovician, the carbonate rocks were exposed to intense erosion, and many layers of sediment were removed. The eroded layers represent an **unconformity**, a gap in the geological record where stratified layers have been interrupted or destroyed due to erosion or deformation. A large, regional unconformity occurs at the top of the Ordovician Knox Group—a formation of **dolomite** and limestone that stretches across eastern Tennessee, northwestern Georgia, western North Carolina, and southwestern Virginia—where several hundred meters (feet) of sediment may have been eroded away.

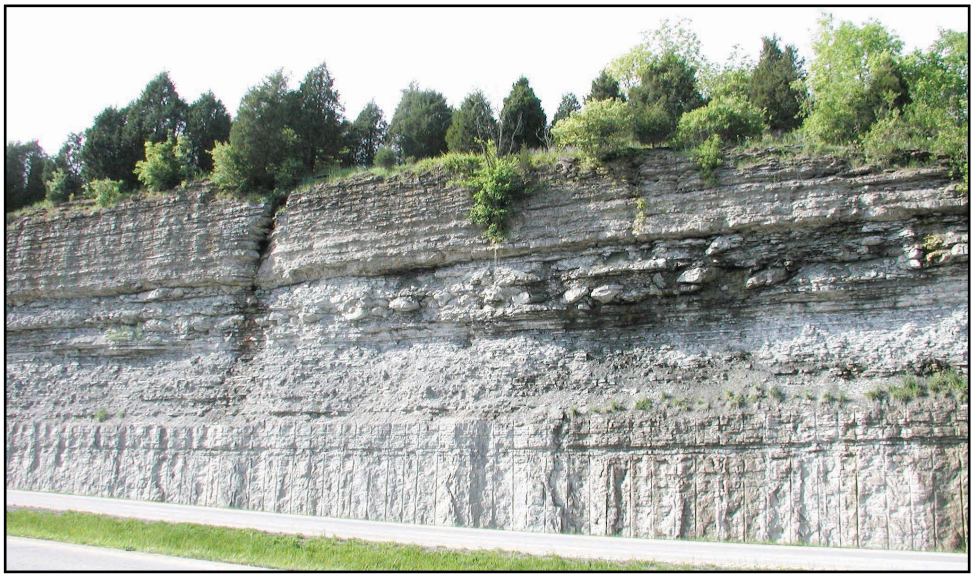
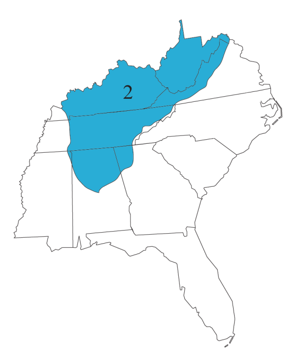


Figure 2.22: Rocks of the Lexington Limestone, which include limestone strata as well as shale layers, are exposed along this roadcut on the Martha Layne Collins Bluegrass Parkway near the Kentucky River.

Figure 2.23: "Let's Play Ball," a giant baseball mitt carved from 15 tons of Kentucky's Ordovician limestone and exhibited in the Louisville Slugger Museum, Louisville, Kentucky.

Toward the later half of the Ordovician, the Iapetus rocks (including the Taconic volcanic islands, Piedmont Terrane, and associated marine sediment) collided with the margin of North America, forming the Taconic Mountains. The Appalachian Basin, created as a result of this collision, was submerged under an inland ocean.



Rocks

Region 2

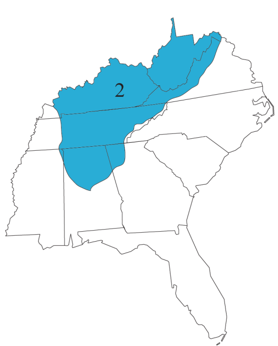
bentonite *• a clay, formed from decomposed volcanic ash, with a high content of the mineral montmorillonite.*

clay *• the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.*

volcanic ash *• fine, unconsolidated pyroclastic grains under 2 millimeters (0.08 inches) in diameter.*

reef *• a feature lying beneath the surface of the water, which is a buildup of sediment or other material built by organisms, and which has positive relief from the sea floor.*

dimension stone *• the commercial term applied to quarried blocks of rock cut to specific dimensions.*



Layers of **bentonite clay**, altered **volcanic ash** from volcanic activity during the collision, were deposited in the inland ocean and subsequently preserved within the region's limestone and shale. In parts of Tennessee, **reefs** developed along the Appalachian Basin's shallow margin, resulting in the formation of coarsely crystalline limestone that is now referred to as "Tennessee marble." While not technically a true marble, this stone gets its moniker from the fact that it polishes to an attractive and architecturally sound **dimension stone**. Many prominent structures throughout the US were built using Tennessee marble; these include the National Air and Space Museum, the National Gallery of Art, and the Taft Memorial in Washington DC, as well as the Tennessee Supreme Court Building in Nashville and the historic Knoxville Post Office (*Figure 2.24*).

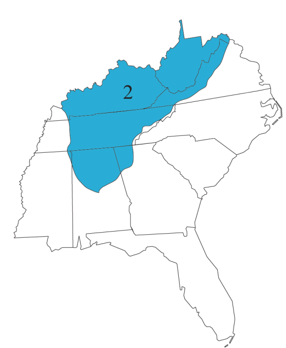
Figure 2.24: The United States Post Office and Courthouse, better known as the Knoxville Post Office, is a historic federal building constructed from Tennessee marble in the early 1930s.

The Ordovician Knox unconformity is one of the most prominent sections of "missing time" in North America, but there are other examples of unconformities in the Inland Basin and throughout the US. For example, there are no rocks representing the Mesozoic, Paleogene, or Neogene in the Inland Basin. The absence of rocks deposited during certain time periods does not mean that no rocks were formed during that time. It may mean, however, that very little sediment was deposited, that the sediment was eroded away, or that the rocks are buried beneath the surface. There is no single place on Earth with a complete sequence of rocks from the Precambrian to the Quaternary. Erosion and weathering over time have removed many meters (feet)—and in some cases kilometers (miles)— of rock from the surface of the Southeast.

Why are there different sedimentary rocks in different environments?

Most sedimentary rock deposited in underwater settings originated from material eroded on land and washed down streams or rivers before settling to the bottom of a body of water. Intuitively, the faster the water is moving, the larger the sediments it may carry. As the water slows down, the size of sediments it can carry decreases. Furthermore, the farther the grains of sediment are carried, the more rounded they become as they are tumbled against each other. In this way, rivers emptying into a sea are effectively able to sort sediment. Near the mouth of the river, the water is still relatively high-energy, dropping only the largest pieces; farther from the shore, the dropped particles get smaller. Therefore, conglomerates and sandstones are interpreted to have been deposited on or near the shore, siltstone farther from the shore, and shale in deep water quite far from shore where currents are slow enough that even very tiny particles may settle out.

Increased distance from shore and water depth can also reduce the presence of oxygen in the water, causing organic material to decompose less completely. This causes darker, carbon-rich rocks (including some that contain exploitable fossil fuels) to form in these areas. Limestone is made primarily of calcium carbonate, the components of which are dissolved in the water. Living creatures, like coral and foraminifera, take those components out of the water to make calcium carbonate shells, which, after the creatures die, accumulate to become limestone. These shelled creatures tend to fare better in clear water, so limestone usually forms far from other sources of sediment. While this process happens over much of the seafloor, if more than 50% of the sediment being deposited is from another source, the rock that forms is, by definition, not limestone.



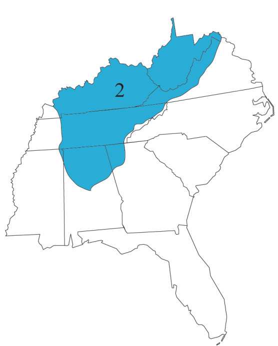
delta • *a typically wedge-shaped deposit formed as sediment is eroded from mountains and transported by streams across lower elevations.*

floodplain • *the land around a river that is prone to flooding.*

estuary • *a place where freshwater and saltwater mix, created when sea level rises to flood a river valley.*

Silurian • *a geologic time period spanning from 443 to 419 million years ago.*

inland basin • *a depression located inland from the mountains, and formed by the buckling (downwarping) of the Earth's crust.*



A **deltaic** wedge of sediment formed on either side of the Taconic Mountains as they eroded. Conglomerates formed close to the highlands, while streams brought sandy, muddy sediment to **floodplains**, lakes, **estuaries**, beaches, and into the inland ocean to form sandstone, siltstone, and shale. Sediment from the Taconic highlands spread as far south as northern Alabama and as far west as central Tennessee, but was concentrated mainly in Virginia and West Virginia. Farther away from the highlands, carbonate rocks continued to form, along with sandstone and shale. Thanks to folds, faults, and erosion, Ordovician rocks are exposed in the Valley and Ridge section of the Inland Basin (*Figure 2.25*), and along the Cincinnati Arch in Kentucky and Tennessee.

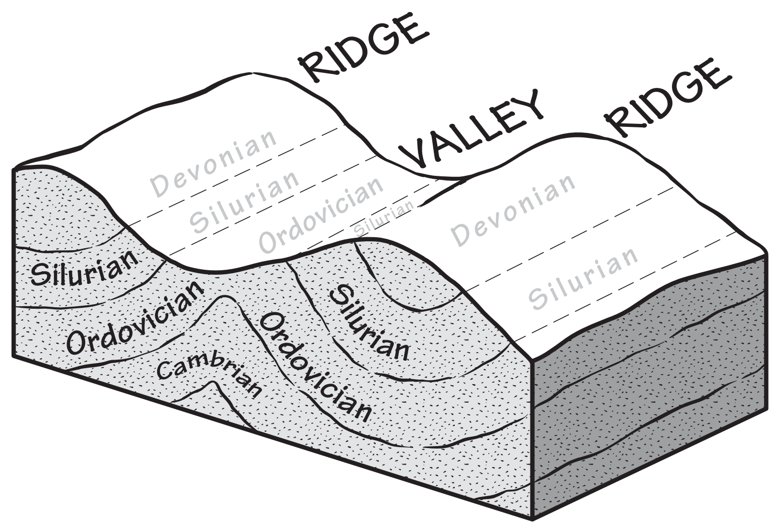


Figure 2.25: The Ordovician, Silurian, and Devonian rocks of the Inland Basin are found in long thin ribbons formed by the way layers of rock have been folded and then sliced at the surface by erosion. In the Valley and Ridge, the rocks were compressed into tight, elongated folds along the Blue Ridge during Paleozoic mountain building events. Rocks above these folds have been uplifted and eroded, exposing the older rock beneath.

Silurian rocks are exposed mainly in the eastern- and westernmost parts of the Inland Basin, where they record the continuing story of the Paleozoic inland sea and the after-effects of the Taconic Orogeny. During this period, sedimentary rocks formed in response to rising and falling sea levels as the convergence of tectonic plates continued to buckle the **inland basins**, deepening the ocean. Erosion of the Taconic Mountains continued to provide sediment for sandstone and shale, while carbonate rocks formed farther from shore. During the late Silurian, as the Appalachian Basin filled with sediment, the ocean became relatively shallow; many **iron**-rich marine sediments were **oxidized** upon exposure to the air, resulting in red sedimentary rocks (including sandstone, siltstone, shale and limestone). A thick band of these "red beds" is found in the Inland Basin, extending from Alabama to New York. In Birmingham, Alabama, roughly 80 meters (260 feet) of a thick Silurian red

See Chapter 5: Mineral Resources to learn how the iron in Red Mountain contributed to Birmingham's once-flourishing steel industry.

bed forms Red Mountain, a 53-kilometer-long (33-mile-long) rust-stained ridge that contains seams of **hematite ore** (*Figure 2.26*). Some of the ore is **oolitic**, containing small pellets of iron oxide that precipitated around grains of sand or small fossil fragments.

Devonian rocks in the Inland Basin record the onset of the Acadian Orogeny, which deepened the Appalachian Basin by downwarping the crust. The Acadian highlands eroded rapidly, filling the Appalachian Basin with a westwardspreading delta called the Catskill Delta. Although the thickest sequences from this delta are found in Pennsylvania and New York, Catskill Delta deposits can also be seen throughout West Virginia and Virginia (*Figure 2.27*). Many of the Devonian rocks produced during the Acadian Orogeny are similar to those of the Ordovician: conglomerate, sandstone, siltstone, shale, and carbonates. Widespread black shales were deposited in deeper waters as organic-rich marine mud. The Devonian Chattanooga Shale, a black shale found throughout the Inland Basin, is an important source rock for **petroleum** and **natural gas**.

See Chapter 6: Energy for more information about shales as source rocks for fossil fuels.

Mississippian rocks dominate the western edge of the Inland Basin, but they are also found in smaller outcrops throughout the region. During the Mississippian, sediment from the Acadian highlands continued to fill the basin's deeper waters with mud, **silt**, and sand. Carbonate deposits from this time are rich in **silica** provided from the shells of siliceous **sponges** as well as **quartz** sand and silt, and chert is common. Many of these carbonate rocks have since been subject to erosion and dissolution, generating a landscape of sinkholes and caverns. The world's longest known cave system, Mammoth Cave in Kentucky, is found in Mississippian limestone. At the southern end of the **Illinois Basin** in western Kentucky, **evaporites** formed where shallow water restricted circulation, aiding evaporation.

See Chapter 4: Topography to learn about the formation of karst.

Toward the end of the Mississippian period, sea level fluctuated, and deltas and coastlines advanced and retreated repeatedly. These rapid changes between coastal and terrestrial environments created deposits called **cyclothems**: alternating sequences of terrestrial and marine sedimentary layers dominated by thick limestones and dolomites (*Figure 2.28*) Thanks to a warm, tropical **climate**, large swamps dominated the shorelines, creating vast marshy areas along basin margins. Decomposing plant material accumulated as thick deposits of **peat**, which was later buried by sediment and compressed to form layers of **coal**. Pennsylvanian cyclothems from the Inland Basin, found in a wide band through the Appalachian Plateau and in western Kentucky, include thick bands of coal within their repeating sedimentary sequences.

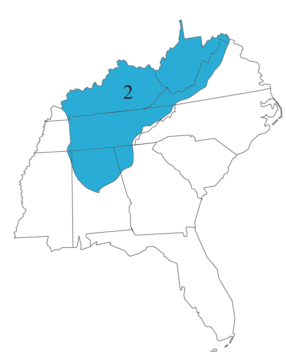
iron • *a metallic chemical element (Fe).*

oxidation • *a chemical reaction involving the loss of at least one electron when two substances interact.*

hematite • *a mineral form of iron oxide (Fe_2O_3), with vivid red pigments that make it valuable as a commercial pigment.*

ore • *a type of rock that contains minerals with valuable elements, including metals, that are economically viable to extract.*

petroleum • *a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface.*



Region 2

Carboniferous • *a geologic time period that extends from 359 to 299 million years ago.*

Gondwana • *the supercontinent of the Southern Hemisphere, composed of Africa, Australia, India, and South America.*

convergent boundary • *an active plate boundary where two tectonic plates are colliding with one another.*

lacustrine • *of or associated with lakes.*

meteorite • *a stony or metallic mass of matter that has fallen to the Earth's surface from outer space.*

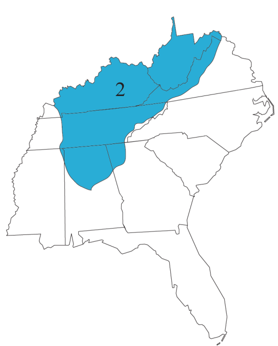


Figure 2.26: The Silurian sandstone strata of Red Mountain are exposed along this roadcut on the Red Mountain Expressway, near Birmingham, Alabama.

Figure 2.27: These ripple marks, found near an outcrop off Route 55 in West Virginia, were formed in the shallow inland sea as wavelets rearranged sediments shed from the Acadian Mountains.

During the late **Carboniferous**, **Gondwana** (a landmass composed of Africa, South America, and Australia) and North America converged into the supercontinent Pangaea. A deep trench formed at the **convergent plate boundary**, and ocean bottom sediments were squeezed up onto the Gulf Coast margin to form the Ouachita Mountains of Arkansas and Texas. Remnants of the Ouachita Mountains also cut across modern-day Mississippi at the collision zone, but they are deeply buried today. As the Iapetus Ocean closed, the Appalachian Mountains were formed on the adjacent plate margin where Africa collided with North America. The collisions created a depression—today known as the Black Warrior Basin—into which sediment was deposited from erosion of both the Appalachian and Ouachita mountains.

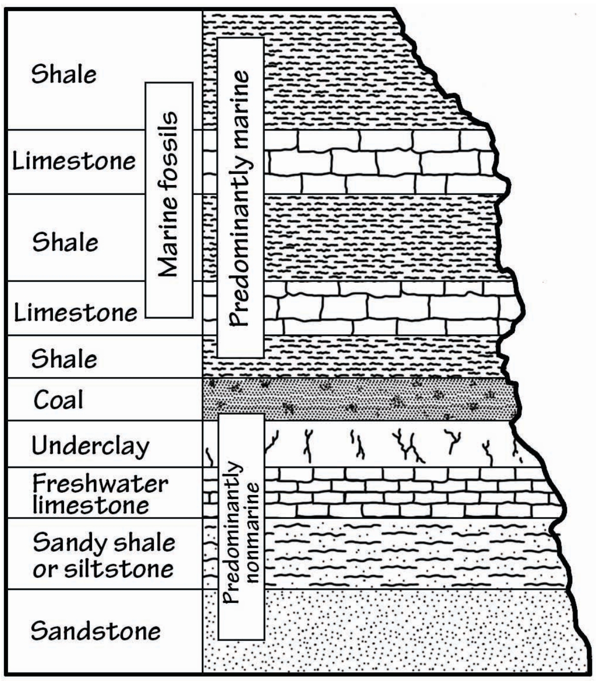


Figure 2.28: An example of a cyclothem.

By the Permian, the assembly of Pangaea was complete, and the Iapetus Ocean began to close. As the inland sea covering eastern North America retreated for the final time, the Southeast's climate became significantly drier, and the lush Pennsylvanian coal swamps were gradually replaced by red beds and **lacustrine** carbonates, typical deposits of drier climates. Some of these Permian-aged deposits are exposed at the surface in West Virginia.

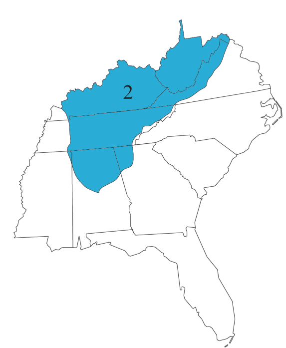
See Chapter 8: Climate to learn how changing climates through geologic time have influenced the environment.

In addition to rocks produced by physical Earth processes, some rocks in the Southeastern states have been influenced by objects of extraterrestrial origin. Geologists in the Southeast have found abundant evidence of **meteorites** striking the Earth in the past (*Figures 2.29 and 2.30*). Impact structures are characterized by a central, upraised area of jumbled rock, geologic disruption that decreases in intensity away from the center, and rings of concentric faults surrounding the area. The abundance of preserved impact structures through time and other evidence of meteoritic materials from sedimentary rocks (such as minerals "shocked" by the impact) makes it clear that meteorite impacts are a common occurrence throughout geologic time—including at the end of the **Mesozoic** era, when a meteorite impact was involved in the **extinction** of the **dinosaurs**.

Mesozoic • *a geologic time period that spans from 252 to 66 million years ago.*

extinction • *the end of species or other taxonomic groups, marked by death of the last living individual.*

dinosaur • *a member of a group of terrestrial reptiles with a common ancestor and thus certain anatomical similarities, including long ankle bones and erect limbs.*



Rocks

Region 2

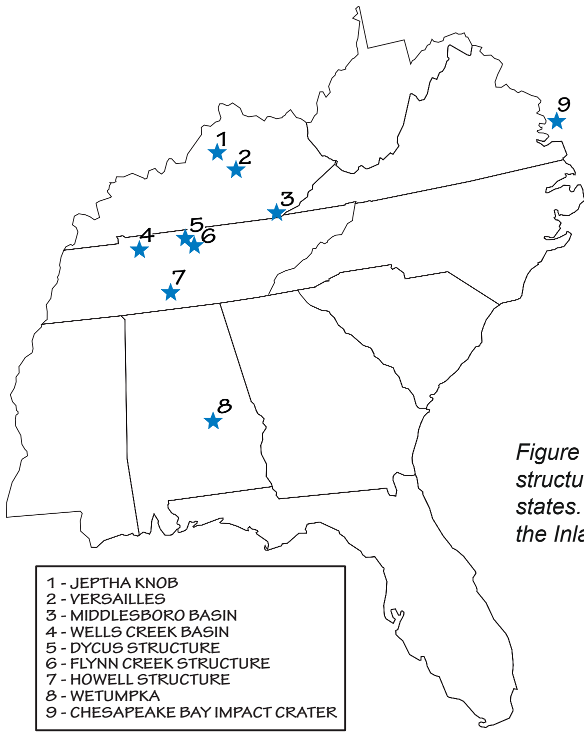


Figure 2.29: Known meteorite impact structures throughout the Southeastern states. Most of these structures are found in the Inland Basin.

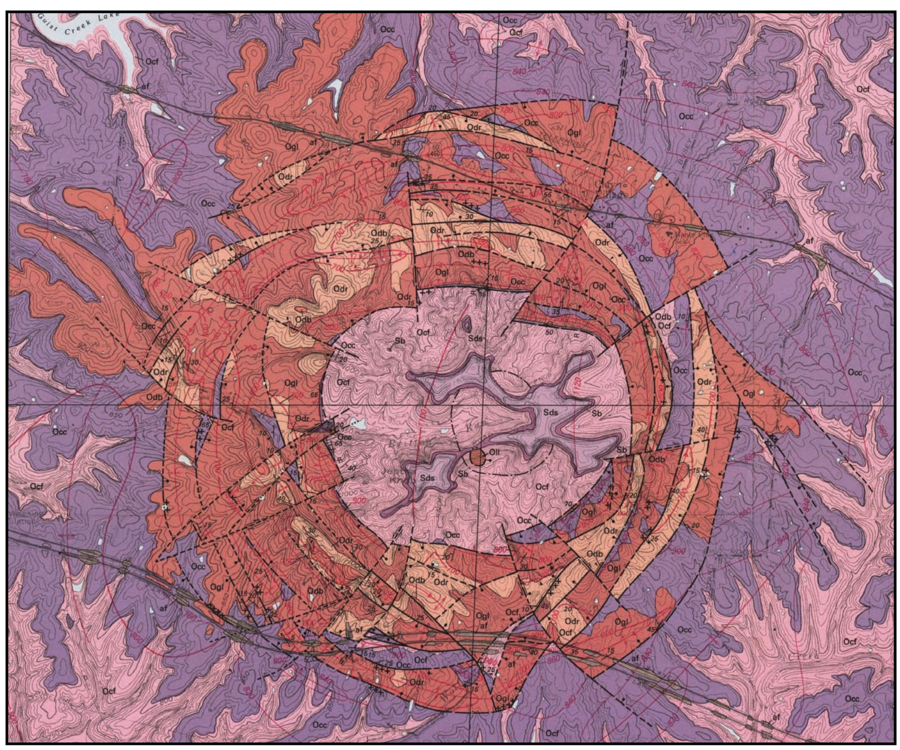
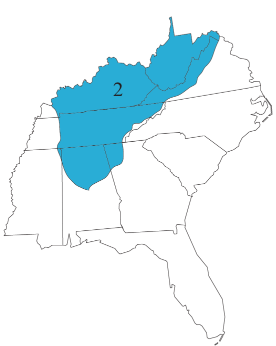


Figure 2.30: A geologic map of the Jeptha Knob impact structure in Shelby County, Kentucky, and associated fault lines. This structure was formed over 440 million years ago when a meteorite impact fractured the landscape and uplifted multiple fault blocks. As the highest point in the county, Jeptha Knob is now used as a location for cell and radio towers.



Rocks of the Coastal Plain
Region 3

After the breakup of Pangaea during the Mesozoic, the North American plate drifted away from the Mid-Atlantic Ridge. Decreased tectonic activity along the continent's eastern and southeastern edge led to the formation of a **passive continental margin**. The Coastal Plain extends along this margin, sweeping in a wide arc through Virginia, around the point of Florida, and up through the **Mississippi Embayment** and across Texas. The sediment and rock of the Coastal Plain is geologically very young, ranging in age from the **Cretaceous** to the present (*Figure 2.31*).

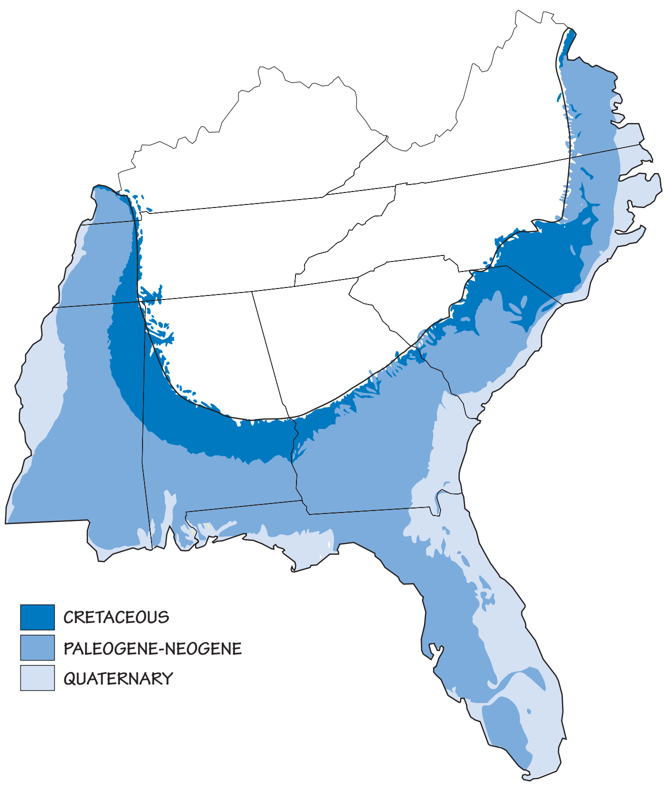


Figure 2.31: A generalized geologic map of the Coastal Plain.

The Coastal Plain's sediment and rock includes **gravel**, sand, silt, clay, **marl**, limestone, and uncommon layers of concentrated shell material called **coquina**. Much of the Coastal Plain's "rock" is actually unconsolidated sediment that has not had enough time to be lithified, cemented, or sufficiently compacted into hard rock. Coastal Plain sediment forms a wedge of gently dipping layers of sediment and sedimentary rock that thickens toward the Gulf of Mexico, overlying older bedrock (*Figure 2.32*). As the Atlantic Ocean and Gulf of Mexico widened following the breakup of Pangaea, the weight of millions of years of sediment accumulation in the basins caused coastal areas to subside, creating a gentle slope eastward toward the Atlantic and southward toward the Gulf

Region 3

passive margin • *a tectonically quiet continental edge where crustal collision or rifting is not occurring.*

Mississippi Embayment • *a topographically low-lying basin in the south-central United States, stretching from Illinois to Louisiana.*

Cretaceous • *a geologic time period spanning from 144 to 66 million years ago.*

gravel • *unconsolidated, semi-rounded rock fragments larger than 2 millimeters (0.08 inches) and smaller than 75 millimeters (3 inches).*

marl • *a fine-grained sedimentary rock consisting of clay minerals, calcite and/or aragonite, and silt.*

Region 3

Cenozoic • *the geologic time period spanning from 66 million years ago to the present.*

kaolinite • *a silicate clay mineral, also known as china clay.*

density • *a physical property of minerals, describing the mineral's mass per volume.*

of Mexico. At its innermost edge (bordering the Piedmont), the wedge of sediments is very thin, but under the continental shelf in the Atlantic Ocean, the wedge of sediment is as much as 4000 meters (13,100 feet) thick, and it reaches thicknesses of up to 12 kilometers (7.5 miles) in some places along the Gulf Coast. The Mississippi River Valley also subsided during the Mesozoic and **Cenozoic**, causing a similar tilting of Coastal Plain sediment toward the Mississippi Embayment. This tilting, although slight, exposes older Cretaceous units that would otherwise be buried by younger sediment.

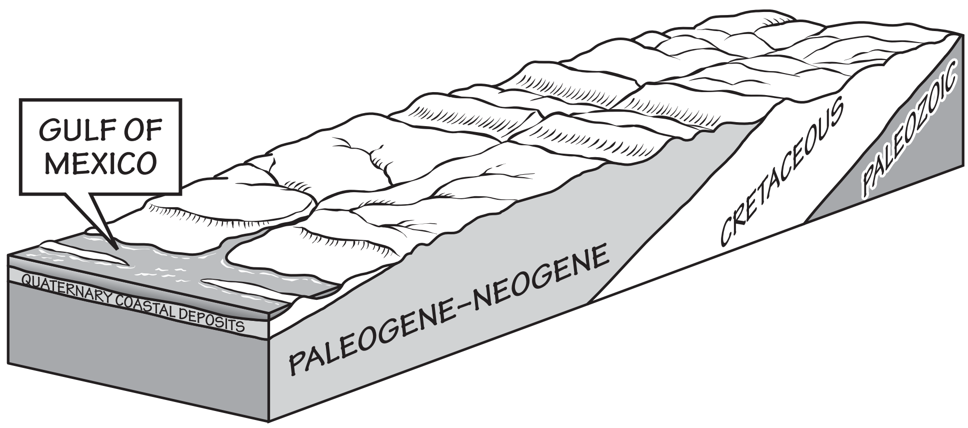


Figure 2.32: Millions of years of sediment accumulation in the Gulf of Mexico and Atlantic Ocean caused coastal areas to subside, creating a gentle slope toward the ocean.

The oldest sediment deposits exposed at the surface in the Coastal Plain are found along the region's inner edge and record the erosion of the Appalachian Mountains. As rivers transported sediment to the coast, successive layers of gravel, sand, silt, and clay fanned out onto the continental shelf. A variety of clays are found in the Cretaceous rocks of the Southeast, including **kaolinite**, a valuable economic resource that is mined in certain areas of the Southeast. Another type of clay, montmorillonite, has been interpreted as weathered volcanic ash that came from central Mississippi or the Rocky Mountains. Volcanic activity associated with the uplift of the Rockies could have generated ash that spread as far as the Southeastern states—but the Southeast has its own volcanic past, attested to by a set of igneous rocks and ash deposits found 900 meters (2900 feet) beneath Jackson, Mississippi. The uplifted terrain from the Jackson Volcano also formed an area of **dense** rock, the Jackson Dome, which is notable as an oil reservoir. Jackson Volcano and other related structures likely formed as the Gulf of Mexico widened and rifting generated significant volcanic activity. Volcanoes located along the rim of the modern Gulf Coast spewed ash that settled in layers at the surface; far below, the volcanoes' magmatic cores eventually cooled to form intrusive rock. Jackson, Mississippi is unique: no other US state capital or large city is situated on top of an extinct volcano!

Toward the end of the Cretaceous, global sea level was high, allowing the deposition of marine sediment across much of the Coastal Plain. Greensand, a green-colored sandstone that gets its color from the green mineral glauconite

(*Figure 2.33*), was deposited in these marine settings during the Cretaceous, **Paleogene**, and **Neogene**. (Since glauconite is associated with modern marine environments, its presence suggests to geologists that this sediment was deposited in the ocean.) Other clues to the marine origin of late Cretaceous sediment in the Southeast include thick deposits of **chalk**, a soft variety of limestone that forms from the buildup of microscopic plates (coccoliths) from single-celled algae. Chalk is common in Cretaceous deposits worldwide, and represents deeper ocean waters in which calcareous detritus settled to the bottom and accumulated as layers of calcium carbonate. White chalk deposits are often mixed with gray-green layers of marl, formed when clay particles settle to the bottom and are mixed with the layers of calcium carbonate. In Alabama and Mississippi, thick chalk and marl layers are found in an area known as the Black Belt, named for its nearly black, rich **topsoil** (*Figure 2.34*).

See Chapter 7: Soils to learn more about the Black Belt.

Paleogene • *the geologic time period extending from 66 to 23 million years ago.*

Neogene • *the geologic time period extending from 23 to 2.6 million years ago.*

chalk • *a soft, fine-grained, easily pulverized, white-to-grayish variety of limestone, composed of the shells of minute planktonic single-celled algae.*

topsoil • *the surface or upper layer of soil, as distinct from the subsoil, and usually containing organic matter.*

Figure 2.33: Late Cretaceous glauconitic sandstone, often called "greensand," exposed near Greenville, Alabama.

Although there are no Cretaceous rocks exposed at the surface in Florida, the carbonate sediment deposited during this period created the foundation of the modern Florida Platform. Following the breakup of Pangaea, the area that is now Florida gradually sank, allowing reef communities to flourish and build on top of each other while sea level slowly rose. Currents in the Gulf Trough (also called the Suwanee Strait), a channel that separated the Florida Platform from the mainland, swept away sediment eroded from the Appalachian Mountains and protected the corals and other organisms whose calcium carbonate skeletons formed Florida's modern foundation.

Region 3

rare earth elements *• a set of 17 heavy, lustrous elements with similar properties, some of which have technological applications.*

siliciclastic *• pertaining to rocks that are mostly or entirely made of silicon-bearing clastic grains weathered from silicate rocks.*

lignite *• a soft, brownish-black coal in which the alteration of plant matter has proceeded farther than in peat but not as far as in bituminous coal.*

Figure 2.34: The White Cliffs of Epes, an exposure of Cretaceous chalk along the Tombigbee River in Alabama.

Within the Atlantic and Gulf Coastal Plain, the Cretaceous-Paleogene (K-Pg) boundary is usually distinguished by a change in lithology. Paleogene sands or sandstones and dark gray marls and clays overlie white Cretaceous chalks and clays, and are visible at Moscow Landing along the Tombigbee River in Sumter County, Alabama; along the south valley wall of Lynn Creek in Noxubee County, Mississippi; and in Providence Canyon State Park in Stewart County, Georgia (*Figure 2.35*). Another common characteristic of the K-Pg boundary is the presence of a thin millimeter-scale layer of clay containing a number of **rare earth elements**, including iridium. Although it is present along the contact zone in many areas of the world, this boundary layer has yet to be documented in either the Gulf or Atlantic Coastal Plain.

During the early Paleogene, carbonate deposits (mainly limestone) dominated the Southeast Coastal Plain as far north as North Carolina. However, erosion of the Appalachian Mountains continued throughout the Paleogene and Neogene, resulting in a thick band of gravel, sand, silt, and clay that was in part collected by the Gulf Trough in northern Florida and deposited along the coastal plains of Georgia, the Carolinas, and Virginia. By the end of the Neogene, **siliciclastic** (non-carbonate) sediment deposits had replaced carbonates as the dominant sediment of the Coastal Plain, transforming the entire area into a peninsula dominated by silts, sands, and clays. Sea level fluctuations shifted shorelines, generating cycles of sand, silt, clay, **lignite**, and carbonate sediments (*Figure 2.36*). The Gulf Trough was gradually filled, and the Florida Platform was blanketed with a layer of siliciclastic Appalachian-derived sediment. With the buildup of sand, silt, and clay, the Florida peninsula began to emerge above sea level.

Figure 2.35: At Providence Canyon State Park in Georgia, the white clays of the Cretaceous Providence Formation are overlain by the red sandstones of the Paleogene Clayton Formation. The gorges that formed this spectacular canyon were created not by natural erosive processes but from poor soil management practices that led to extensive agricultural runoff during the 1800s.

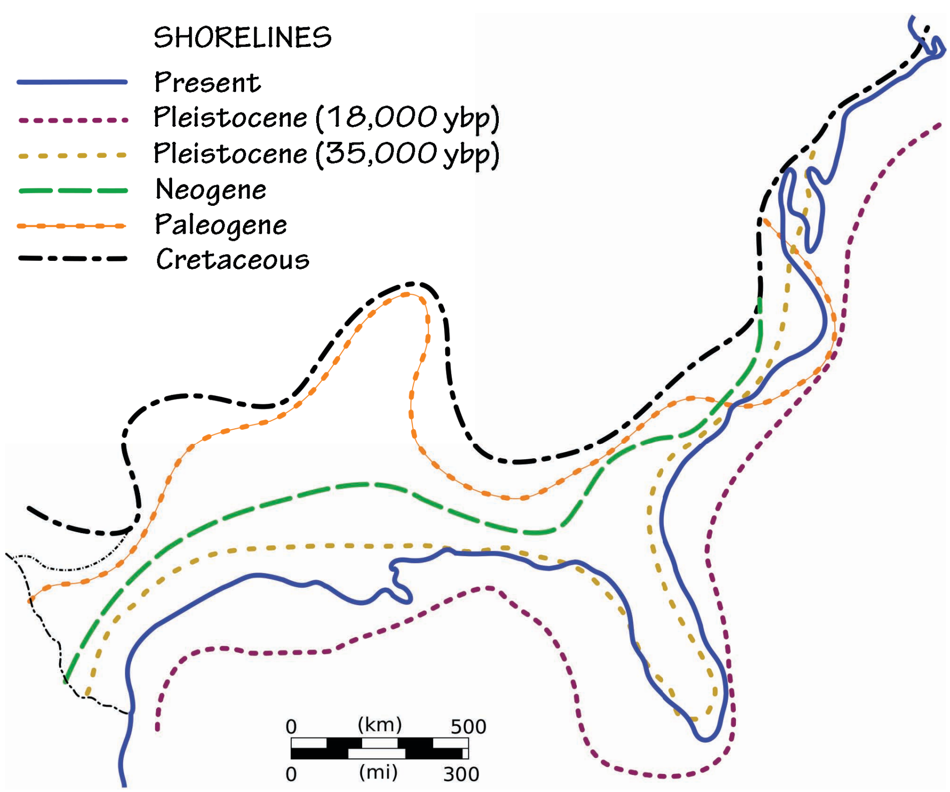


Figure 2.36: Shoreline positions along the Coastal Plain during the past 70 million years. (See TFG website for full-color version.)

Region 3

Quaternary • *a geologic time period that extends from 2.6 million years ago to the present.*

ice sheet • *a mass of glacial ice that covers part of a continent and has an area greater than 50,000 square kilometers (19,000 square miles).*

Pleistocene • *a subset of the Quaternary, lasting from 2.5 million to about 11,700 years ago.*

Deposition on the Florida Platform from about 25 million years ago to the present has consisted primarily of siliciclastic sediment, with the exception of the peninsula's southern tip. Carbonate sediment continues to build up on the seaward side of the Florida Keys today, thanks to a warm, subtropical climate and clear, shallow water that allows organisms with carbonate skeletons to thrive and grow. Due to the state's low relief, sea level fluctuations have affected Florida more dramatically than other parts of the Southeast, altering regional environments from shallow lagoons and tidal flats to deep waters and back again. In and after the Neogene, shell beds and fossiliferous sand and limestone were commonly deposited on the Florida Peninsula. When cemented together, these shell beds formed a rock known as coquina (*Figure 2.37*). Coquina layers are quite common in Florida's Neogene rocks, and are dominated by mollusk shells. The shelly rock was quarried and used as a construction material in Florida for over 400 years, and many of the state's historic buildings are made from this stone. Coquina was a favorite material for the building of military forts, as the rock was able to withstand cannon fire (*Figure 2.38*).

Figure 2.37: A chunk of fossiliferous limestone called coquina, from the Quaternary of Florida.

The **Quaternary** period is recorded in the youngest sediments of the Coastal Plain, and deposits from this time make up much of the sediment found immediately adjacent to modern estuaries, streams, floodplains, and creek beds throughout the Southeast. The **ice sheet** that repeatedly advanced southward over North America during the **Pleistocene** never made it to the Southeastern states, but the ice age indirectly left its mark on the area. As glaciers

See Chapter 8: Climate to learn about ancient and recent glaciations.

Region 3

Figure 2.38: The Castillo de San Marcos, a 17th century fort in St. Augustine, Florida, was constructed from coquina.

moved over the northern part of the continent, they scraped up the surface and pushed tons of sediment before them like bulldozers. When the climate warmed and ice sheets melted back, sea level rose and meltwater streaming off the retreating glaciers dumped gravel, sand, silt, and clay into streambeds. The Ohio River Valley, which borders much of the Southeast's northern edge, was formed by glacial meltwater. **Erratics**—boulders, cobbles, pebbles, gravel, and sand carried far from their origin by glacial melt—are also commonly found in the Southeastern states, as sediment from the melting ice was transported through the Ohio River in Kentucky, West Virginia, and down the Mississippi River Valley. The Chickasaw Bluffs adjacent to the Mississippi River formed from glacial sediment (including **rock flour** and **loess**) that was deposited in the Mississippi River Valley when the last ice sheet melted around 10,000 years ago (*Figure 2.39*). Thick, wind-blown deposits of glacial loess were eroded from the Mississippi River floodplain and cover large swaths of northwestern Alabama. Layers of loess also form the bluffs at Vicksburg, Mississippi, which are up to 24 meters (80 feet) thick in some places. The high ground provided by these bluffs made Vicksburg easily defensible through an extended siege during the Civil War.

At the southern rim of the Florida Platform lie the Florida Keys, a fringe of fossil reefs and associated sediment with living reefs located on the Keys' seaward side. The Florida Keys initially formed during the Pleistocene, when colonies of coral flourished along the edge of the Florida Platform. As sea level rose, the reefs grew upward, and when sea level fell, parts of the coral became exposed and died. Dead reefs became foundations for new coral growth, forming the

erratic • *a piece of rock that differs from the type of rock native to the area in which it rests, carried there by glaciers often over long distances.*

rock flour • *very fine sediments and clay resulting from the grinding action of glaciers.*

loess • *very fine grained, wind-blown sediment, usually rock flour left behind by the grinding action of flowing glaciers.*

exhumation • *the erosional uncovering or exposing of a geological feature that had been previously covered by deposited sediments.*

alluvium • *a layer of river-deposited sediment.*

Holocene • *the most recent portion of the Quaternary, beginning about 11,700 years ago and continuing to the present.*

bolide • *an extraterrestrial object of any composition that forms a large crater upon impact with the Earth.*

basement rocks • *the foundation that underlies the surface geology of an area, generally composed of igneous or metamorphic crystalline rock.*

Figure 2.39: A Chickasaw Bluff along the Mississippi River in Tipton County, Tennessee. These features, formed from Pleistocene loess, can be found along the Mississippi River from Hickman, Kentucky all the way to Baton Rouge, Louisiana.

thick (23–60 meter [75-200 foot]) Key Largo Limestone, which can be seen at the surface of the Florida Keys today. The Miami Limestone, a similar formation, underlies Miami and much of Florida's southern peninsula.

The Miami Limestone is composed of ooids, spheroidal particles that form when concentric layers of calcium carbonate are precipitated around a bit of shell or other material. Ooids commonly form in warm, shallow waters such as those of Florida or the Bahamas.

As in the Inland Basin, meteorite impacts have had an important effect on the geologic structures found within the Southeastern Coastal Plain. The Wetumpka impact structure, estimated to have formed 83 million years ago from the impact of an object 350 meters (1150 feet) in diameter, is a relatively well-preserved feature of Alabama's inner coastal plain. The impact energy from the Wetumpka event is estimated to have had an energy equivalent of 2600 megatons of TNT. Although this sounds large, there is no evidence that the impact had any major local biological effect. The impact structure, which is 7.6 kilometers (4.7 miles) across, has been filled with sediment since the late Cretaceous and is now in the process of being **exhumed** from Quaternary **alluvial** sedimentary fill. During the **Holocene**, the geology of Wetumpka's rim and crater floor has had a strong effect upon the drainage of local streams and the course of the Coosa River. The largest impact crater in the US is located off the coast of Virginia in Chesapeake Bay, and at 85 kilometers (53 miles) across is far larger than Wetumpka. The heat from the impact of a **bolide** three to five kilometers (two to three miles) in diameter vaporized land, fractured **basement rock** to depths of 8 kilometers (5 miles), and generated an enormous tsunami that could have reached as far as the Blue Ridge Mountains. Millions of tons of water, sediment, and melted rock were spattered across hundreds of kilometers (miles) of the East Coast. **Tektites,** natural glass formed from the melted rock, can be found in several areas of the US. In Georgia, tekites from the Chesapeake Bay event are called "georgiaites," and they have modest value as collectibles.

Look closely at the sand!

If you travel around the southeastern Coastal Plain and closely examine the sand at different beaches, you will notice incredible differences! Parts of the Southeast, especially the Gulf Coast, are known for their pure white sand, made almost entirely of quartz grains. Western Tennessee has "glass sand," which has a high silica content. Other beaches may be pink (indicating a high concentration of the mineral feldspar), have black specks (heavy minerals), or they may be white sands entirely composed of calcium carbonate shell material. A surprising number of organisms can sometimes be identified by closely studying the tiny shell pieces in this type of sand, including parts of corals, *bryozoans*, *echinoderms*, *shark* teeth, clams, and *snails*.

Why are there so many different types of sand? The answer lies in their origins. What rock was eroded to make up the sand, and for how long was it weathered? How much of the sand is shell material that grew on or near the beach? Sand eroded from granite highlands may still have grains of granite left in it, but if the sand is heavily weathered, the granite pieces will have broken down into their individual mineral components. Further erosion will entirely break down certain minerals, such as feldspar, into clays that are winnowed away, leaving only quartz and other resistant minerals behind. Weathering also changes the appearance of sand—for example, grains of dune sand that have been constantly moved around by the wind often have a polished, frosted surface.

Region 3

tektite • *gravel-sized glass formed when melted rock from the Earth's surface is ejected during meteorite impacts.*

bryozoan • *a marine or freshwater colonial invertebrate animal characterized by an encrusting or branching calcareous skeleton from which multiple individuals (zooids) extend from small pores to filter-feed using crowns of tentacles (lophophores).*

echinoderm • *a member of the Phylum Echinodermata, which includes starfish, sea urchins, and crinoids.*

shark • *a large fish characterized by a cartilaginous skeleton and five to seven gill slits on the side of the head.*

snail • *a marine, freshwater, or terrestrial invertebrate animal belonging to the class Gastropoda of the Phylum Mollusca*

> ***gem*** *• a mineral that has aesthetic value and is often cut and polished for use as an ornament.*

> ***amphibole*** *• a group of dark colored silicate minerals, or either igneous or metamorphic origin.*

> ***chalcedony*** *• a crystalline silicate mineral that is a microcrystalline variety of quartz.*

State Rocks, Minerals, and Gems

Alabama

State rock: marble

Also known as Sylacuaga marble, Alabama's marble has been called the "world's whitest" and has been used in sculpture and architecture throughout the United States for over 160 years. This metamorphic rock formed after limestone was put under immense pressure during the Taconic Orogeny.

State mineral: hematite

Hematite, also called red iron ore, crystallizes from the reaction of dissolved iron and oxygen. Roughly 375 million tons of hematite were mined in central and eastern Alabama between 1840 and 1975.

State **gem**: star blue quartz

Although quartz is a common silicate mineral, star blue quartz has an uncommon color derived from the presence of **amphibole** within the crystal structure. This stone occasionally exhibits asterism, or the reflection of a star-like shape when polished.

Florida

Florida has no state mineral.

State rock: agatized coral

Although technically a fossil, agatized coral became Florida's state "rock" in 1979. These corals are unique formations found in the Econfina and Suwanne riverbeds as well as Tampa Bay. They formed over a period of 20–30 million years as silica in the ocean water replaced the coral polyps with **chalcedony**.

State gem: moonstone

Moonstone, a variety of feldspar that refracts light, is not actually found in Florida (or on the moon for that matter)! Moonstone was selected as Florida's state gem because the moon-landing missions were launched and controlled from the Kennedy Space Center in Cape Canaveral.

Georgia

Georgia has no state rock.

State mineral: staurolite

Staurolite is a dark crystal, usually red or black, that often forms in a twinned or cross-shaped formation. Staurolite crystals are sometimes called "fairy stones" or "fairy crosses," and are often kept as good luck charms.

State gem: quartz

Quartz is the second most abundant mineral in Earth's crust and comes in many different varieties including amethyst, citrine, and clear quartz. Quartzes of many different colors are commonly found throughout Georgia.

Region 3

Kentucky

State rock: Kentucky **agate**
Agate is a fine-grained and layered form of quartz, often having bright colors exhibited in patterns and bands. Kentucky agates are Mississippian in age and come in a variety of beautiful colors including red, black, gray, and yellow.

State mineral: coal
Although the coal is not technically a mineral, it is legally considered a mineral resource thanks to its use as a fossil fuel. Kentucky is one of the top producers of coal in the US, mining 150–160 million tons annually.

State gem: freshwater pearl
While most gemstones are minerals, pearls are formed when an irritant (usually a sand grain) makes its way inside the body of a **bivalve** mollusk such as a mussel. The animal secretes a lining of calcium carbonate called nacre around the irritant to protect itself, forming a pearl. Due to overharvesting, pollution, and habitat loss, Kentucky's natural pearl-producing mussels are at risk.

Mississippi

Mississippi has no state mineral or gem.

State rock: petrified wood
Petrified wood is designated as Mississippi's state rock, although it is actually a type of fossil. At the Mississippi Petrified Forest in Flora, Mississippi, a large number of logs became fossilized after they washed down an ancient river channel and were buried by sediment, preventing them from decaying. Eventually, the organic material was replaced with silicate minerals.

North Carolina

State rock: granite
North Carolina contains abundant quantities of this igneous rock, which is mined for a number of construction purposes. The state is home to the world's largest open-faced granite quarry, near Mt. Airy in Surry County.

State mineral: gold
The North Carolina gold rush began in 1799 when an 8-kilogram (17-pound) nugget was found by a boy named Conrad Reed. The state's gold deposits formed **hydrothermally** during the process of mountain building, when pressurized fluids and gases were ejected from magma and interacted with heated water to deposit gold.

State gem: emerald
Emerald is a variety of **beryl**, valued for its green hue. The largest emerald ever found in North America was found in Statesville, North Carolina in 2003 and weighed 310 carats (62 grams [2 ounces]).

agate • *a crystalline silicate rock with a colorful banded pattern. It is a variety of chalcedony.*

bivalve • *a marine or fresh-water invertebrate animal characterized by right and left calcareous shells (valves) joined by a hinge.*

hydrothermal solution • *hot, mineral-rich water moving through rocks.*

beryl • *a white, blue, yellow, green, or pink mineral, found in coarse granites and igneous rocks.*

Rocks

State Rocks

bituminous coal • *a relatively soft coal containing a tarlike substance called bitumen, which is usually formed as a result of high pressure on lignite.*

South Carolina
South Carolina has no state mineral.

State rock: blue granite
Blue granite is unique to the South Carolina's Midlands and Piedmont, and its blue color is most likely due to the presence of certain potassium feldspars in the rock. South Carolina is one of the nation's top producers of granite for construction purposes.

State gem: amethyst
This type of quartz crystal is typically found in elongated clusters, and can range from a pale lilac color to a deep purple based on iron content. One of the largest amethyst clusters ever found, weighing in at 53 kilograms (118 pounds), was found at the Diamond Hill Quartz Prospect near Antreville, South Carolina in 2008.

Tennessee
State rock: limestone
Limestone is abundant throughout central Tennessee, and the state even has a town named Limestone, said to be the birthplace of Davy Crockett. Tennessee limestone has historically been used as a building material and was also used in the process of smelting iron ore.

State mineral: agate
Tennessee agate is also known as "painted rock" thanks to its wide variety of colors and patterns. The silicate stone is most commonly clear or slightly milky, with swirling bands of red, yellow, and brown.

State gem: Tennessee pearl
The American Pearl Company, located in Camden and Nashville, Tennessee, is the only producer of farmed freshwater pearls in the United States, making Tennessee the leading state for pearl production since the 1960s.

Virginia
Virginia has no state rocks, minerals, or gemstones.

West Virginia
West Virginia has no state mineral.

State rock: **bituminous coal**
West Virginia is the nation's second largest producer of coal, specifically bituminous coal, a medium-grade form. The state adopted bituminous coal as its official rock in 2009 thanks to the fossil fuel's central role in the state's industrial economy.

State gem: *Lithostrotionella* (chalcedony)
Lithostrotionella is not a true gemstone, but rather a silicified fossil of Mississippian coral that has been preserved as chalcedony. It can be found in Greenbrier and Pocahontas counties, and is prized for its use in jewelry.

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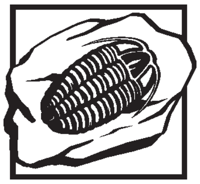


Chapter 3: Fossils of the Southeastern US

Fossils (from the Latin word *fossilis*, meaning "dug up") are the remains or traces of organisms that lived in the geologic past (older than the last 10,000 years), now preserved in the Earth's **crust**. Most organisms never become fossils, but instead decompose after death, and any hard parts are broken into tiny fragments. In order to fossilize, an organism must be buried quickly before it is destroyed by **weathering**, decomposed, or eaten by other organisms. This is why fossils are found almost exclusively in sediment and **sedimentary rocks**. **Igneous rocks**, which form from cooling **magma** or **lava**, and **metamorphic rocks**, which have been altered by **heat** and pressure, are unlikely to contain fossils (but may, under special circumstances). Different fossils are found in different regions because of the presence of rocks deposited at different times and in a variety of environments. Since rapid burial in sediment is important for the formation of fossils, many fossils are from marine environments, where sediments are more likely to accumulate.

Fossils come in many types. Those that consist of an actual part of an organism, such as a bone, shell, or leaf, are known as **body fossils**; those that record the actions of organisms, such as footprints and burrows, are called **trace fossils**. Body fossils may be preserved in a number of ways. These include preservation of the original **mineral** skeleton of an organism, mineral **replacement** (chemical replacement of the material making up a shell by a more

Lagerstätten

The "soft" tissues of an organism, such as skin, muscles, and internal organs, are typically not preserved as fossils. Exceptions to this rule occur when conditions favor rapid burial and mineralization or very slow decay. The absence of oxygen and limited disruption of the sediment by burrowing are both important for limiting decay in those deposits where soft tissues are preserved. The Southeastern states contain numerous examples of such exceptional preservation, also called Lagerstätten, including the mid-Cambrian Conasauga Formation of northwestern Georgia and the Triassic-Jurassic insect fossil beds in Virginia's Culpepper Rift Basin.

crust • *the uppermost, rigid outer layer of the Earth.*

weathering • *the breakdown of rocks by physical or chemical means.*

sedimentary rock • *rock formed through the accumulation and consolidation of grains of broken rock, crystals, skeletal fragments, and organic matter.*

magma • *molten rock located below the surface of the Earth.*

lava • *molten rock located on the Earth's surface.*

heat • *a form of energy transferred from one body to another as a result of a difference in temperature or a change in phase.*

mineral • *a naturally occurring solid with a specific chemical composition and crystalline structure.*

CHAPTER AUTHOR

Warren D. Allmon

3

Fossils

Overview

silt • *fine granular sediment most commonly composed of quartz and feldspar crystals.*

filter feeder • *an animal that feeds by passing water through a filtering structure that traps food.*

intertidal • *areas that are above water during low tide and below water during high tide.*

crystal form • *a physical property of minerals, describing the shape of the mineral's crystal structure.*

Discovering Ancient Environments

The kinds of animals and plants living in a particular place depend on the local environment. The fossil record preserves not only fossil organisms, but also evidence of what their environments were like. By studying the geological and biological information recorded in a rock that contains a fossil, scientists can determine some aspects of the paleoenvironment.

***Grain size and composition* of the rock can tell us what type of sediment surface the animal lived on, what the water flow was like, and whether the sediment was transported in a current. Grain size also tells us about the clarity of the water. Fine-grained rocks such as shales are made of tiny particles of *silt* or clay that easily remain suspended in water. Thus, a fossil found in shale might have lived in muddy or very quiet water. *Filter-feeding* organisms, such as clams or corals, are not usually found in muddy water because the suspended sediment can clog their filters.**

***Sedimentary structures*, such as asymmetrical ripples and cross-beds, can indicate that the organism lived in moving water. Mud cracks or symmetrical ripples are characteristic of shoreline or *intertidal* environments.**

***Broken shells* or *concentrated layers of shells* may indicate transportation and accumulation by waves or currents.**

***Color of the rock* may indicate the amount of oxygen in the water. If there is not enough oxygen in the water, organic material (carbon) in sediments will not decompose, and the rock formed will be dark gray or black in color.**

stable mineral), **recrystallization** (replacement by a different **crystal form** of the same chemical compound), **permineralization** (filling of empty spaces in a bone or shell by minerals), and molds and casts, which show impressions of the exterior or interior of a shell. **Chemical fossils** are chemicals produced by an organism that leave behind an identifiable trace in the geologic record, and it is these fossils that provide some of the oldest evidence for life on Earth.

Fossils 3

Overview

Paleontologists use fossils as a record of the history of life. They tell us that an incredible multitude of organisms lived prior to the species that we see on Earth today; that most species that ever lived have become extinct; and that living things have changed through evolution over time, from one species into another, and adapted to changing environments. Fossilized organisms are also extremely useful in understanding the ancient environment that existed when they were alive. The study of the relationships of fossil organisms to one another and their environment is called **paleoecology**.

Fossils are the most important tool for dating the rocks in which they are preserved. Because species only exist for a certain amount of time before going **extinct**, their fossils only occur in rocks of a certain age. The relative age of such fossils is determined by their order in the stacks of layered rocks that make up the **stratigraphic** record (older rocks are on the bottom and younger rocks on the top—a principle called **superposition**). Such fossils are known as **index fossils.** The most useful index fossils are abundant, widely distributed, easy to recognize, and occur only during a narrow time span. This use of fossils to determine relative age in geology is called **biostratigraphy**. The **geologic time scale** is in part based on sequences of fossils correlated from around the world.

Some of the most useful index fossils are hard-shelled organisms that were once part of the marine plankton.

Ancient Biodiversity

Since life began on Earth more than 3.7 billion years ago, it has continuously grown more abundant and diverse. It wasn't until the beginning of the **Cambrian** period, around 541 million years ago, that *complex life*—living things with cells that are differentiated for different tasks—became predominant. This event at the beginning of the Cambrian, called the Cambrian Explosion, resulted in the emergence of most major animal phyla. The diversity of life has generally increased through time since then. Measurements of the number of different kinds of organisms—for example, estimating the number of species alive at a given time—attempt to describe Earth's **biodiversity**. With a few exceptions, the rate at which new species evolve is significantly greater than the rate of extinction.

Most species have a lifespan of several million years; rarely do species exist longer than 10 million years. The extinction of a species is a normal event in the history of life. There are, however, intervals of time during which extinction rates are unusually high, in some cases at a rate of 10 or 100 times the normal pace. These intervals are known as **mass extinctions**. There were five particularly devastating mass extinctions in geologic history (*Figure 3.1*), and these specific events have helped to shape life through time. Unfortunately, this is not just a phenomenon of the past—it is estimated that the extinction rate on Earth right now may be as much as 1000 times higher than normal, due mostly to human activity, and that we are currently experiencing a sixth mass extinction event.

paleoecology • *the study of the relationships of fossil organisms to one another and their environment.*

extinction • *the end of species or other taxonomic groups, marked by death of the last living individual.*

stratigraphy • *the branch of geology specifically concerned with the arrangement and age of rock units.*

geologic time scale • *a standard timeline used to describe the age of rocks and fossils, and the events that formed them.*

Cambrian • *a geologic time period lasting from 541 to 485 million years ago.*

biodiversity • *the number of kinds of organisms at any given time and place.*

mass extinction • *the extinction of a large percentage of the Earth's species over a relatively short span of geologic time.*

3 Fossils

Overview

erosion • *the transport of weathered materials.*

trilobite • *an extinct marine invertebrate animal characterized by a three-part body and a chitinous exoskeleton divided longitudinally into three lobes.*

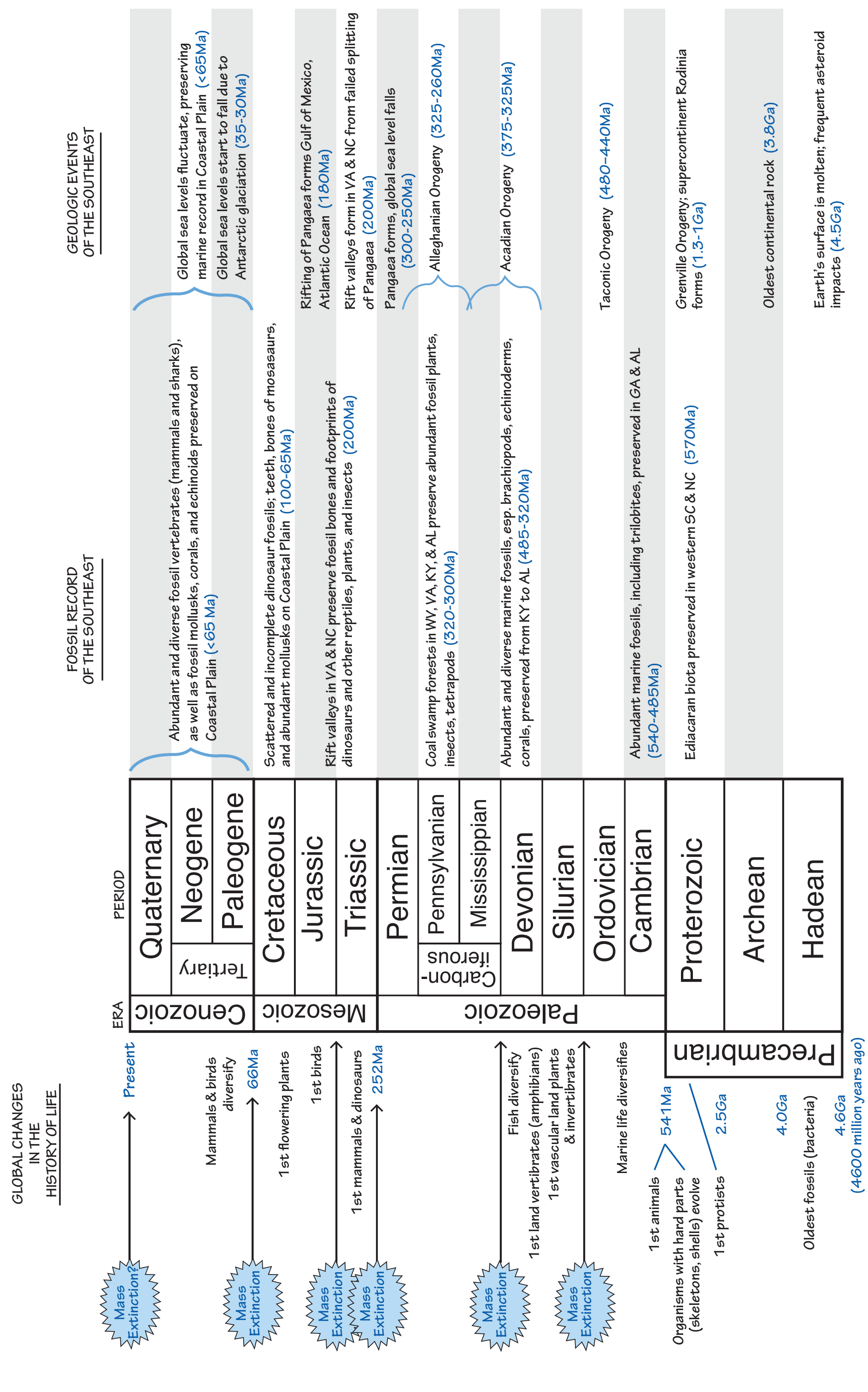


Figure 3.1: The history of life in relation to global and regional geological events and the fossil record of the Southeastern US (Time scale is not to scale).

Fossils 3

Fossils of the Southeastern US

The Southeast contains layers of sedimentary rock that preserve a tremendous variety of fossils and provide glimpses of what life was like over the last 560 million years. Fossils can be found in nearly every part of the Southeast, representing most major categories of organisms and most periods of geologic time. The history of life in the Southeast has been pieced together from the fossil record in many different areas, and from many different layers of rocks in these areas. Particular fossil organisms lived only in certain environments, and these changing environments did not exist continuously through time, nor were they all necessarily preserved in the rock record. Nowhere in the Southeast (or anywhere) is a complete record of rock from every period preserved. Not all sediment ends up as rock, and likewise, rock that formed long ago may have been **eroded** away. Not all organisms are preserved as fossils, and rocks that have contained fossils have not necessarily been preserved, or they may still be buried well below the current surface of the Earth, out of sight from paleontologists.

In the remainder of this chapter, we will highlight the major types of fossils present in most of the geologic periods represented by rocks in each state. The references at the end of the chapter should be consulted for details, especially for identifying particular fossils you might find.

Fossils of the Blue Ridge and Piedmont

Region 1

The rocks of the Blue Ridge and Piedmont are largely metamorphic and igneous, although many of them were initially sedimentary and may have contained fossils. Remarkably, a few fossils managed to escape the destructive heat and pressure of metamorphism. The oldest known fossils in the Southeast come from Stanly County in North Carolina, where in the early 1970s, a man found what looked like a **trilobite** in one of the rocks he was using to build a chimney. It turned out to be not a trilobite, but a fossil from the latest interval of the **Proterozoic**—part of what is called the Ediacara **biota** (*Figure 3.2*), a world-wide assemblage of fossils generally accepted as among the oldest known animals in the fossil record. A small number of additional Ediacaran-type fossils have been found in similar rocks in Stanly County. All of these rocks appear to date to between 542 and 556 Ma, putting them just before the Cambrian Explosion, making these fossils among the youngest representatives of the Ediacara biota in the world.

Cambrian rocks are not widespread in the Southeast (as they are, for example, in parts of the Western US), but some Cambrian sediments exposed in the southern Appalachians do contain well-preserved fossils. For example, **archaeocyathids** are found in metamorphosed early Cambrian **carbonate rocks** (**marbles**) in the Talladega Slate Belt of northeastern Alabama and northwest Georgia. Several species of middle Cambrian trilobites occur in rocks that are part of the Carolina Slate Belt. For example, trilobites from the Asbill Pond Formation near Batesburg (Lexington County), South Carolina (*Figure 3.3*) are similar to

Region 1

Proterozoic • *a geologic time interval that extends from 2.5 billion to 541 million years ago.*

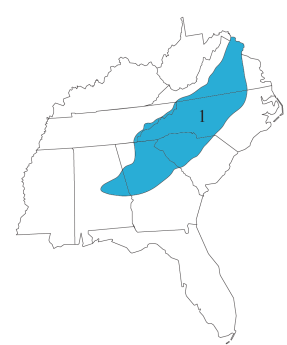
biota • *the organisms living in a given region, including plants, animals, fungi, protists, and bacteria.*

archaeocyathid • *a vase-shaped organism with a carbonate skeleton, generally believed to be a sponge.*

carbonate rocks • *rocks formed by accumulation of calcium carbonate, often made of the skeletons of aquatic organisms.*

marble • *a metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite.*

Baltica • *a late-Proterozoic, early-Paleozoic continent that included ancient Europe.*



3 Fossils

Region 1

terrane • *a piece of crustal material that has broken off from its parent continent and become attached to another plate.*

Paleozoic • *a geologic time interval that extends from 541 to 252 million years ago.*

Triassic • *a geologic time period that spans from 252 to 201 million years ago.*

Jurassic • *the geologic time period lasting from 201 to 145 million years ago.*

rift basin • *a topographic depression caused by subsidence within a rift.*

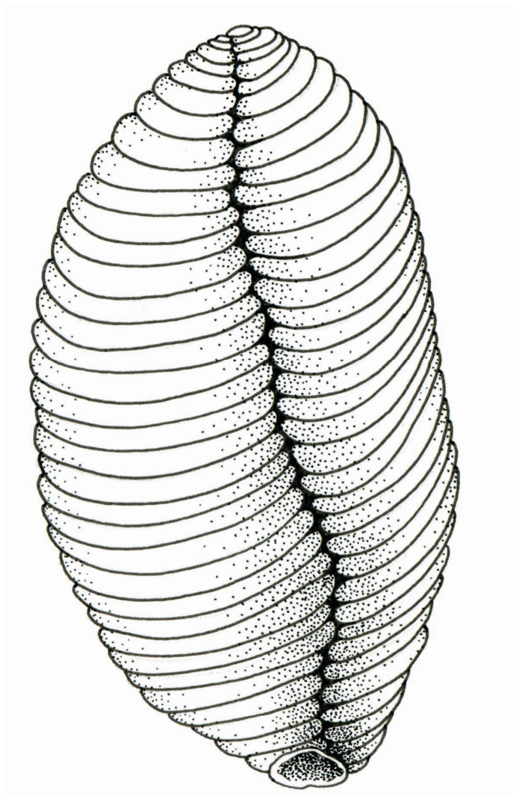


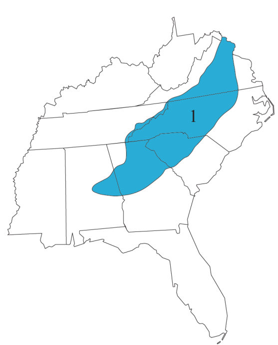
Figure 3.2: Fossil "frond" assigned to the Ediacaran organism Pteridinium*, late Precambrian, Stanly County, North Carolina. Approximately 9 centimeters (3.5 inches) long.*

trilobites from ancient paleocontinents that geologists call Armorica and **Baltica** (modern western and central Europe), but bear little similarity to the fossils of Laurentia (modern North America and western Europe). This peculiar fossil distribution is compatible with the Carolina Slate Belt's history as an exotic **terrane** that was added to North America during the early to middle **Paleozoic**. Almost all younger Paleozoic rocks in the Piedmont are metamorphic, and fossils are uncommon in them. In some places, such as Buckingham County, Virginia, fossils are found that were deformed by the tectonic forces of mountain-building long after they had been buried (*Figure 3.4*).

See Chapter 2: Rocks to learn more about the Carolina Slate Belt and other metamorphosed rocks in the Blue Ridge.

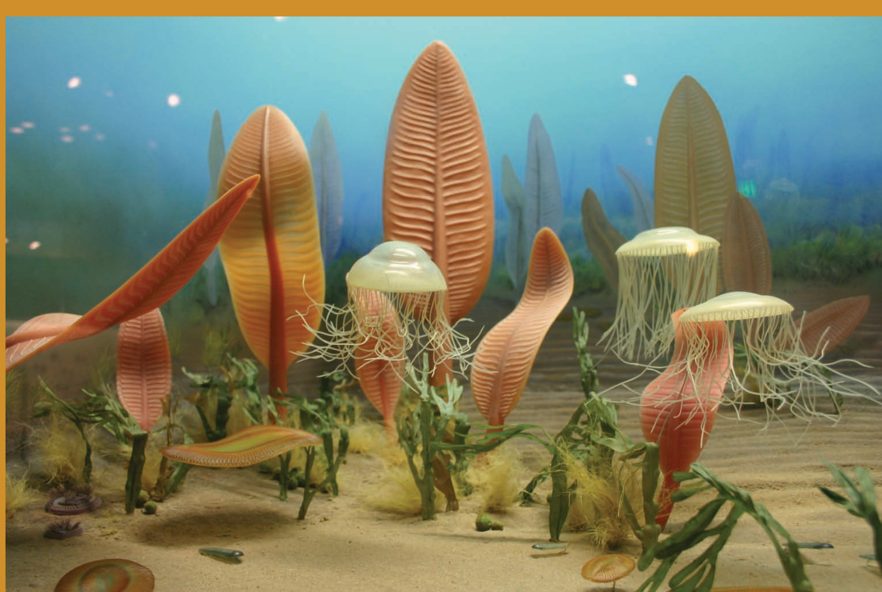
The **Triassic-Jurassic rift basin** rocks of the Piedmont formed after the Paleozoic **orogenies** had ended and the Atlantic Ocean began to widen. Lakes were common in these basins. Sediments deposited in and around the lakes—part of what geologists call the **Newark Supergroup**—contain fossils that record freshwater environments as well as terrestrial habitats along lake margins. The most common fossils are fishes, plant remains, and the footprints (trace fossils) of reptiles and amphibians.

See Chapter 1: Geologic History to learn about the formation of rift basins in the Mesozoic.



Ediacara: a Fossil Mystery

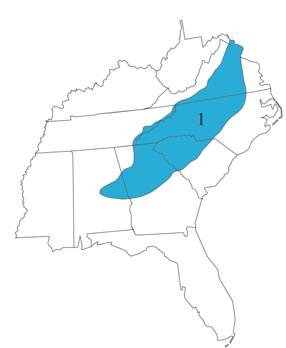
The Ediacaran biota is an assemblage of fossils, first described from southern Australia and subsequently worldwide, that dates to just before the beginning of the Cambrian (578–542 million years ago). Although the evolutionary affinities of the Ediacara organisms have been controversial, it is widely accepted that they include some of the earliest-known fossil animals. Ediacara fossils include a range of forms, including enigmatic centimeter-to-meter-long fronds, disks, and other shapes, as well as some that generally resemble modern animal groups. All appear to have been soft-bodied (i.e., lacking mineralized skeletons). None show evidence of appendages or sensory structures, and most show no sign of feeding, digestive, or locomotory structures. Scientists do not know whether they are all related to each other, or represent several branches of the evolutionary tree. Nevertheless, the Ediacaran biota is an extremely important piece of the story of how and when complex animal life evolved during the late Precambrian and Cambrian Explosion. It is therefore especially noteworthy that the Southeast has produced Ediacaran fossils.



A diorama depicting life in the Ediacaran sea.

orogeny • *a mountain-building event generally caused by colliding plates and compression of the edge of the continents.*

Newark Supergroup • *a sequence of nonmarine sedimentary rocks that accumulated along what is now eastern North America in the late Triassic to early Jurassic.*



3 Fossils

Region 1

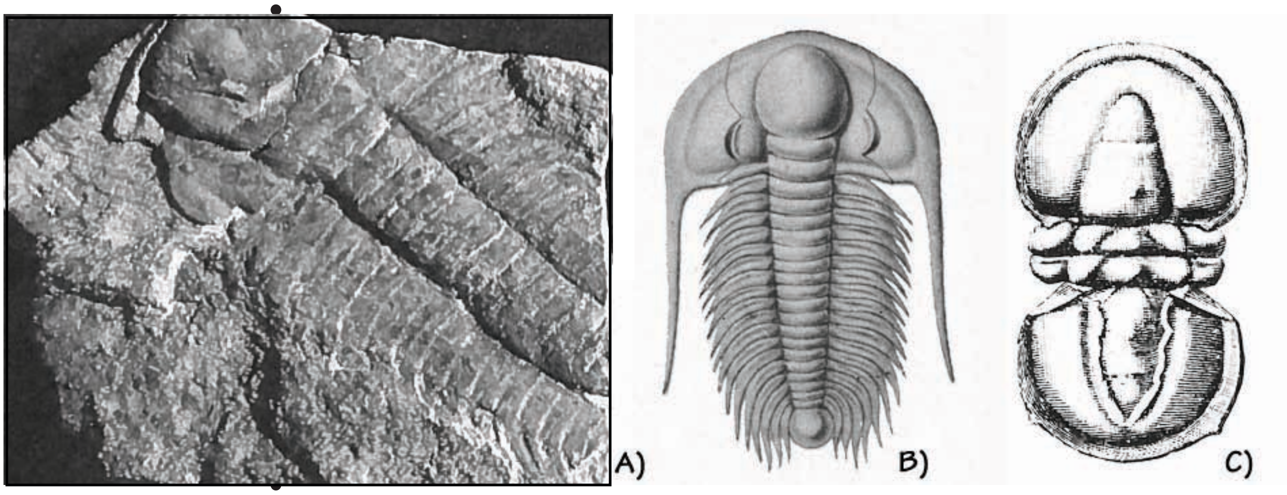
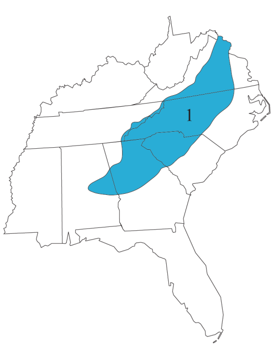


Figure 3.3: Carolina Slate Belt trilobites. A) Paradoxides (Acadoparadoxides) grandoculus*, from early Cambrian rocks in South Carolina; reconstructed length of the complete trilobite is approximately 7–8 centimeters (2.7–3.1 inches) long. B) For comparison, the very similar* Paradoxides harlani*, from early Cambrian rocks of eastern Massachusetts, approximately 30 centimeters (12 inches) long. C) A tiny, eyeless agnostid trilobite, similar to those found in the early Cambrian of South Carolina, approximately 0.8 centimeters (0.3 inches) long.*

Figure 3.4: A Cambrian trilobite deformed by mountain building.



Region 1

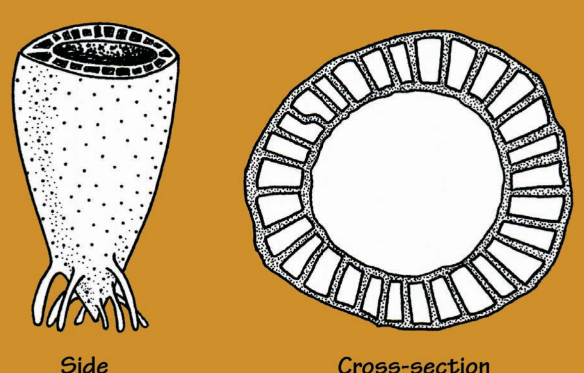
Permian • the geologic time period lasting from 299 to 252 million years ago.

Trilobites

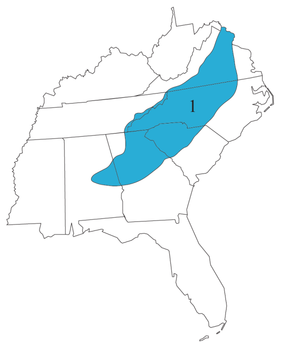
Trilobites are iconic Paleozoic fossils; they were more common in the Cambrian and Ordovician than in later periods, and became extinct at the end of the *Permian*. They were marine arthropods, and had well-defined head, tail, and thoracic (leg-bearing) segments. Most had large compound eyes, often with lenses that are visible to the naked eye. In life, they had antennae like many other arthropods, but since these were not mineralized, they only fossilize under exceptional circumstances. Many could roll up for protection, and several species also had large spines.

Archaeocyathids

Archaeocyathids were the first important animal reef builders, originating in the early Cambrian. These vase-shaped organisms had carbonate skeletons and are generally believed to be sponges. They went extinct in the late Cambrian, but were very diverse. Archeocyathids are often easiest to recognize in limestones by their distinctive cross-sections.



Archaeocyathids are found in lower Cambrian rocks in the Talladega Slate Belt of northeastern Alabama and northwest Georgia. Their vase-shaped calcite skeletons commonly reached lengths of 5 to 20 centimeters (2 to 8 inches).



3

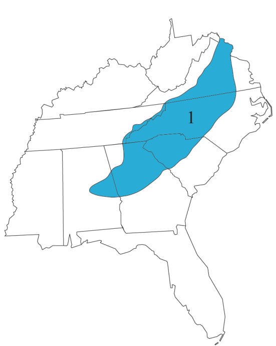
Fossils

Region 1

__rift__ • a break or crack in the crust that can be caused by tensional stress as a landmass breaks apart into separate plates.

__dinosaur__ • a member of a group of terrestrial reptiles with a common ancestor and thus certain anatomical similarities, including long ankle bones and erect limbs.

__trackway__ • a set of impressions in soft sediment, usually a set of footprints, left by an animal.



Trace fossils are marks left by the behavior of organisms on sediment or other substrate. Traces include burrows, footprints, tooth marks, holes drilled in shells by predators, and the tunnels left by plant roots. Because paleontologists can almost never be sure of exactly which kind of organism made a particular trace, there is a completely separate system of naming trace fossils that does not refer to organisms represented by body fossils. Despite this difficulty, trace fossils are widely used to help reconstruct ancient environments. The Triassic-Jurassic **rift** basins of the East Coast have been renowned for their **dinosaur trackways** since the early nineteenth century, and the basins of North Carolina and Virginia do not disappoint in this respect (*Figure 3.5*). The tracks and skeletal fossils of other reptiles such as crocodilians are also well documented from other sites, including the famous Solite Quarry near the Virginia-North Carolina state line (*Figure 3.6*). The rift valley lakes also contained abundant fish, as we know from numerous fossils found in rocks that formed from lake-bottom sediments. Many of these fossils are from an extinct group armored with thick bony scales (*Figure 3.7*).

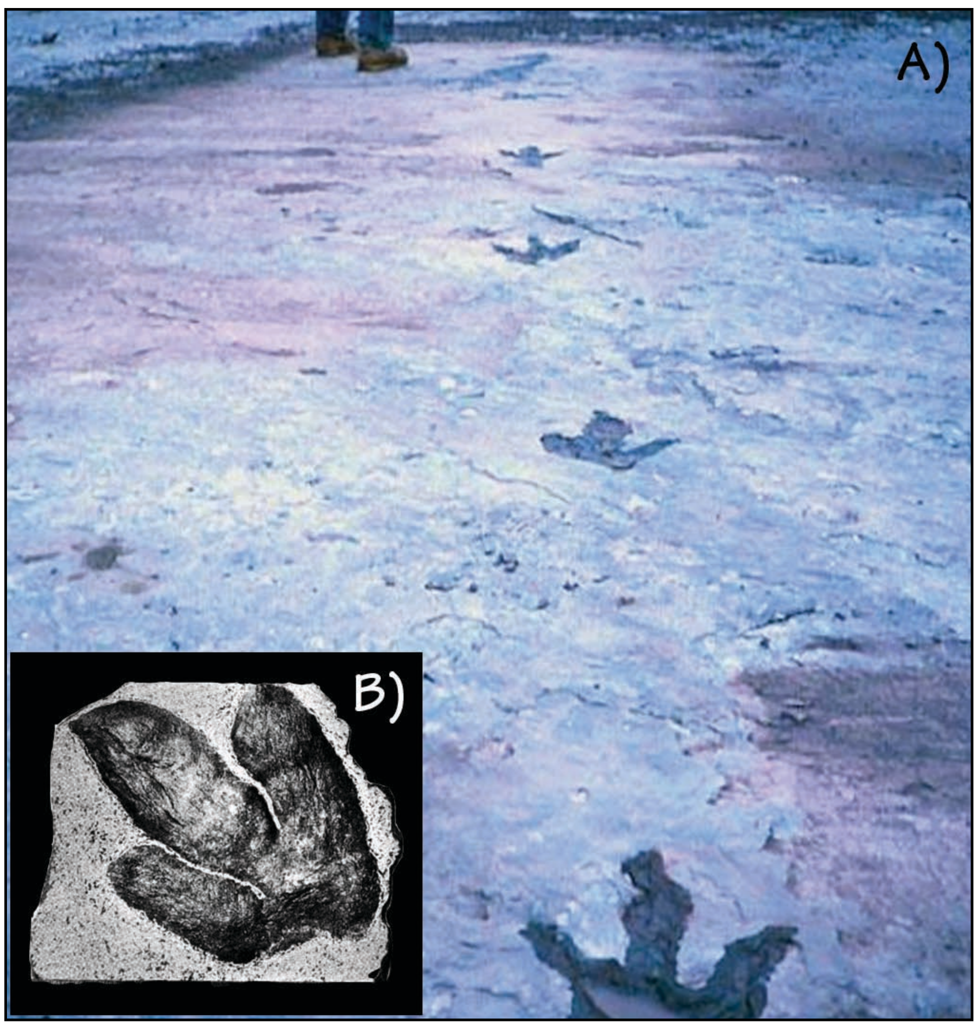


Figure 3.5: Late Triassic dinosaur footprints from the Culpepper Basin of Virginia. A) Trackway. B) Single track, from near Aldie, Loudon County, approximately 30 centimeters (1 foot) long.

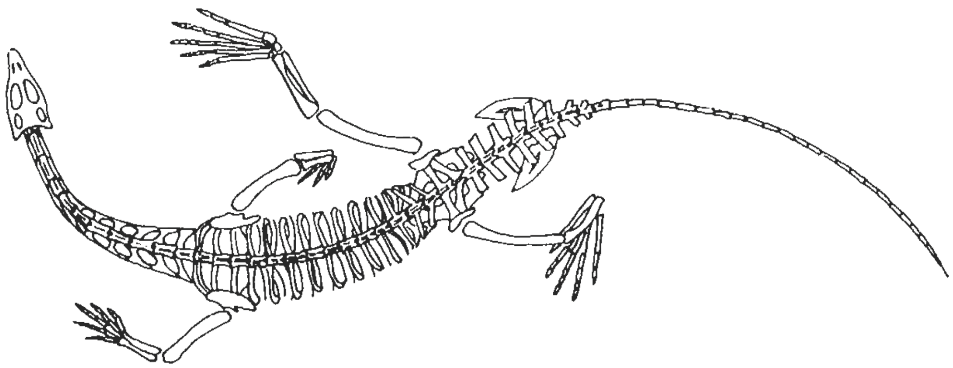


Figure 3.6: Skeleton of the small, late Triassic reptile Tanytrachelos. *Animal was approximately 13 centimeters (5 inches) long.*

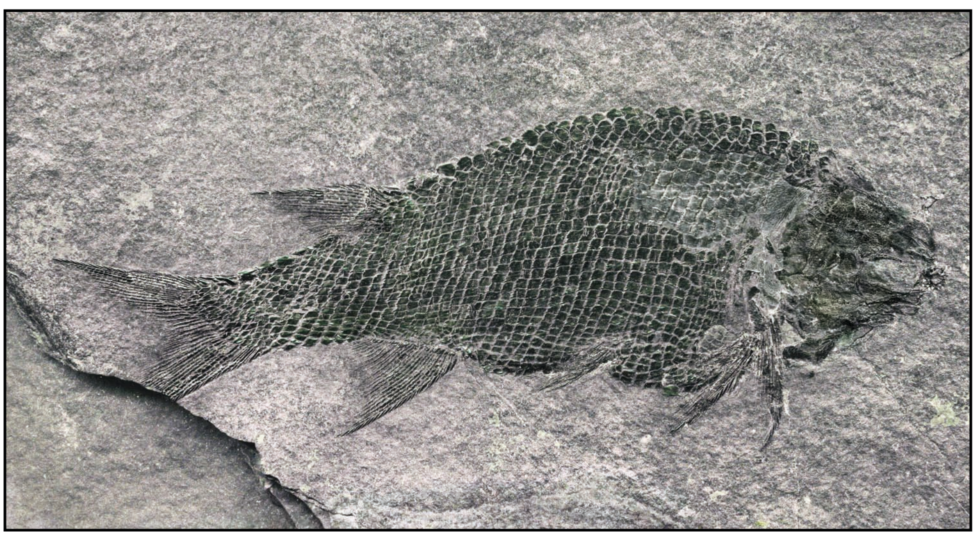


Figure 3.7: Triassic fossil fish, Redfieldius *sp., from the Culpepper Basin in Virginia, approximately 13 centimeters (5.1 inches) long.*

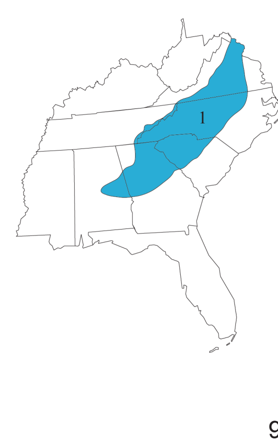
Fossil invertebrates in the Newark Supergroup rocks include clams, crustaceans, and abundant insects, many of which include soft tissue and delicate features (e.g., wings and antennae) (*Figure 3.8*). These fragile organisms may have been so well preserved thanks to poorly oxygenated lake bottom waters that slowed decomposition, or because of saline and alkaline water chemistry, which may have discouraged predators and **bioturbation** (burrowing) that otherwise would have contributed to deterioration of the body parts. Plant remains can also be particularly abundant in these rift valley sediments, and include a variety of foliage types such as **cycad** fronds, ferns, **ginkgos**, and **conifers** (*Figure 3.9*).

bioturbation *• the displacement of sediment and soil by animals or plants.*

cycad *• a palm-like, terrestrial seed plant (tree) characterized by a woody trunk, a crown of stiff evergreen leaves, seeds without protective coatings, and no flowers.*

ginkgo *• a terrestrial tree belonging to the plant division Ginkgophyta, and characterized by broad fan-shaped leaves, large seeds without protective coatings, and no flowers.*

conifer *• a woody plant bearing cones that contain its seeds.*



3 Fossils

Region 1

inland sea • *a shallow sea covering the central area of a continent during periods of high sea level.*

brachiopod • *a marine invertebrate animal characterized by upper and lower calcareous shell valves joined by a hinge, and a crown of tentacles (lophophore) used for feeding and respiration.*

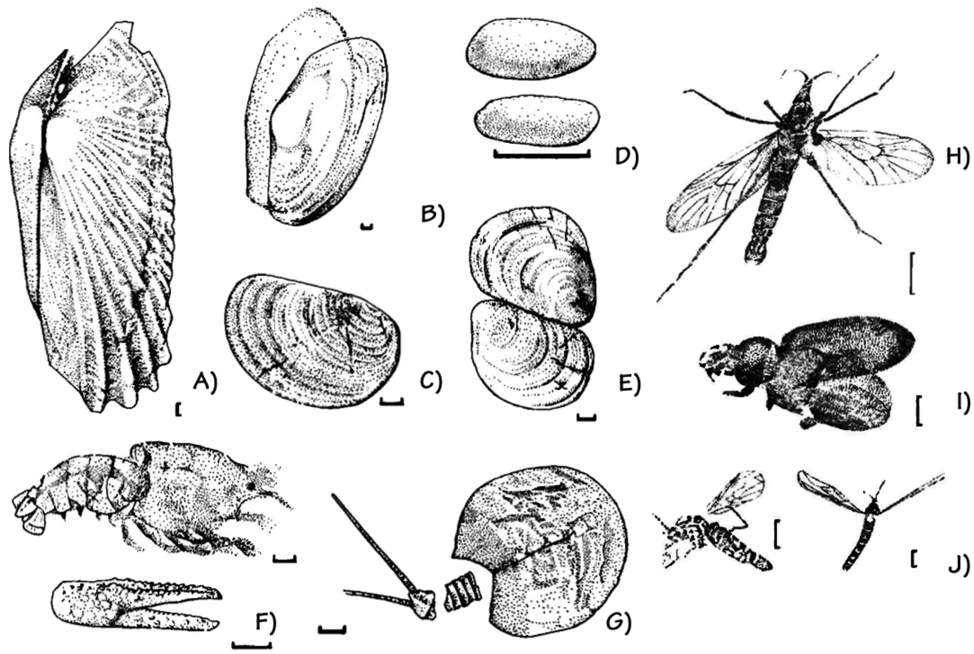


Figure 3.8. Fossil invertebrates from the lake sediments of the Newark Series in Virginia and North Carolina (scale bars = 1 millimeter [0.03 inches]). A) Diplodontid freshwater clam. B) Unionid freshwater clam. C) Cyzicus*, freshwater crustacean. D)* Darwinula*, ostracod. E) Corbiculid freshwater clam. F) Body and claw of the crustacean* Cytioclopsis*. G)* Triops*, notostracan crustacean. H) Dipterid insect. I) Beetle. J) Dipterid insects.*

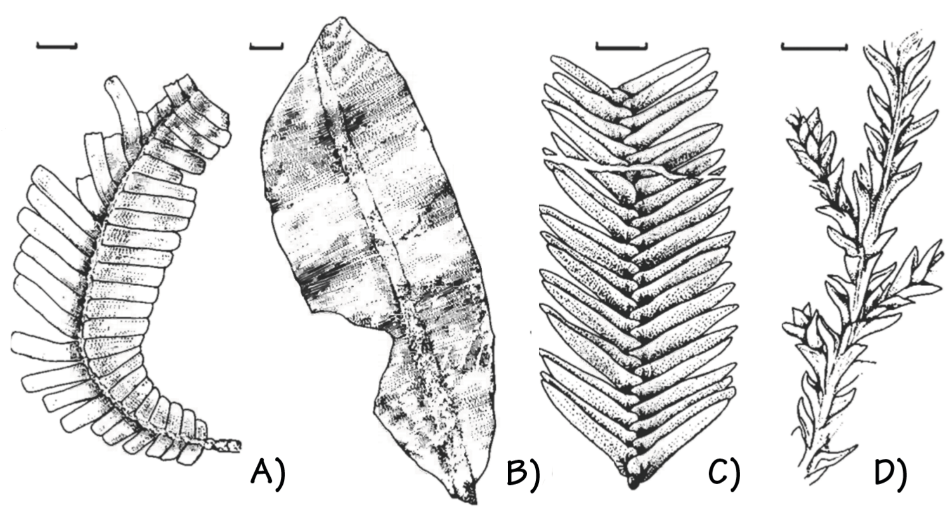
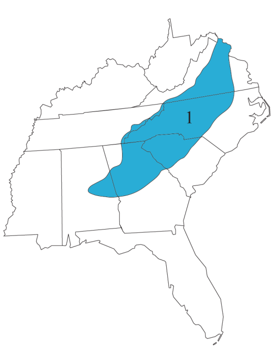


Figure 3.9: Fossil plants from the lake sediments of the Newark Series in Virginia and North Carolina (scale bars = 1 centimeter [0.4 inches]). A) Zamites powelli*, a cycadeoid. B)* Macrotaenipteris magnifolia*, a cycadeoid. C)* Otozamites *sp., a cycadeoid. D)* Pagiophyllum *sp., a conifer.*



Fossils of the Inland Basin
Region 2

The Inland Basin region primarily contains the story of Paleozoic mountain-building events, associated sediment deposited in the **inland sea**, and changes in relative sea level, superimposed on the evolution of Paleozoic marine and coastal plant life.

See Chapter 4: Topography to learn how changes in sea level influenced the Inland Basin's landscape.

Exposures of Cambrian rocks with fossils are uncommon in this region, but a few can still be found. The early Cambrian Antietam Sandstone of West Virginia and Virginia contains *Skolithos* trace fossils (*see Figure 3.19*), as well as occasional trilobites and **brachiopods**. Early Cambrian fossils, especially trilobites, are also found in western Virginia, eastern Tennessee, and northwestern Georgia (*Figure 3.10*). In eastern Tennessee (near Knoxville), trilobite trace fossils are common in Cambrian rocks that appear to have been deposited in intertidal environments (*Figure 3.11*).

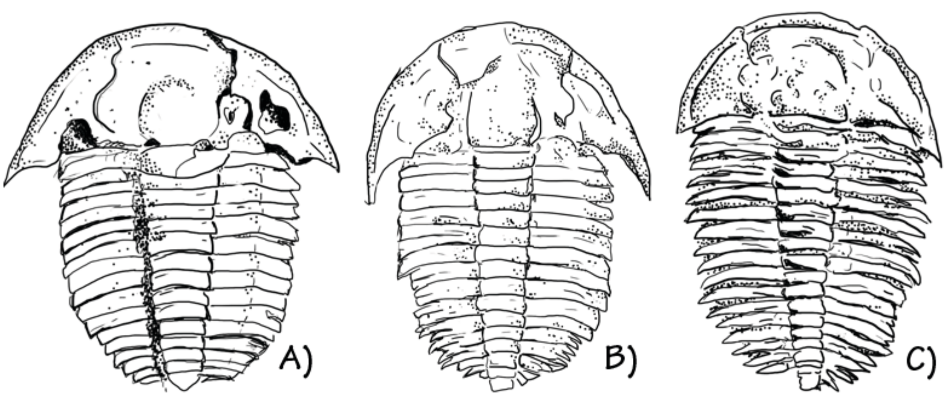


Figure 3.10: Cambrian trilobites from northwestern Georgia and northeastern Alabama. A) Elrathia antiquata*, approximately 2 centimeters (0.8 inches) long. B)* Aphelaspis brachyphasis*, approximately 2.5 centimeters (1 inch) long. C)* Modocia sp.*, approximately 2 centimeters (0.8 inches) long.*

Shales and **concretions** in the middle Cambrian Conasauga Formation of northeastern Alabama and northwestern Georgia contain body and trace fossils showing the preservation of diverse soft-bodied organisms, as well as many mineralized skeletons. These include algae, **sponges**, **arthropods**, brachiopods, **echinoderms**, mollusks, and trace fossils. Some of the most curious Conasauga fossils are "star cobbles," referred to the genus *Brooksella* (*Figure 3.12*). These enigmatic fossils have been variously thought of as medusae (jellyfish), algae, trace fossils, or inorganic structures. Recent research suggests, however, that they are most likely sponges with **siliceous** (SiO_2) skeletons.

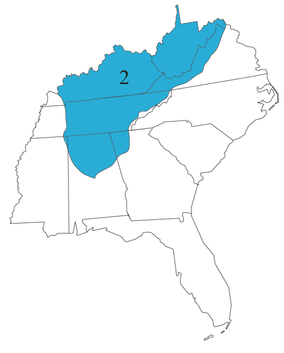
shale • *a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.*

concretion • *a hard, compact mass, usually of spherical or oval shape, found in sedimentary rock or soil.*

sponge • *a marine invertebrate belonging to the Phylum Porifera, and characterized by a soft shape with many pores and channels for water flow.*

arthropod • *an invertebrate animal, belonding to the Phylum Arthropoda, and posessing an external skeleton (exoskeleton), body segments, and jointed appendages.*

echinoderm • *a member of the Phylum Echinodermata, which includes starfish, sea urchins, and crinoids.*



Region 2

silica • *a chemical compound also known as silicon dioxide (SiO_2).*

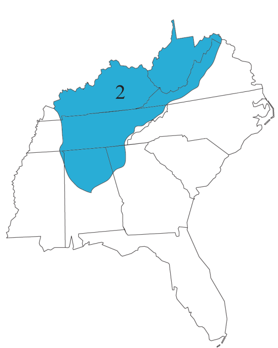
Ordovician • *a geologic time period spanning from 485 to 443 million years ago.*

Silurian • *a geologic time period spanning from 443 to 419 million years ago.*

Devonian • *a geologic time period spanning from 419 to 359 million years ago.*

graptolite • *an extinct colonial invertebrate animal characterized by individuals housed within a tubular or cup-like structure.*

crinoid • *a marine invertebrate animal characterized by a head (calyx) with a mouth surrounded by feeding arms.*



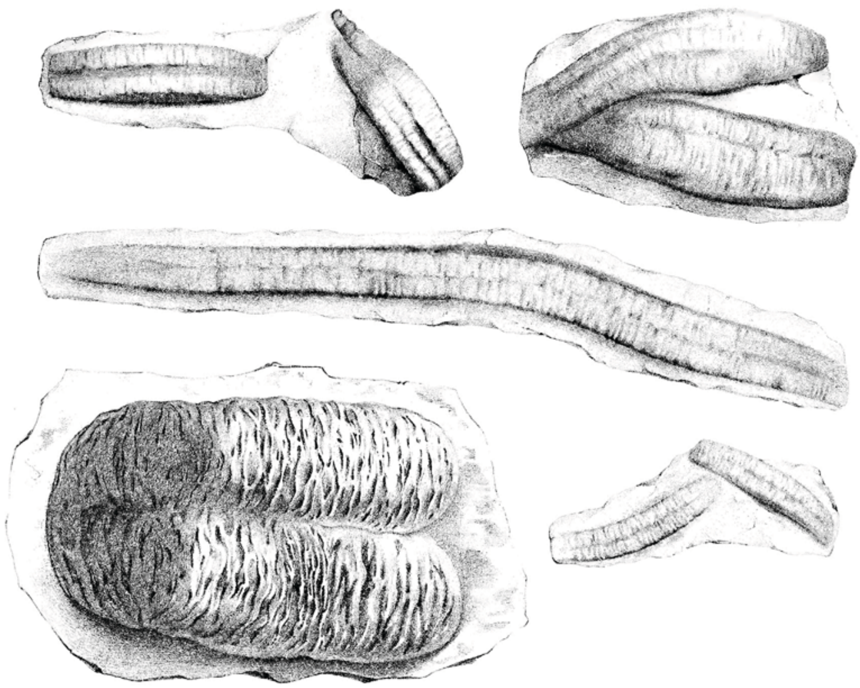


Figure 3.11: Trace fossils commonly associated with trilobites. Rusophycus *are resting traces, recording the outline of the organism while it remains still.* Cruziana *are elongate, bilaterally symmetrical paths with repeated striations, recording the animal's movement through the mud.*

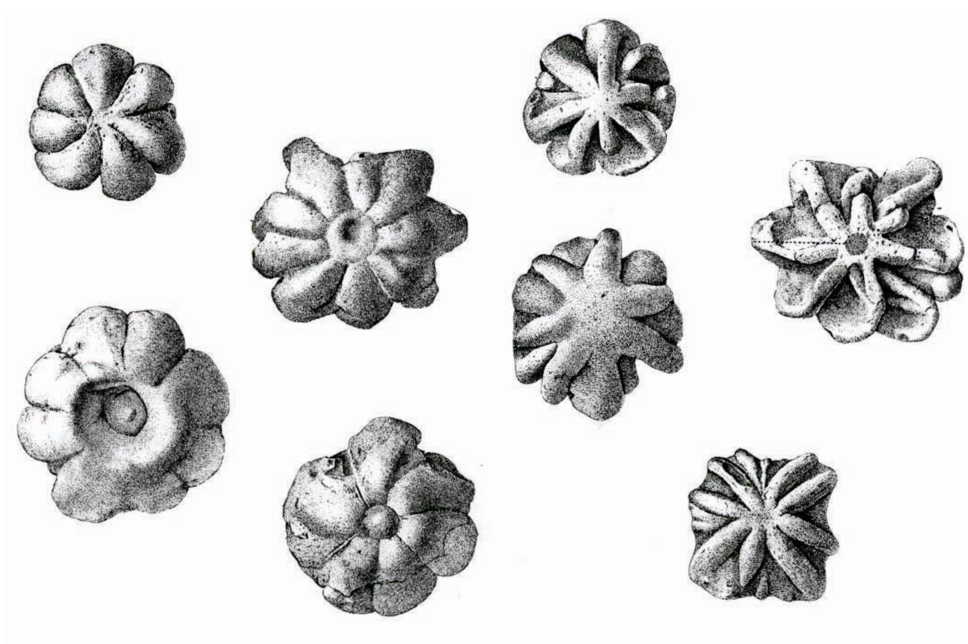


Figure 3.12: "Star cobbles" (Brooksella) *from the Cambrian Conasauga Formation. Fossils are 2.5–5 centimeters (1–2 inches) across.*

Fossils

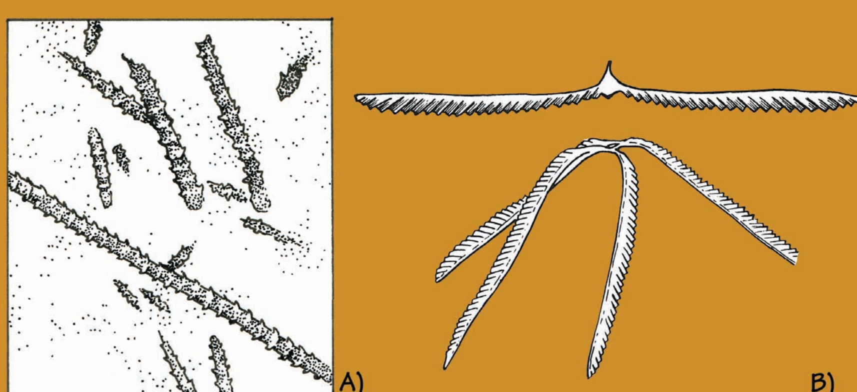
3

Region 2

Ordovician, **Silurian**, and **Devonian** marine fossils are widespread in the Inland Basin and are typically abundant, diverse, and beautifully preserved. These fossil assemblages are nearly always dominated by brachiopods, but also contain trilobites, **graptolites**, corals, clams, **crinoids**, *Skolithos*, and many others (*Figures 3.13–3.16*). Middle Ordovician **limestones** in Tennessee are well known for containing numerous crinoids and fossils of the large **gastropod** *Maclurites* (*Figure 3.17*). In Kentucky and Tennessee, trilobites, brachiopods, **bryozoans**, corals, and the distinctive sponge *Brachiospongia* are also found in Ordovician rocks (*Figure 3.18*). Late Ordovician fossils are abundant in central Tennessee (around Nashville), central Kentucky (southeast of Louisville), and northern Kentucky; Ordovician limestones in the area around Strasburg, Virginia contain abundant trilobites (*see Figure 3.16*). The fossils are preserved as silica (SiO_2), and can therefore be extracted from the surrounding carbonate rock by treating it with dilute acid. This allows for the examination of delicate fossils that would otherwise be impossible to study.

Graptolites

Graptolites (meaning "rock writing") are an extinct group of colonial, free-floating organisms. They lived from the Cambrian to the Carboniferous, and were relatives of modern hemi*chordates* such as acorn worms. Graptolites are frequently preserved as thin, black, sawblade-like streaks across black shale; tiny cups along these structures held individual animals. Graptolites are often useful as index fossils.



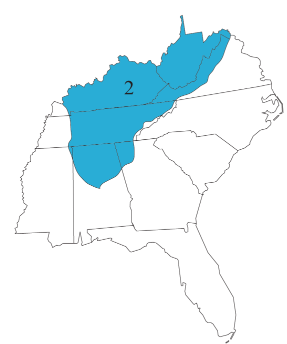
A) Specimen with many fragments of colonies of Climacograptus. *Slab is 7.5 centimeters (3 inches) on each side. B) Restoration of what graptolite colonies may have looked like when they were alive and floating in the water.*

limestone • *a sedimentary rock composed of calcium carbonate ($CaCO_3$).*

gastropod • *a marine, freshwater, or terrestrial invertebrate animal characterized by a single, coiled, calcareous shell, a muscular foot for gliding, and internal asymmetry caused by torsion.*

bryozoan • *a marine or freshwater colonial invertebrate animal characterized by an encrusting or branching calcareous skeleton from which multiple individuals (zooids) extend from small pores to filter-feed using crowns of tentacles (lophophores).*

chordate • *an animal that has a notochord, a hollow dorsal nerve cord, pharyngeal gill slits, an endostyle, and a post-anal tail during at least one stage of its development.*



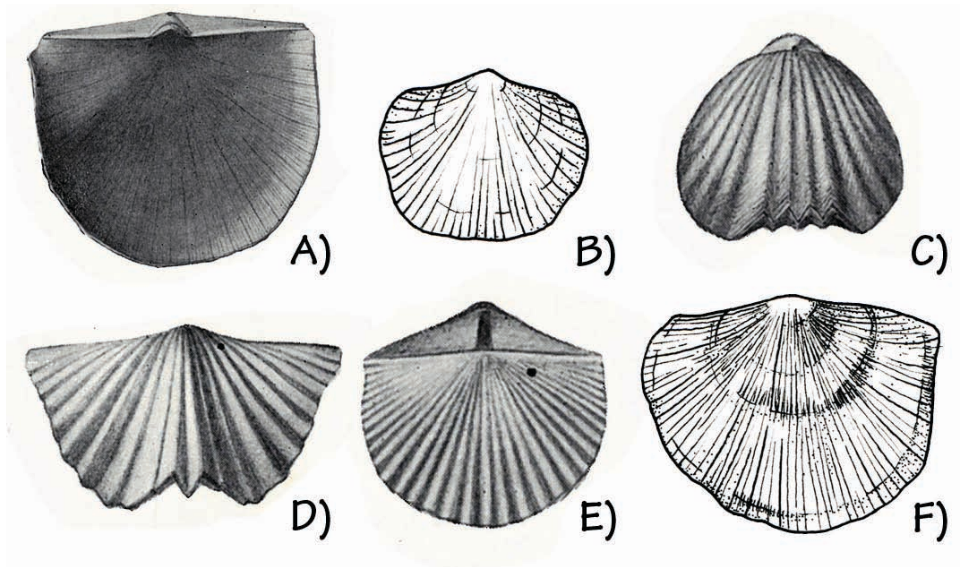


Figure 3.13: Common Ordovician brachiopods of the Interior Basin. A) Rafinesquina alternata*, approximately 4 centimeters (1.6 inches) wide. B)* Resserella *sp., approximately 1 centimeter (0.4 inches) wide. C)* Rhynchotrema capax*, approximately 1 centimeter (0.3 inches) wide. D)* Platystrophia laticosta*, approximately 2.5 centimeters (1 inch) wide. E)* Hesperorthis tricenaria*, approximately 1 centimeter (0.3 inches) wide. F)* Strophomena *sp., 1–2 centimeters (0.5–1 inch) wide.*

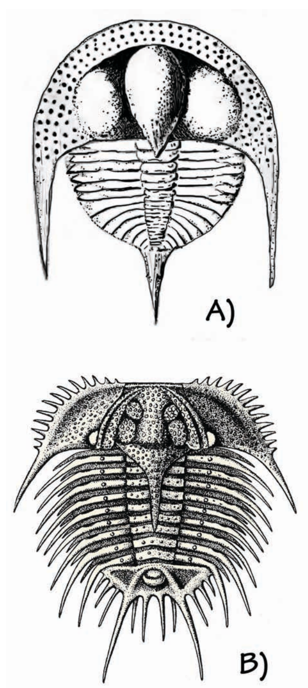


Figure 3.14: Ordovician trilobites of the Interior Basin. A) Trinucleus *sp., approximately 3 centimeters (1.5 inches) long. B)* Acidaspis rebecca*, 13 centimeters (5 inches) long.*

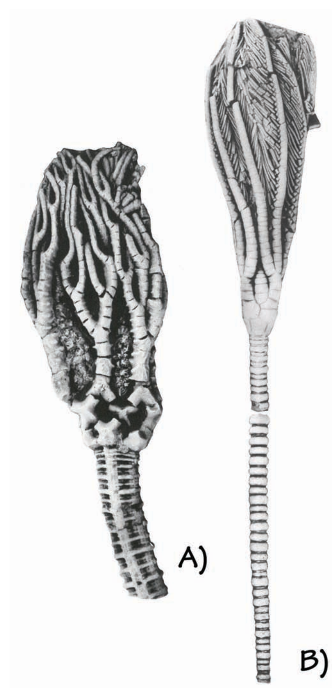
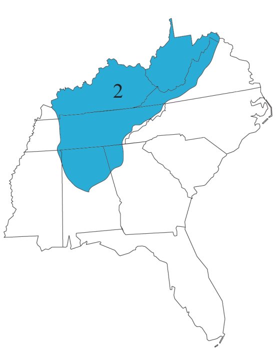
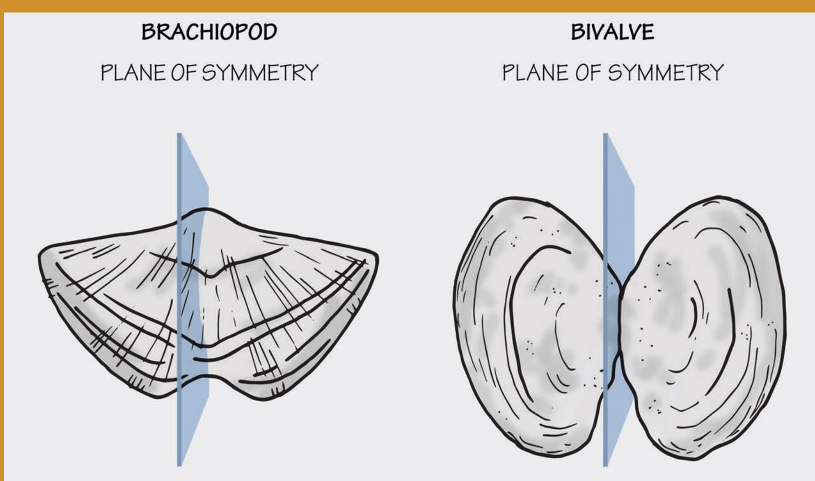


Figure 3.15: Crinoid calyces with arms and stem. A) Reteocrinus alveolatus*, approximately 6 centimeters (2.4 inches) long. B)* Cremacrinus *sp., approximately 16 centimeters (6.3 inches) long.*

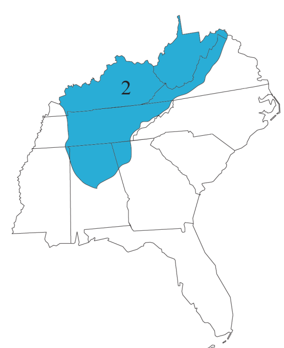


Brachiopods

Brachiopods are filter-feeding animals that have two shells and are superficially similar to bivalves (such as clams). Instead of being mirror images between shells (symmetrical like your hands), brachiopod shells are mirror images across each shell (symmetrical like your face). There are two major types of brachiopod shells, distinguished by how the two valves connect to each other: articulate brachiopods have tooth-and-socket hinges that tightly interlock, whereas inarticulate brachiopod shells lack hinge structures entirely. Internally, brachiopods are substantially different from bivalves, with a lophophore (filter-feeding organ made of thousands of tiny tentacles), and a small and simple gut and other organs. Bivalves, in contrast, have a fleshier body and collect their food with large gills.



The difference between the shells of a typical brachiopod (left) and a typical bivalve mollusk (right). Most brachiopods have a plane of symmetry across the valves (shells), whereas most bivalves have a plane of symmetry between the valves.



iron • *a metallic chemical element (Fe).*

hematite • *a mineral form of iron oxide (Fe_2O_3), with vivid red pigments that make it valuable as a commercial pigment.*

reef • *a feature lying beneath the surface of the water, which is a buildup of sediment or other material built by organisms, and which has positive relief from the sea floor.*

stomatoporoid • *a type of calcareous sponge that acted as an important reef-builder throughout the Paleozoic and the late Mesozoic.*

Mississippian • *a subperiod of the Carboniferous, spanning from 359 to 323 million years ago.*

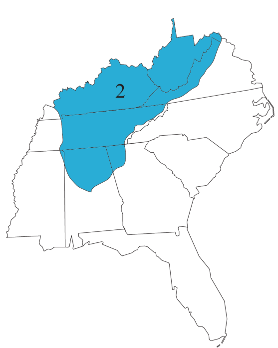


Figure 3.16: Slab of trilobites, Homotelus *sp., Ordovician of Virginia, approximately 38 centimeters (15 inches) across.*

Figure 3.17: Gastropod, Maclurites *sp. Fossils are approximately 2.5–5 centimeters (1–2 inches) across.*

In Alabama, the Silurian Red Mountain Formation, which is rich in the **iron** mineral **hematite**, contains significant **reefs** made largely of **stromatoporoid** sponges. *Skolithos* can be found throughout Silurian deposits in Tennessee (*Figure 3.19*), while Silurian deposits in Virginia contain abundant corals and brachiopods (*Figure 3.20*). Early to middle Devonian marine fossils are spectacularly exposed in the 390-million-year-old rocks at Falls of the Ohio in northern Kentucky. These beds of limestone are among the largest naturally exposed Devonian fossil deposits in the world, packed with the skeletal remains of countless corals, stromatoporoid sponges, echinoderms, brachiopods, mollusks, arthropods, and microscopic organisms. Well-preserved Devonian marine invertebrate fossils also occur in Tennessee, Virginia, and West Virginia (*Figure 3.21*).

See Chapter 5: Mineral Resources to learn about Alabama's iron and steel industry.

Mississippian limestones from West Virginia to Alabama contain numerous fossils, including corals, gastropods, **bivalves**, bryozoans, **blastoids** (*Figure 3.22*), and fossilized **shark** teeth. In fact, West Virginia's official state "**gemstone**" is *Lithostrotionella*, a Mississippian fossil coral from the Hillsdale Limestone found in portions of Greenbrier and Pocahontas counties. Crinoids are especially abundant (*Figure 3.23*); the Mississippian is sometimes referred to as the "age of crinoids," because they were so abundant that entire rocks are made up of bits of their **calcite** skeletons. **Carboniferous** trilobites have also been found in northwestern Georgia and northern West Virginia.

See Chapter 2: Rocks for a list of state rocks, minerals, and gems.

Sponges

Sponges (Phylum Porifera) are the simplest major group of animals; their earliest fossils appear in the late Precambrian. Most modern sponges live in the ocean and usually have basket-shaped bodies. They live by filtering food and oxygen out of water pumped in through openings in their body walls and out through a larger opening at the top. The familiar bath sponge has no mineralized skeleton, but many other kinds of sponges have skeletons composed of tiny structures called *spicules*, which are made of *calcium carbonate* ($CaCO_3$) or silica (SiO_2). It is these skeletonized sponges that have the greatest likelihood of becoming fossils. Over their long history, such sponges have frequently been important contributors to reefs and reef-like mounds.

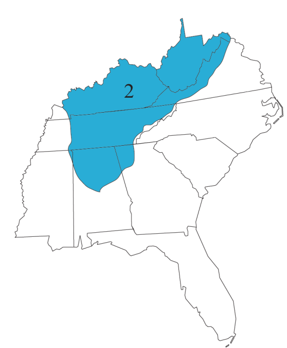
bivalve • *a marine or freshwater invertebrate animal characterized by right and left calcareous shells (valves) joined by a hinge.*

blastoid • *an extinct form of stemmed echinoderm, similar to crinoids, possessing a nut-shaped body covered with interlocking plates.*

shark • *a large fish characterized by a cartilaginous skeleton and five to seven gill slits on the side of the head.*

gemstone • *a mineral that has aesthetic value and is often cut and polished for use as an ornament.*

calcite • *a carbonate mineral, consisting of calcium carbonate ($CaCO_3$).*

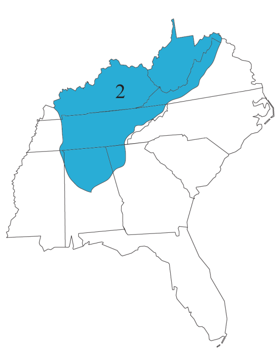


sessile • *unable to move, as in an organism that is permanently attached to its substrate.*

rugose coral • *an extinct group of corals that were prevalent from the Ordovician through the Permian.*

tabulate coral • *an extinct form of colonial coral that often formed honeycomb-shaped colonies of hexagonal cells.*

scleractinian coral • *a colonial or solitary marine invertebrate animal characterized by an encrusting calcareous skeleton enclosing polyps that capture prey with small tentacles equipped with stinging cells (nematocysts).*



Bryozoans

Bryozoans are colonial invertebrates, many of which build elaborate skeletons of calcium carbonate. Bryozoans are common in today's oceans, where they are frequently found encrusting rocks or shells. During the Paleozoic era, however, bryozoans commonly grew off of the sea floor as erect structures. After they died, their skeletons accumulated into thick beds of limestone. Although they do not appear to be, bryozoans are actually closely related to brachiopods—both groups have the same distinctive feeding and respiratory structure, the lophophore.

Corals

Corals are *sessile* relatives of jellyfish and sea anemones. They possess stinging tentacles, which they use to feed on small planktonic prey. Each group of coral possesses distinctly shaped "cups" that hold individual animals, or polyps. Colonial corals live in colonies of hundreds or even thousands of individuals that are attached to one another. Solitary coral lives independently, as a single isolated polyp.

Rugose corals were both colonial and solitary. (Solitary forms are often called "horn corals.") *Tabulate corals* were exclusively colonial and produced a variety of shapes, including sheetlike and chainlike forms. These corals receive their name from the table-like horizontal partitions within their chambers. Both rugose and tabulate corals went extinct at the end of the Permian. Modern corals—*scleractinians*—first appeared in the Triassic, and include both solitary and colonial species. Many scleractinian corals have photosynthetic symbiotic algae in their tissues, called zooxanthellae. This algae provides nutrition to the coral polyps, helping them to grow more rapidly.

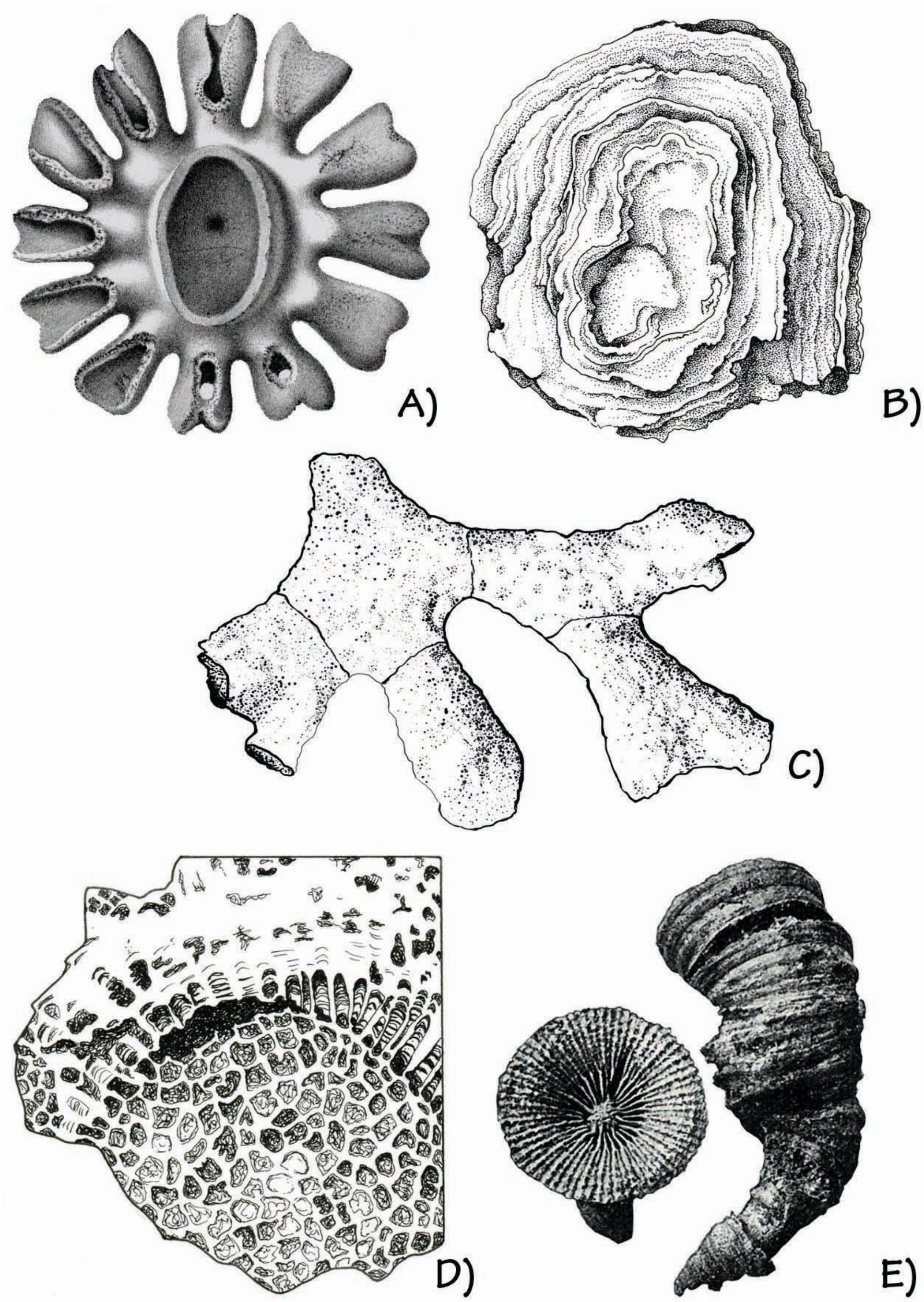
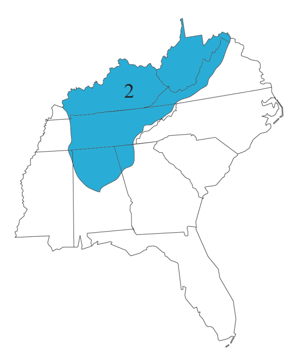


Figure 3.18: Common Ordovician reef-building organisms of the Interior Basin. A) Sponge, Brachiospongia digitata*, approximately 25 centimeters (10 inches) wide. B) Stromatoporoid sponge, approximately 30 centimeters (12 inches) across. C) Bryozoan,* Dekayia aspera*, approximately 1 inch (2.54 centimeters) across. D) Tabulate coral,* Favistella *sp., approximately 8 centimeters (3.2 inches) wide. E) Solitary rugose ("horn") coral,* Heliophyllum juvenae*, approximately 15 centimeters (6 inches) tall.*



Fossils

Figure 3.19: Skolithos *burrows from the lower Silurian Clinch Formation at Clinch Mountain, Tennessee. Rocks with abundant* Skolithos *are sometimes called "pipe rock." The organism that made these burrows is unknown, but their shape suggests a worm-like creature that lived in the vertical burrows. Rock containing burrows is approximately 15 x 30 centimeters (6 x 12 inches).*

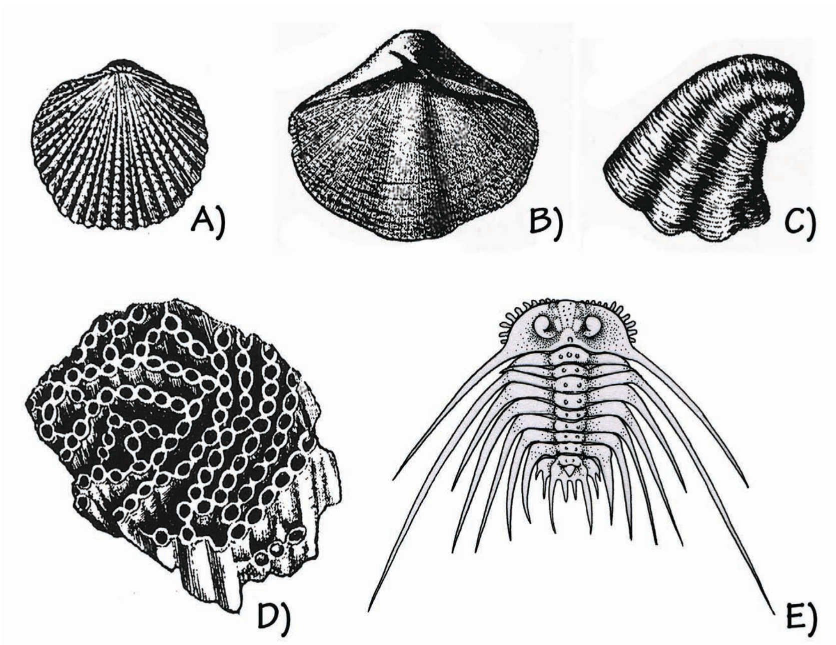
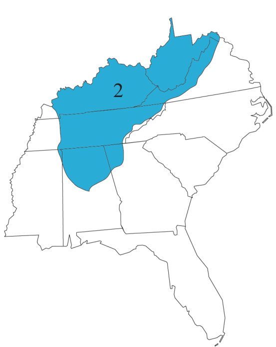


Figure 3.20: Common Silurian marine invertebrates of the Interior Basin region. A) Brachiopod, Atrypa nodostriata, *approximately 2.5 centimeters (1 inch) wide. B) Brachiopod,* Spirifer radiatus, *approximately 4 centimeters (1.6 inches) wide. C) Gastropod,* Platyceras angulatum, *1–4 centimeters (0.5–1.5 inches) tall. D) Tabulate coral,* Halysites *sp., 15–20 centimeters (6–8 inches) wide. E) Trilobite,* Leonaspis williamsi, *approximately 3 centimeters (1.2 inches) long.*



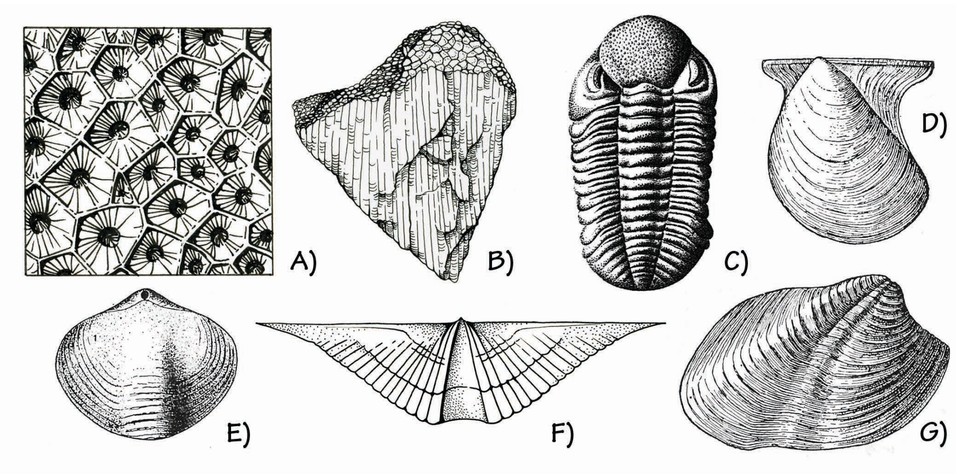


Figure 3.21: Common Devonian marine invertebrates of the Interior Basin region. A) Colonial rugose coral, Hexagonaria*, field of view approximately 2.5 centimeters (1 inch) wide. B) Tabulate coral,* Favosites*, 1–4 centimeters (0.4–1.5 inches) wide. C) Trilobite,* Eldredgeops rana*, approximately 2.5 centimeters (1 inch) long. D) Bivalve,* Leiopteria*, approximately 5 centimeters (2 inches) tall. E) Brachiopod,* Athyris spiriferoides*, approximately 2.5 centimeters (1 inch) tall. F) Brachiopod,* Mucrospirifer mucronatus*, 2–5 centimeters (1–2 inches) wide. G) Bivalve,* Grammysia*, approximately 4 centimeters (1.5 inches) wide.*

placoderms *• an extinct class of heavily armored fishes.*

edestid *• a member of a group of primitive sharks from the Carboniferous period known for their "tooth-whorls."*

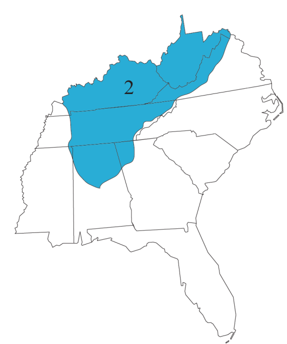
coal *• a combustible, compact black or dark-brown carbonaceous rock formed by the compaction of layers of partially decomposed vegetation.*

tree *• any woody perennial plant with a central trunk.*

Pennsylvanian *• a subperiod of the Carboniferous, spanning from 323 to 299 million years ago.*

Sharks and bony fishes evolved rapidly during the Devonian and Carboniferous periods, and their fossils can sometimes be found in the rocks of the Inland Basin. Fossils of heavily armored bony fishes called **placoderms** are found in Kentucky and Tennessee, including the enormous *Dunkleosteus* (*Figure 3.24*). The teeth of sharks, which first appeared in the late Silurian period, are also preserved in these rocks (*Figure 3.25*). Among these are the bizarre and puzzling coiled tooth whorls of **edestid** sharks—these are sometimes found in shales overlying **coal** seams, indicating that the sharks inhabited shallow waters near shore.

The oldest known fossils of land plants are isolated spores dating to the Ordovician period. By the late Silurian, fossils of simple, leafless stems just a few centimeters tall are found in sediments that accumulated in low, wet, coastal environments. The first **trees** date to the early part of the Devonian period, and the first seeds to the middle Devonian; Devonian plant fossils are found in northeastern Alabama (Cherokee County). By the end of the Devonian, extensive forests containing many different kinds of trees and other plants had developed, and this continued into the Carboniferous period that followed. During the Mississippian and (especially) the **Pennsylvanian**, what is now the Interior Basin region of the Southeast was a broad, low coastal plain near the Equator and home to extensive swampy forests.



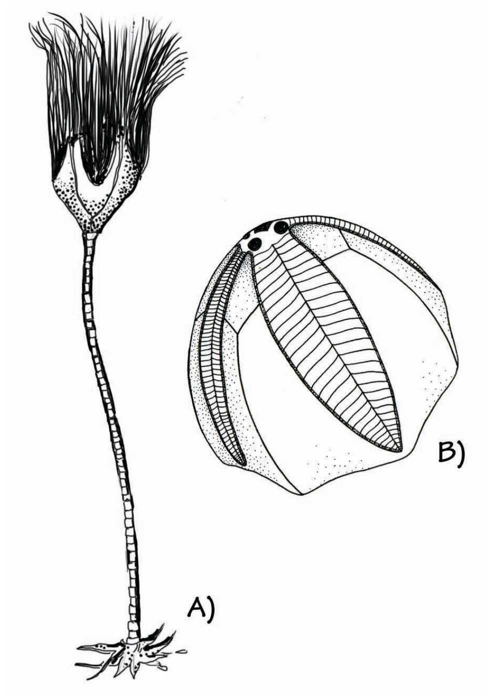
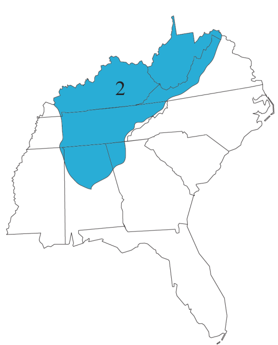


Figure 3.22: Blastoid, Pentremites *sp. Blastoids were a group of stalked echinoderms similar to crinoids. The calyx of a blastoid did not have long arms, but instead a series of holes called brachioles that held much shorter arms. A) Restoration, approximately 15 centimeters (6 inches) tall. B) Calyx.*

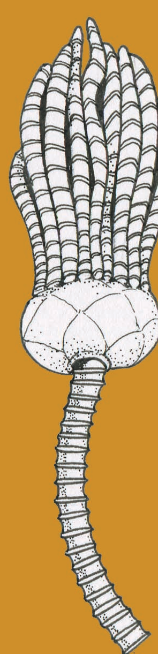
Figure 3.23: Gilbertsocrinus typus, *a crinoid from the Mississippian Borden Formation of north-central Kentucky, 8.5 centimeters (3.4 inches).*



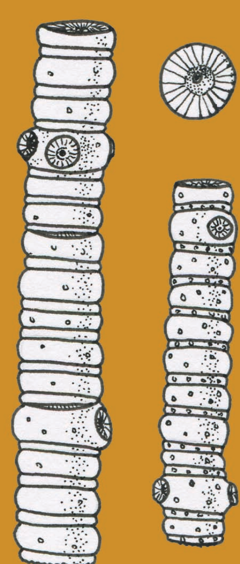
calyx • *the head of a crinoid.*

Crinoids

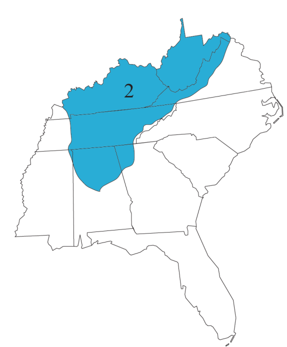
Crinoids are echinoderms, related to sea urchins and sea stars. These invertebrate animals feed by using their arms to filter food out of the water. Most are attached to the sediment by a stalk that ends in a root-like structure called the holdfast—some forms, however, are free floating. Crinoid fossils are most commonly found as "columnals," pieces of the stalk that hold the head (*calyx*) above the surface. The calyx and the holdfast are only occasionally preserved as fossils. Crinoids are still around today; those in shallow water are mostly stalkless, while those with stalks are restricted to deep water.



Crown and stem, about 15 centimeters (6 inches) long.



Stem fragments.



Region 2

lycopod • *an extinct, terrestrial tree characterized by a tall, thick trunk covered with a pattern of diamond-shaped leaf scars, and a crown of branches with simple leaves.*

sphenopsid • *a terrestrial plant characterized by hollow, jointed stems with reduced, unbranched leaves at the nodes.*

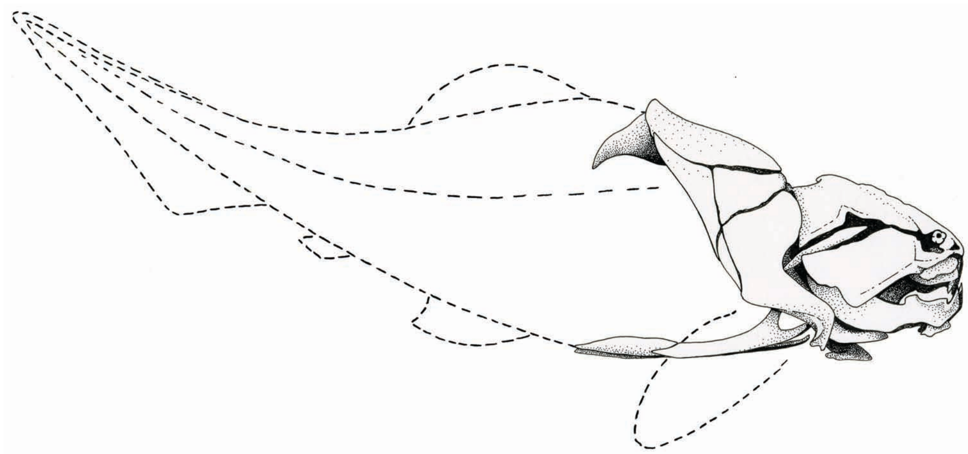


Figure 3.24: The giant Devonian placoderm fish Dunkleosteus. *The dotted lines show the inferred shape of the unpreserved part of the body. Total length was probably approximately 9 meters (30 feet).*

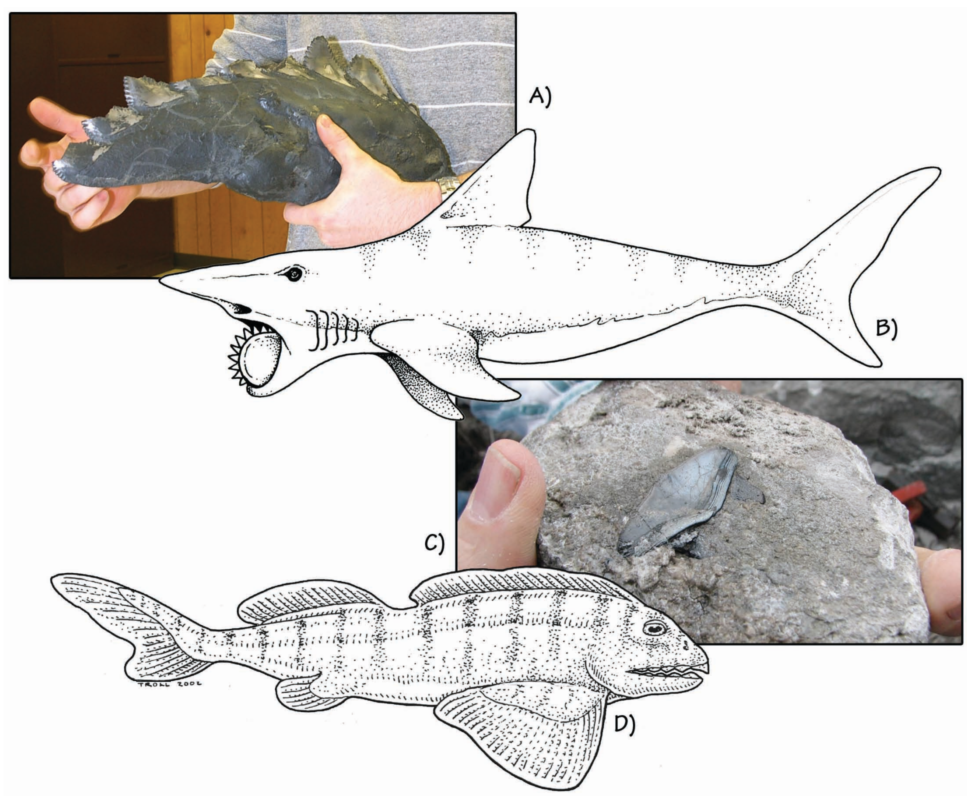
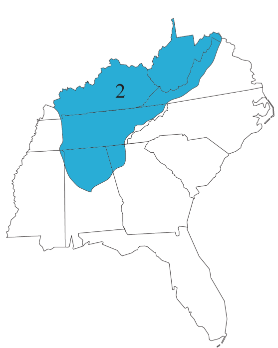


Figure 3.25: Carboniferous sharks. A) Jaw of the bizarre Pennsylvanian shark Edestus, *discovered in a coal mine in Webster County, Kentucky, 210 meters (700 feet) below the surface. B) Restoration of* Helicoprion, *an edestid shark, 3–4 meters (10–13 feet) long. C) Tooth of the Mississippian shark* Petalodus, *from Morgan County, Alabama. D) Restoration of* Petalodus, *approximately 1 meter (3 feet) long.*



The swamp forests that grew on Carboniferous coastal plains west of the Appalachian Mountains were dominated by four major groups of plants, each of which had independently evolved the style of growth known as the tree (a plant held erect by a single stem made of a stiff tissue called wood). The trees found in these forests, however, did not belong to the familiar groups that dominate modern forests, such as conifers and flowering broadleaf trees. Instead, these early forests were built by groups of plants that are either extinct or much less conspicuous today (*Figures 3.26 and 3.27*). These groups were the **lycopods** (club mosses), the **sphenopsids** (horsetails), the ferns, and the **cordaites**. Lycopods and horsetails survive today, but only as small, non-woody herbaceous plants. Tree ferns still grow today, but only in relatively restricted environments such as permanently moist subtropical forests. Cordaites are extinct.

The Carboniferous coal swamps were also home to a great diversity of animals, including insects, amphibians, and early reptiles (*Figures 3.28 and 3.29*). Although fossil bones have been found in Mississippian and Pennsylvanian rocks in West Virginia, Virginia, and Alabama, trace fossils are more common. One particular trackway site in Walker County, Alabama is one of the largest known Carboniferous tracksites in the world.

The Interior Basin contains no fossil-bearing outcrops of **Mesozoic** age. It does, however, have a rich fossil record from the Neogene, including numerous sites at which **Pleistocene** and older terrestrial vertebrates have been found. For instance, the Gray Fossil Site is located near the small town of Gray in

Fossils and Coal

Coal is technically a metamorphic rock formed of highly *compressed* and altered peat. As is the case in most metamorphic rocks, this alteration (sometimes called *coalification*) means that coal itself does not usually contain well-preserved plant fossils. Instead, we learn about the plants that make up coal from two kinds of fossils: impressions and compressed plant parts left in shales deposited above or below coal seams, and coal balls, which are masses of calcium carbonate that crystalize inside coals from minerals dissolved in groundwater, protecting the plants they contain from alteration. Coal balls are usually studied by slicing them with a saw, polishing the sliced surfaces, and then making peels of the surface using sheets of acetate. These coal-ball peels are then examined under a microscope. See Chapter 6: Energy for more information on coal in the Southeast.

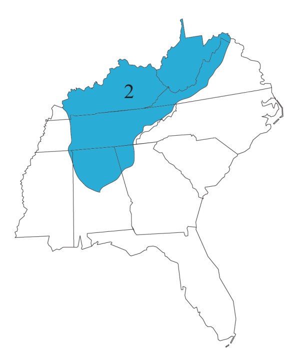
cordaite • *a member of the group Cordaitales, which were closely related to early members of the conifers.*

Mesozoic • *a geologic time period that spans from 252 to 66 million years ago.*

Pleistocene • *a subset of the Quaternary, lasting from 2.5 million to about 11,700 years ago.*

compression • *flattening or squeezing as a result of forces acting on an object from all or most directions.*

coalification • *the process by which coal is formed from plant materials through compression and heating over long periods of time.*



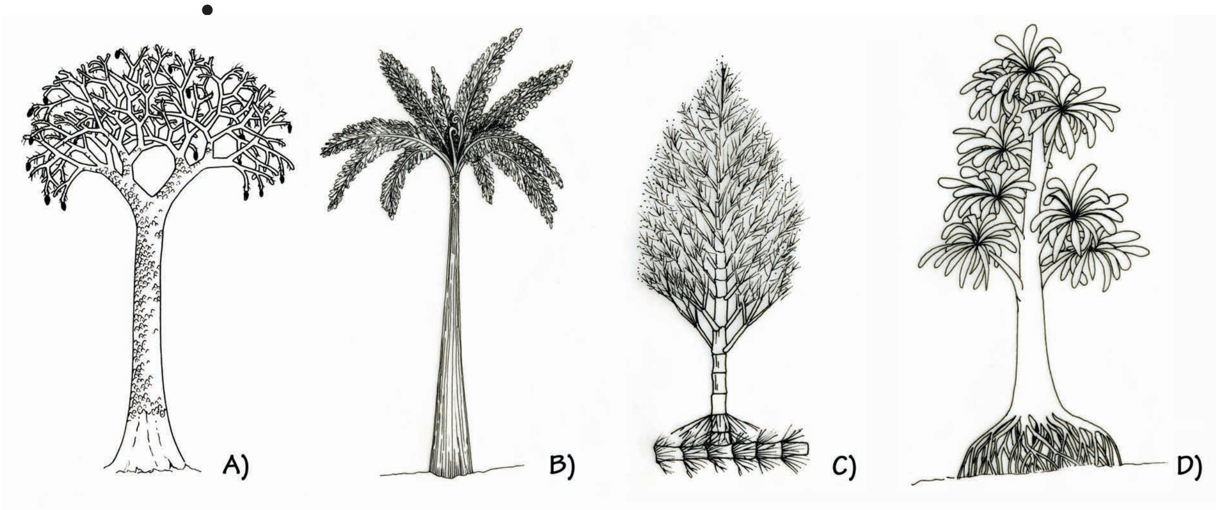


Figure 3.26: Restorations of Pennsylvanian coal swamp trees. A) Lepidodendron*, a lycopod (club moss), reached 30 meters (100 feet) tall. B)* Psaronius*, a tree fern, reached 3 meters (10 feet) tall. C)* Calamites*, a sphenopsid (horsetail), reached 20 meters (65 feet) tall. D)* Cordaites*, a conifer-like seed plant; reached 10 meters (35 feet) tall.*

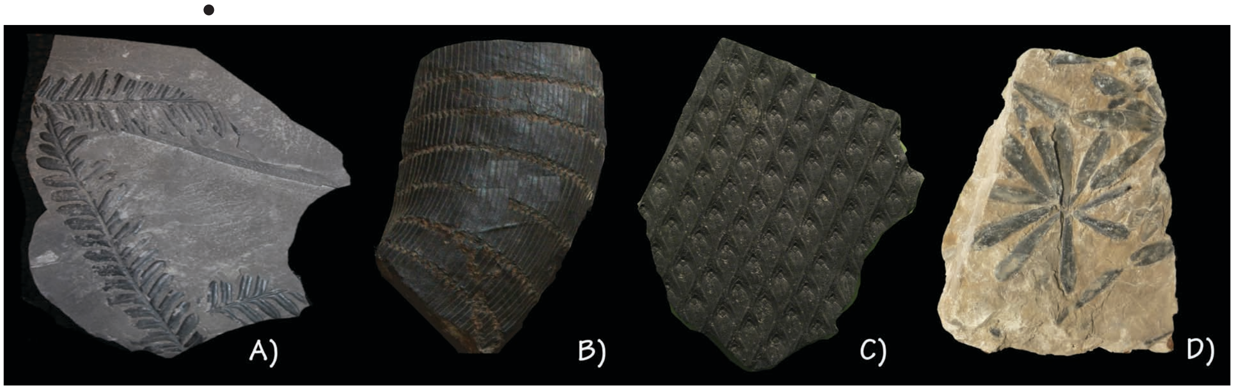
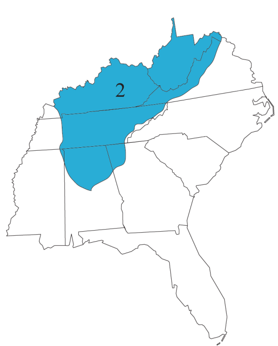


Figure 3.27: Coal swamp plant fossils. A) Seed fern frond, Alethopteris*, slab approximately 10 x 10 centimeters (4 x 4 inches). B)* Calamites *trunk, approximately 25 centimeters (10 inches) tall. C) Lycopod bark impression,* Lepidodendron *sp. Pennsylvanian lycopods reached huge sizes, up to 50 meters (150 feet) tall and 1 meter (3 feet) in diameter. D) Cordaite leaves,* Cordaites *sp., slab approximately 1.2 meters (4 feet) long.*



Washington County, northeastern Tennessee. It was discovered in 2000, when a road project unearthed fossil bones in a thick bed of **clay** that had apparently accumulated in a flooded sinkhole. Subsequent excavation revealed the bones of numerous species of mammals, reptiles, and amphibians. The particular species present constrain the age of the surficial fossil-bearing layer to the late **Miocene** (7–4.5 million years ago). The fossils recovered from the site so

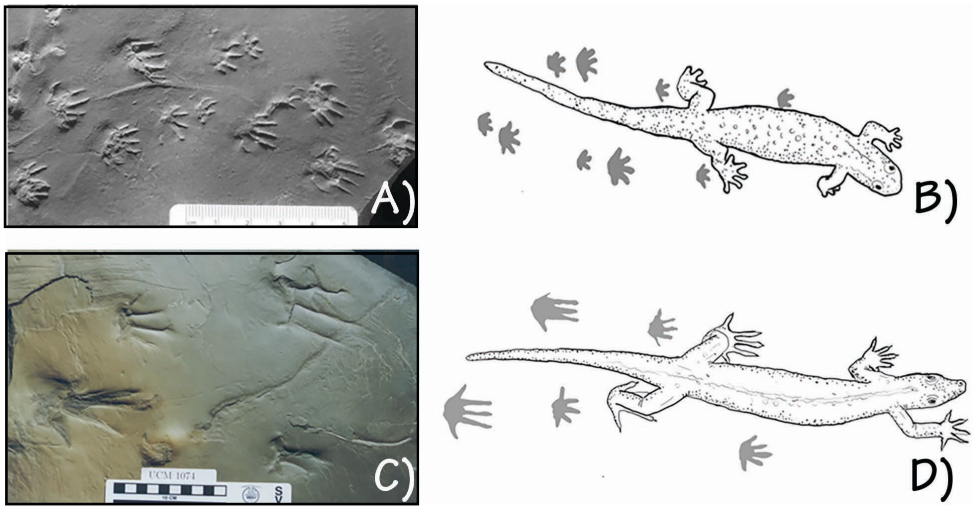


Figure 3.28: Some Pennsylvanian coal swamp animals, represented by fossils from the Union Chapel Mine site in northern Alabama. A) and B) Trackway and restoration of an amphibian, Nanopus reidiae*. Length of animal is approximately 15 centimeters (6 inches). C) and D) Trackway and restoration of an early reptile,* Attenosaurus subulensis*. Length of animal is approximately 1 meter (3 feet).*

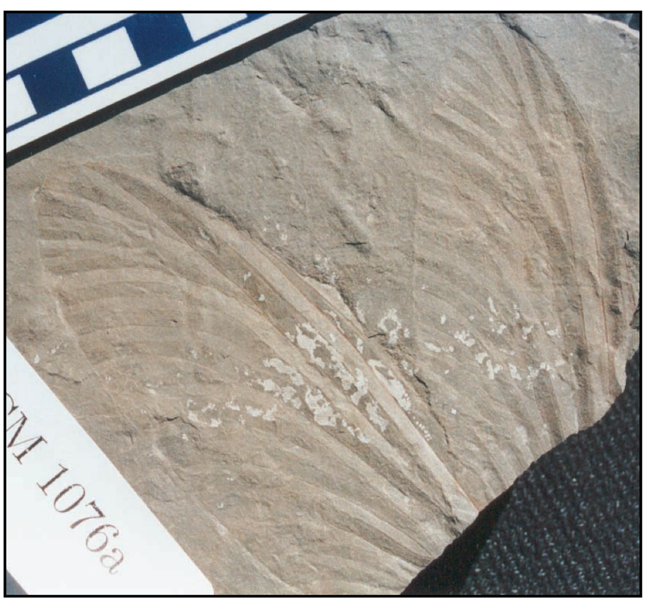
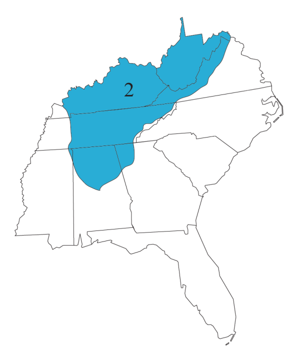


Figure 3.29: Wings of the insect Anniedarwinia alabamensis*. Scale above is in centimeters.*

clay • *the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.*

Miocene • *a geological time unit extending from 23 to 5 million years ago.*

far are noteworthy for other reasons. The site is the world's largest fossil tapir find; it also contains the most complete skeleton of *Teleoceras* (an ancient rhinoceros) found in eastern North America, as well a new species of red panda that marks only the second (and most complete) record of this group in North America (*Figures 3.30 and 3.31*). Other fossil mammals present at the Gray Site include shrews, moles, rabbits, rodents, weasels, short-faced bears, sabertoothed cats, shovel-tusked elephants (gomphotheres), camels, peccaries, ground sloths (*Figure 3.32*), and three-toed horses.



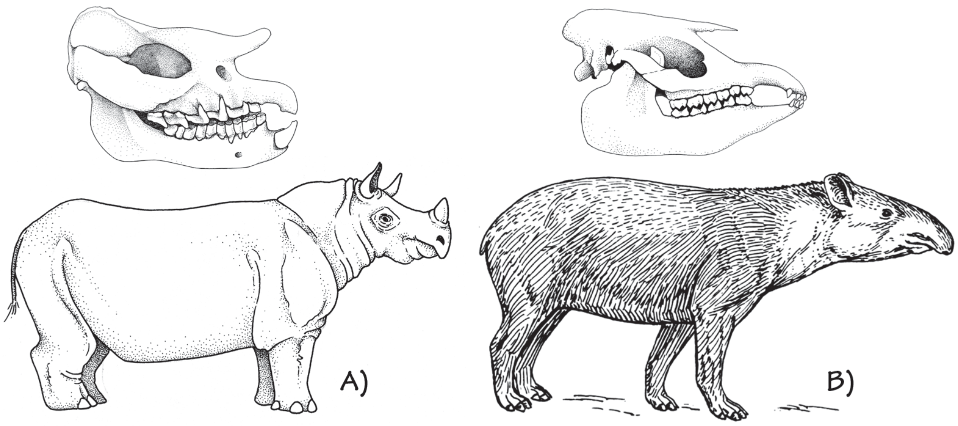


Figure 3.30: Common mammals found at the Gray fossil site in Washington County, Tennessee. A) Skull and life restoration of the rhinoceros Teleoceras, *body approximately 4 meters (13 feet) long. B) Skull and life restoration of a tapir, such as those found in Miocene sediments; skull is approximately 30 centimeters (12 inches) long.*

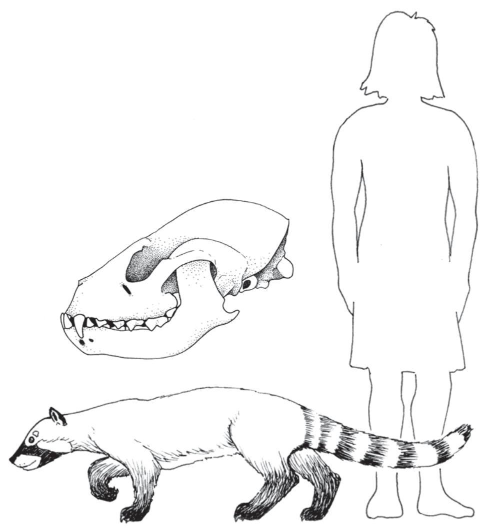


Figure 3.31: Skull and life restoration of an extinct species of red panda, Pristinailurus bristoli.

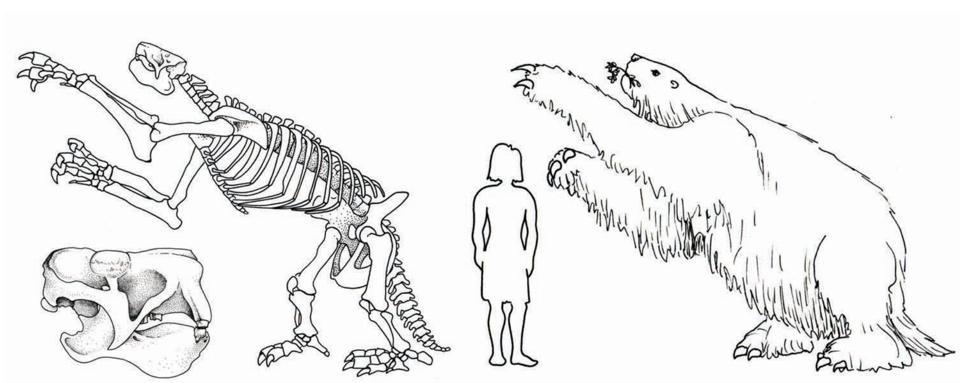
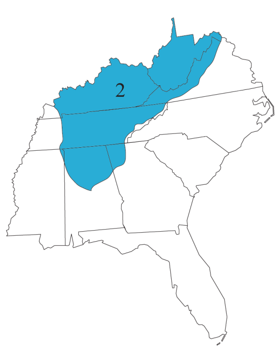


Figure 3.32: Skeleton, skull, and life restoration of the giant sloth Megatherium, *which lived throughout the Southeastern states during the Pleistocene. Skull is approximately 60 centimeters (24 inches) long.*



Bones of Pleistocene mammals are widespread and locally abundant throughout Kentucky, Tennessee, western Virginia and West Virginia, and northern Alabama. They occur mainly in caves, sinkholes, and boggy deposits, and include **mastodons**, **mammoths**, giant sloths, and peccaries. Fossils of bats from the late Pleistocene (38,000 years ago) have been found in guano deposits in Mammoth Cave, Kentucky. Perhaps the most famous Pleistocene mammal site in the region is Big Bone Lick, located less than 2 kilometers (1.2 miles) south of the Ohio River in Boone County, Kentucky (*Figure 3.33*). Big Bone Lick is sometimes called the "birthplace of American vertebrate paleontology" because the first published illustration of a mastodon fossil (in 1756) was based on a tooth collected there. US President Thomas Jefferson acquired fossils from the site in 1808 that eventually ended up at the Academy of Natural Sciences of Philadelphia, the Natural History Museum in Paris, and as part of Jefferson's personal collection at Monticello. Big Bone Lick gets its name from the large number of natural **salt** springs, or **salt licks**, in the area. During the late Pleistocene, these saline springs attracted numerous large mammals, many of which died and were buried there. The fauna includes an extinct horse (*Equus complicatus*), two giant ground sloths (*Megalonyx jeffersonii* and *Paramylodon harlani*), mammoths (*Mammuthus* sp.), mastodons (*Mammut americanum*), and caribou (*Rangifer tarandus*). **Radiocarbon dating** shows that the age of the bones at Big Bone Lick are between 11,000 and 12,300 years old.

See Chapter 4: Topography to learn more about Mammoth Cave and other karst formations in the Southeast.

Figure 3.33: Entryway sign at Big Bone Lick, Kentucky.

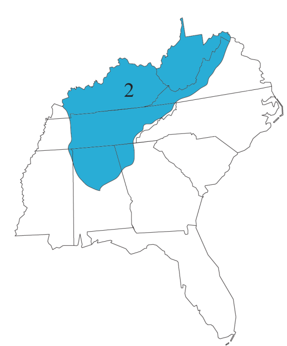
mastodon • *an extinct terrestrial mammal belonging to the Order Proboscidea, characterized by an elephant-like shape and size, and massive molar teeth with conical projections.*

mammoth • *an extinct terrestrial mammal belonging to the Order Proboscidea, from the same line that gave rise to African and Asian elephants.*

salt • *a mineral composed primarily of sodium chloride (NaCl).*

salt lick • *a naturally occurring salt deposit that animals regularly lick.*

radiocarbon dating • *a method of determining the age of a biological object by measuring the ratio of carbon isotopes* ^{14}C *and* ^{12}C*.*



3 Fossils

Region 3

Cretaceous • *a geologic time period spanning from 144 to 66 million years ago.*

cephalopod • *a marine invertebrate animal characterized by a prominent head, arms and tentacles with suckers, and jet propulsion.*

mosasaur • *an extinct, carnivorous, marine vertebrate reptile characterized by a streamlined body for swimming, a powerful fluked tail, and reduced, paddle-like limbs.*

plesiosaur • *a member of a group of extinct long-necked Mesozoic marine reptiles.*

Fossils of the Coastal Plain
Region 3

The late **Cretaceous** marine sediments of the Coastal Plain are frequently rich in both invertebrate and vertebrate fossils. Mollusks are especially common, including snails (gastropods), clams (bivalves), and **cephalopods** (*Figures 3.34 and 3.35*). Crabs are also sometimes locally abundant. Vertebrates include sharks, as well as marine reptiles: **mosasaurs** and, more rarely, **plesiosaurs** (*Figures 3.36 and 3.37*).

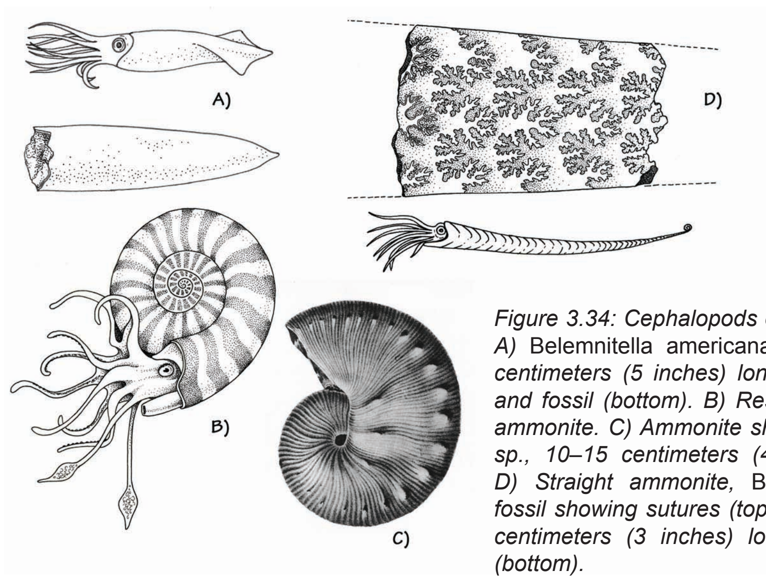


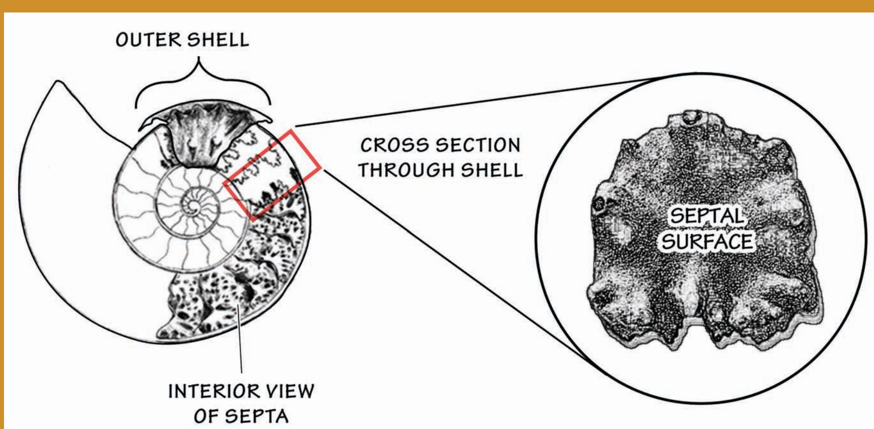
Figure 3.34: Cephalopods of the Coastal Plain. A) Belemnitella americana, *approximately 12 centimeters (5 inches) long. Restoration (top) and fossil (bottom). B) Restoration of a coiled ammonite. C) Ammonite shell fossil,* Scaphites sp., *10–15 centimeters (4–6 inches) across. D) Straight ammonite,* Baculites sp. *Partial fossil showing sutures (top), approximately 7.5 centimeters (3 inches) long, and restoration (bottom).*

Cephalopods

Cephalopods, such as squid, octopods, nautiloids, ammonoids, and belemnites, are mollusks with tentacles and beak-shaped mouths for catching prey. Some cephalopods such as belemnites and living cuttlefish have internal shells, while others have straight or coiled shells, such as those of ammonoids or nautiloids. Still other cephalopods, such as the octopus, have no shell. The mass extinction at the end of the Cretaceous (famous for eliminating the non-avian dinosaurs) also eliminated belemnites and ammonoids, which had been extremely diverse during the Mesozoic.

Ammonoids

Ammonoids are a major group of cephalopods that lived from the Devonian to the end of the Cretaceous. Both nautiloids (the group that today contains the chambered nautilus) and ammonoids have chambered shells subdivided by walls, or septa (plural of septum). These shells are frequently, but not always, coiled. The term "ammonoid" refers to the larger group of these extinct cephalopods, distinguished by complex, folded septa. Within ammonoids, "ammonites" is a smaller sub-group, distinguished by the extremely complex form of their septa. Ammonites were restricted to the Jurassic and Cretaceous periods. The form of the septa in nautiloids and ammonoids is not visible in a complete shell; it is most often seen in the trace of the intersection between the septum and the external shell. This trace is called a suture. Sutures are usually visible in fossils when sediment has filled the chambers of a shell, and the external shell has been broken or eroded away.



Ammonite shell break-away cross-section; surface plane of a septum and sediment-filled chamber.

ammonoid • *a member of a group of extinct cephalopods belonging to the Phylum Mollusca, and posessing a spiraling, tightly coiled shell characterized by ridges, or septa.*

chalk • *a soft, fine-grained, easily pulverized, white-to-grayish variety of limestone, composed of the shells of minute planktonic single-celled algae.*

coccolithophore • *a marine phytoplankton with a skeleton made up of microscopic calcareous disks or rings, and forming much of the content of chalk rocks.*

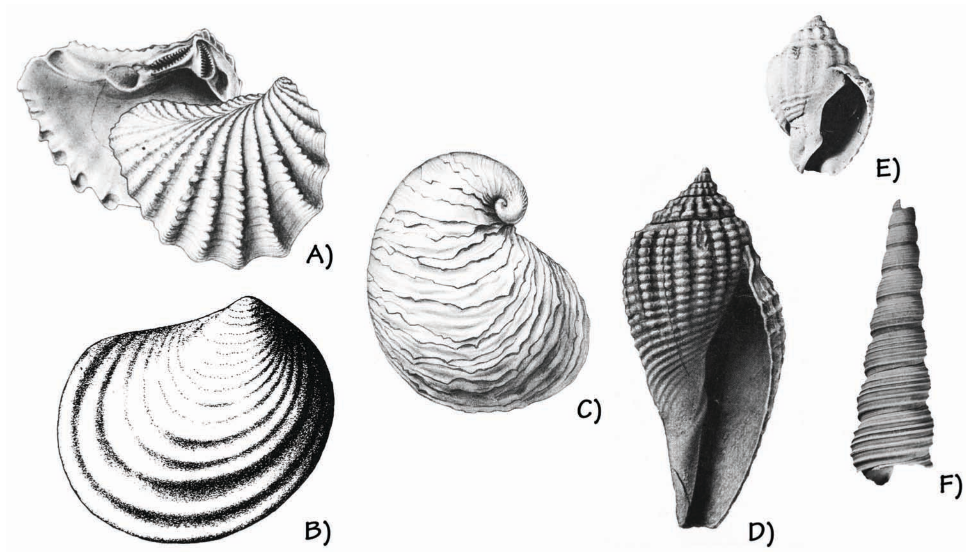


Figure 3.35: Common late Cretaceous marine mollusks from the Coastal Plain. A) Bivalve, Pterotrigonia thoracica, *5 centimeters (2 inches) wide. B) Bivalve,* Inoceramus *sp., 15 centimeters (6 inches) wide. C) Bivalve,* Exogyra ponderosa, *20 centimeters (8 inches) wide. D) Gastropod,* Volutomorpha mutabilis, *8.5 centimeters (3.3 inches) tall. E) Gastropod,* Buccinopsis solida, *4 centimeters (1.6 inches) tall. F) Gastropod,* Turritella vertebroides, *7 centimeters (2.8 inches) tall.*

Figure 3.36: Cretaceous shark teeth, Greene County, Alabama.

During the Cretaceous, the Western Interior Seaway (*Figure 3.38*) stretched across the center of North America from the Gulf of Mexico to the Arctic Ocean, and from the foot of the still-forming Rocky Mountains to as far east as Iowa. In some areas of this seaway there was deposition of **chalk**—a kind of limestone made up primarily of the shells of microscopic marine algae, called **coccolithophores** (*Figure 3.39*). Today, such sediments accumulate mainly in the deep sea, but during the Cretaceous, when sea levels were much higher than

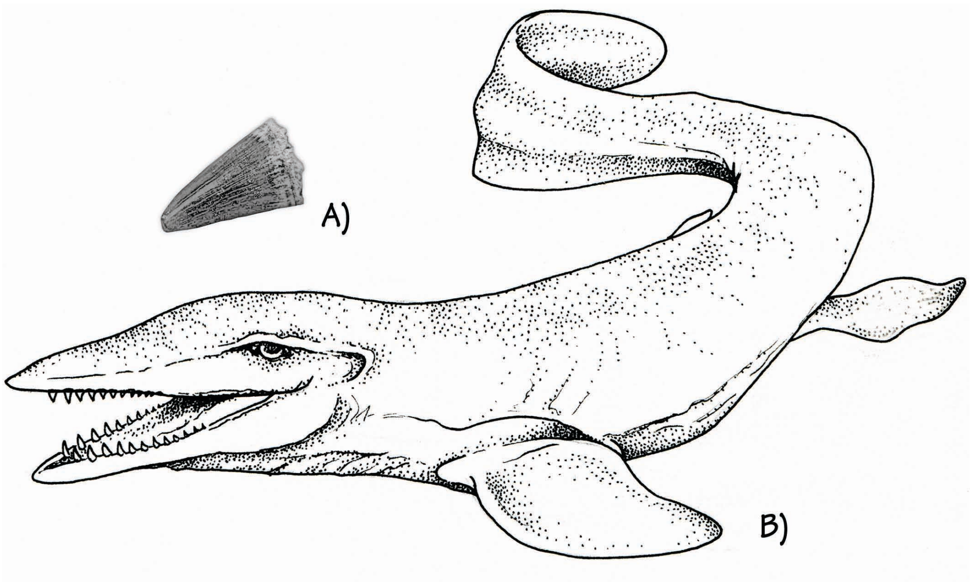


Figure 3.37: A) Mosasaur tooth, approximately 3 centimeters (1.2 inches) long. B) Restoration. Mosasaurs reached lengths of more than 10 meters (33 feet).

Figure 3.38: The Western Interior Seaway.

pterosaurs • *extinct flying reptiles with wingspans of up to 15 meters.*

Cenozoic • *the geologic time period spanning from 66 million years ago to the present.*

those of today, chalk accumulated in extensive shallow seas. The Cretaceous period, in fact, is named for the abundance of chalk that accumulated during this time. (The Latin word for chalk is *creta.*) Cretaceous chalk is common across much of central Alabama.

Florida's Only Trilobite

There are no rocks at the surface in Florida older than Eocene in age (approximately 55 million years old), but older rocks and fossils have been found in cores drilled deep below the surface. The oldest of these rocks dates to the early Ordovician period, about 480 million years ago, as determined by index fossils such as graptolites and brachiopods. The only trilobite ever found in Florida is a single specimen from one such core, drilled in Madison County, at a depth of around 1570 meters (4630 feet).

The trilobite* Plaesiacomia exsul, *recovered from middle Ordovician rocks in a deep core from northern Florida. Field of view approximately 1.4 centimeters (0.7 inches) wide.

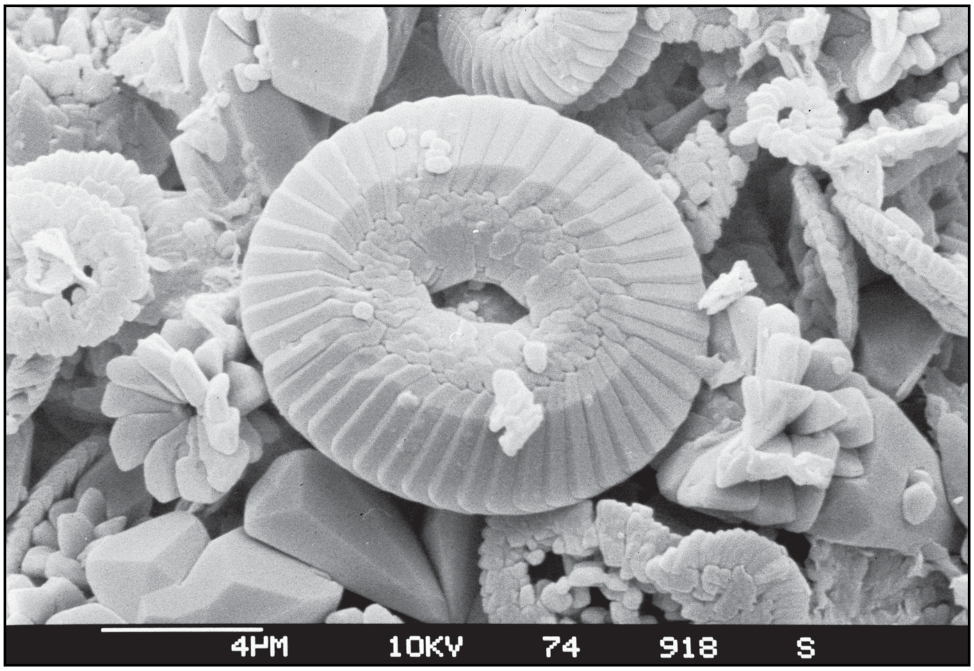


Figure 3.39: Microscopic view of Cretaceous chalk, showing that it is composed almost completely of the shells of protists called coccolithophores. Scale bar = 4 nanometers (4 x 10^{-9} meters; approximately 0.0000001575 inches).

Dinosaur fossils are not common in Coastal Plain sediments, thanks to the absence of Cretaceous-aged terrestrial deposits, although they have been found in almost every state (*Figure 3.40*). The region's dinosaur fossils all come from marine sediments, and were preserved when dinosaur carcasses floated out to sea. Most of these finds are isolated bones or partial skeletons, and are therefore difficult to identify. Dinosaurs represented include both herbivores (mostly hadrosaurs or "duckbills") and carnivores (theropods) (*Figure 3.41*). Other reptile groups are also known from the Coastal Plain's Cretaceous sediment, including flying reptiles (**pterosaurs**) from North Carolina and Georgia, and the giant crocodilian *Deinosuchus* (*Figure 3.42*), which reached lengths of up to 12 meters (39 feet) and is found from New Jersey to Texas.

Despite the lack of terrestrial sediments in the Coastal Plain, fossils of Cretaceous and **Cenozoic** land plants are known from a number of localities (*Figure 3.43*). These deposits formed in near-shore environments where land plants washed into coastal marshes. They include fossil leaves, and some, such as those in the late Cretaceous Ingersoll Shale of eastern Alabama, are extremely well preserved. Late Cretaceous **amber** (fossil tree resin) is found in several places, including Russell County, Alabama and Tishomingo County, Mississippi. Cenozoic plant fossils are surprisingly common across the Coastal Plain (*Figure 3.44*); fossil leaves are especially abundant in deposits of early **Eocene** age in the **Mississippi Embayment** (portions of Alabama, Mississippi, Arkansas, Louisiana, Texas, Kentucky, and Tennessee), occasionally forming localized deposits of brown coal (**lignite**). Petrified wood can also be found in a number of places in the Coastal Plain—Mississippi even has its own "petrified forest" in the town of Flora in Madison County (*Figure 3.45*).

amber *• a yellow or yellowish-brown hard translucent fossil resin that sometimes preserves small soft-bodied organisms inside.*

Eocene *• a geologic time period extending from 56 to 33 million years ago.*

Mississippi Embayment *• a topographically low-lying basin in the south-central United States, stretching from Illinois to Louisiana.*

lignite *• a soft, brownish-black coal in which the alteration of plant matter has proceeded farther than in peat but not as far as in bituminous coal.*

3 Fossils

Region 3

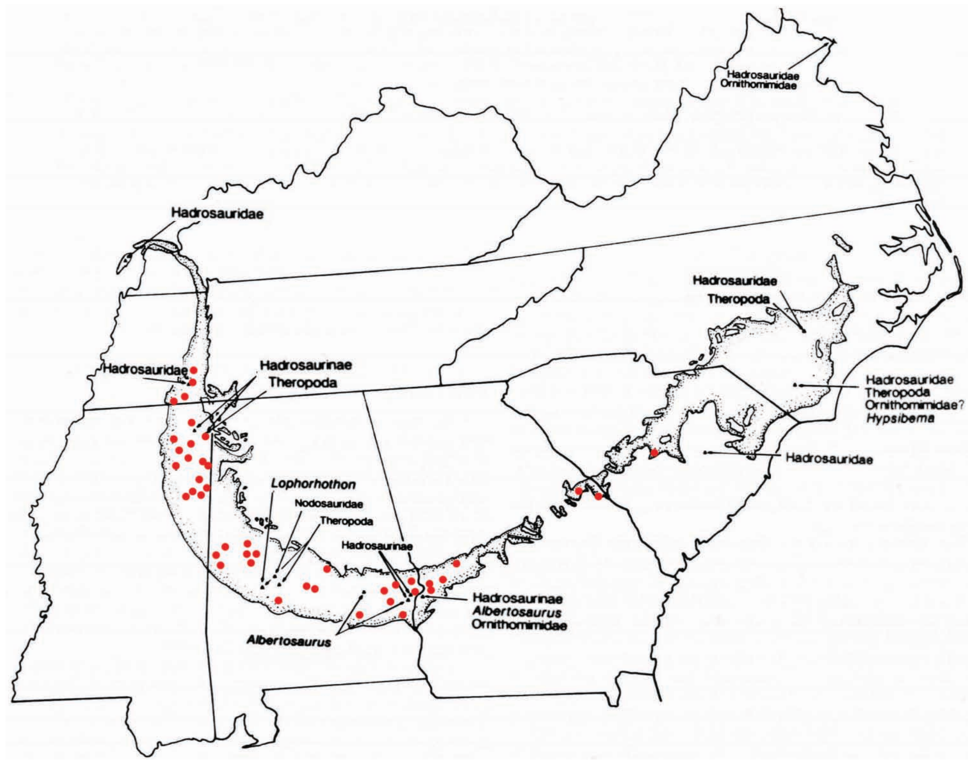


Figure 3.40: Map showing outcrop pattern of Cretaceous sediment and localities where dinosaurs have been found in the Southeastern US. (See TFG website for full-color version.)

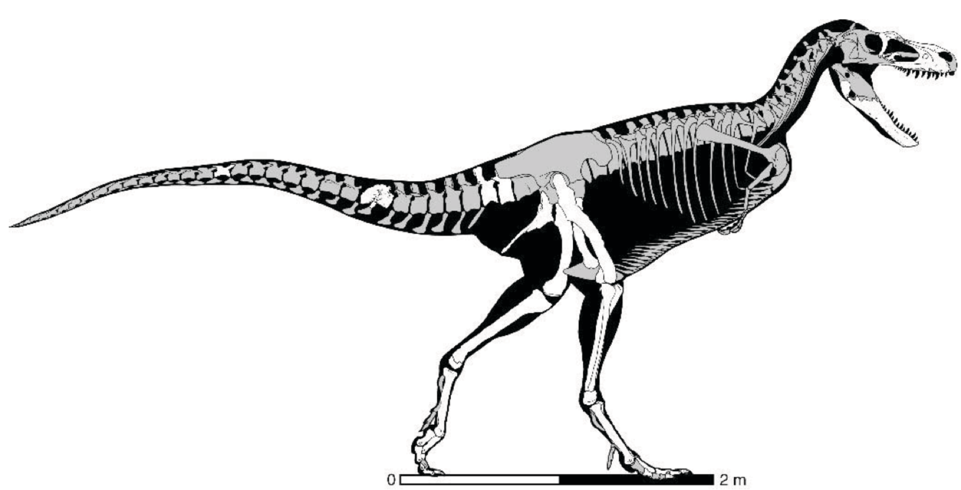


Figure 3.41: Skeletal reconstruction of the theropod dinosaur Appalachiosaurus montgomeriensis, *based on a juvenile specimen discovered in Alabama in 1982. The animal measured approximately 7 meters (23 feet) long and probably weighed approximately 590 kilograms (1300 pounds) in life.*

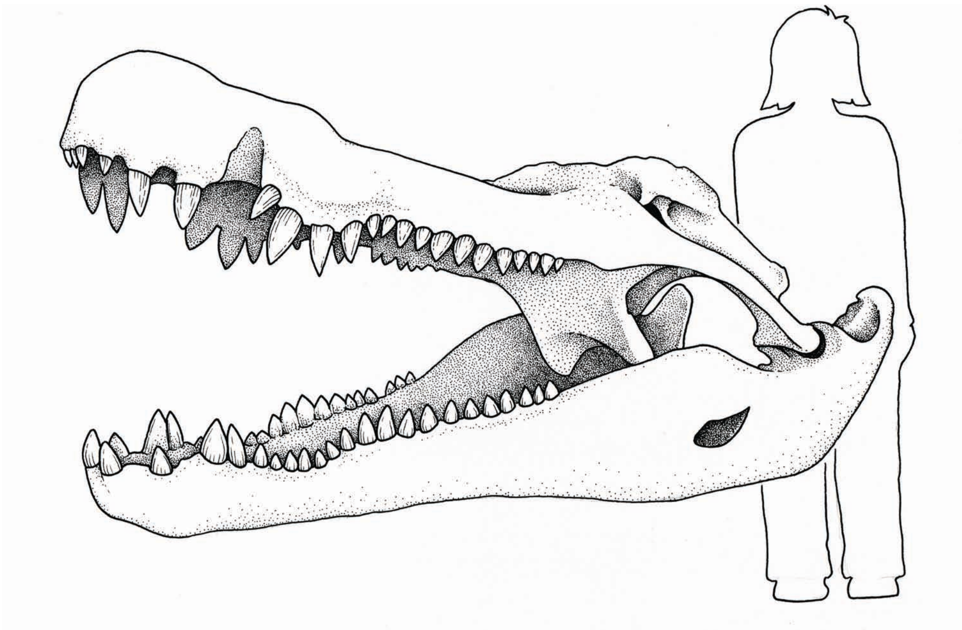


Figure 3.42: Reconstruction of the skull of the giant Cretaceous crocodillian Deinosuchus.

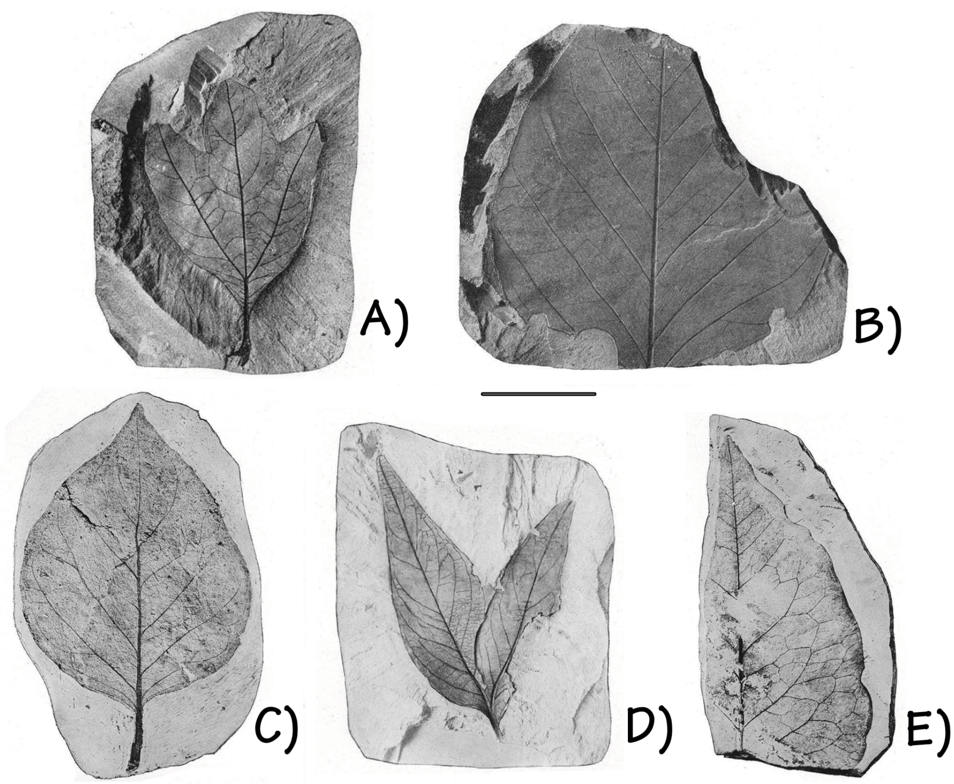


Figure 3.43: Cretaceous angiosperm (flowering plant) fossils from the Gulf Coastal Plain. All except E from Fayette County, Alabama. A) Platanus shirleyensis. *B)* Magnolia lacoeana. *C)* Cordia apiculata. *D)* Hymenaea fayetensis. *E)* Magnolia capellinii, *McNairy County, Tennessee. Scale bar is 1 centimeter (0.4 inch) long.*

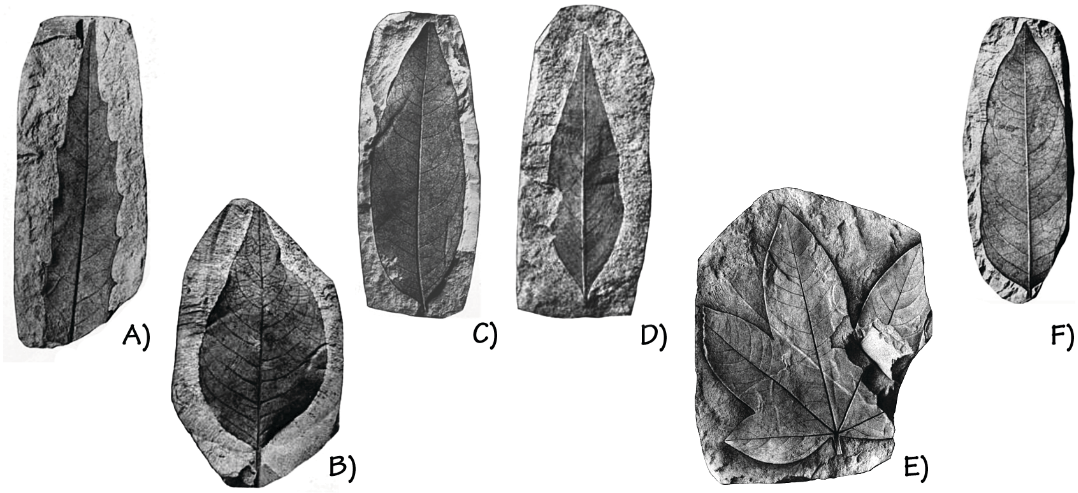


Figure 3.44: Cenozoic fossil plant leaves from the Gulf Coastal Plain. A) Dryophyllum anomalum*, Wilcox, Puryear, TN. B)* Euonymus splendens*. Grand Junction, TN. C)* Ficus puryearensis*, Wilcox, Puryear, TN. D)* Cassia puryearensis*. E)* Stercula puryearensis*. F)* Banisteria repandifolia*.*

***Paleogene** • the geologic time period extending from 66 to 23 million years ago.*

Figure 3.45: A permineralized log from the Mississippi Petrified Forest near Flora, Mississippi.

Paleogene sediments of the Coastal Plain are frequently extremely fossiliferous. Indeed, some deposits are among the most famous fossil beds in the world from this age, and have been studied since the early 1800s, longer than almost any other fossil-bearing sediments anywhere in America. For example, the late Eocene Gosport Sand in southwestern Alabama contains fossils of more than 500 species of mollusks. Fossil mollusks—mainly clams and snails—of

Region 3

Paleocene, Eocene, and **Oligocene** age occur across the Gulf and Atlantic Coastal Plains, from Texas to Maryland, frequently in beautifully preserved shell beds that contain scores to hundreds of different species. More than 3000 different species of mollusks have been described from these beds (*Figures 3.46 and 3.47*). In Florida, Eocene limestones also contain abundant mollusks (usually only as molds and casts) and echinoids (sand dollars and sea urchins) (*Figure 3.48*).

Paleocene *• a geologic time interval spanning from about 66 to 56 million years ago.*

Oligocene *• a geologic time interval spanning from about 34 to 23 million years ago.*

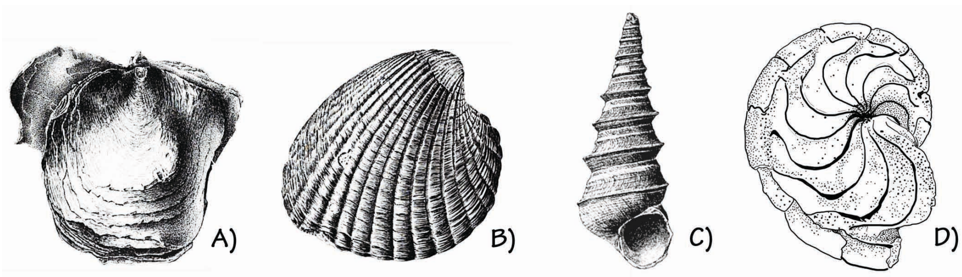


Figure 3.46: Atlantic Coastal Plain Paleogene mollusks; A–C: from the Paleogene Aquia Formation of northeastern Virginia; or D: the early Oligocene of Florida. A) Bivalve, Cubitostrea sellaeformis, *approximately 15 centimeters (6 inches) wide. B) Bivalve,* Venericardia *sp., approximately 7.5 centimeters (3 inches) wide. C) Gastropod,* Turritella mortoni*, approximately 10 centimeters (4 inches) tall. D) Nautiloid,* Aturia alabamiensis*, approximately 15 centimeters (6 inches) in diameter.*

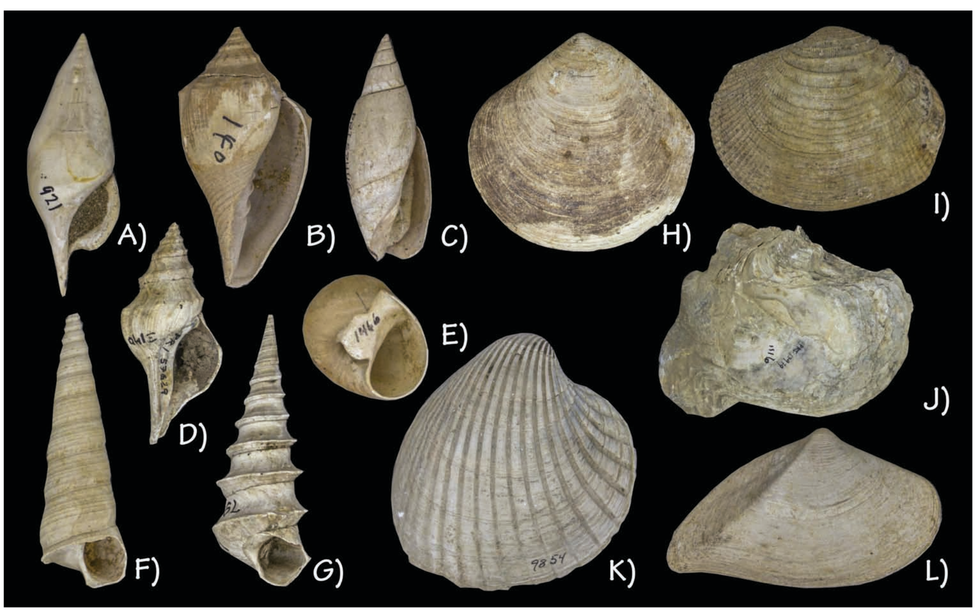


Figure 3.47: Gulf Coastal Plain Paleocene and Eocene mollusks from Mississippi and Alabama. A–G) Gastropods; H–L) bivalves. A) Calyptraphorus velatus*, late Eocene, 5 centimeters (2 inches) tall. B)* Athleta sayana*, middle Eocene, 5 centimeters (2 inches) tall. C)* Agaronia alabamensis*, middle Eocene, 4 centimeters (1.6 inches) tall. D)* Levifusus prepagoda*, early Eocene, 5 centimeters (2 inches) tall. E)* Neverita limula*, middle Eocene, 4 centimeters (1.6 inches) tall. F)* Turritella arenicola*, late Eocene, 3.8 centimeters (1.5 inches) tall. G)* Turritella mortoni postmortoni*, late Paleocene, 6 centimeters (2.4 inches) tall. H)* Crassatella alta*, middle Eocene, 10 centimeters (3.9 inches) wide. I)* Corbis distans*, middle Eocene, 4.5 centimeters (1.8 inches) wide. J)* Cubitostrea sellaeformis*, middle Eocene, 10 centimeters (3.9 inches) wide. K)* Venericardia planicosta*, early Eocene, 5.5 centimeters (2.2 inches) wide. L)* Crassatellites protextus*, middle Eocene, 5 centimeters (2 inches) wide.*

Region 3

passive margin *• a tectonically quiet continental edge where crustal collision or rifting is not occurring.*

Pangaea *• supercontinent, meaning "all Earth," which formed over 300 million years ago and lasted for almost 150 million years.*

embayment *• a bay or recess in a coastline.*

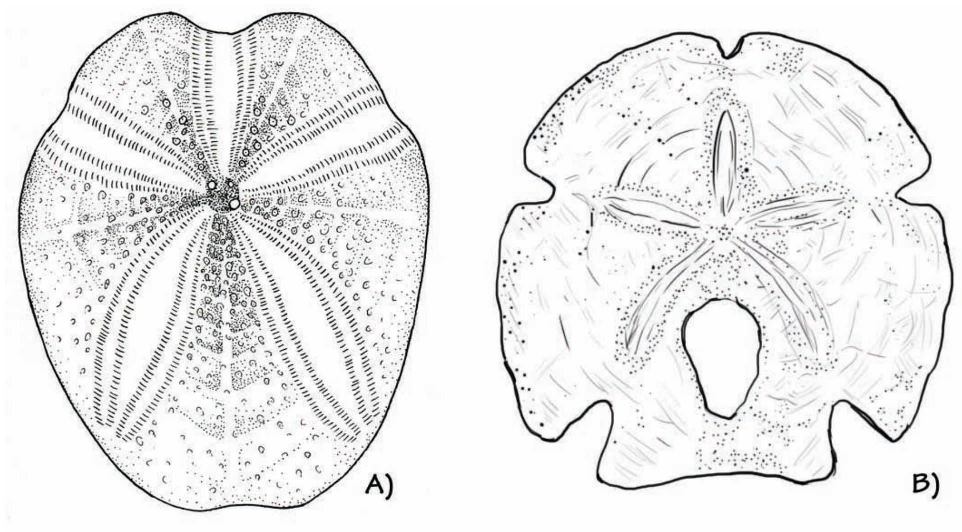


Figure 3.48: Cenozoic sand dollars (echinoids) of Florida. A) Eupatagus antillarum*, Eocene, 4 centimeters (1.6 inches) in diameter. B)* Encope tamiamiensis*, Pliocene, 10 centimeters (4 inches) in diameter.*

Echinoids

Echinoids (sea urchins and sand dollars) are echinoderms, related to sea stars and crinoids. All echinoderms have external skeletons made of numerous plates of the mineral calcite (a form of calcium carbonate), and a unique water vascular system that drives most of their motion. Echinoids have rounded or flattened shells, called tests, which bear numerous spines. Tiny tube feet, connected to the water vascular system, extend through holes in the test and allow the animals to move on or within the sea floor. All echinoids exhibit the characteristic five-fold symmetry of echinoderms.

The Gulf and Atlantic coasts of North America are **passive margins**, formed when the supercontinent **Pangaea** broke apart between 200 and 100 million years ago. The continents did not break smoothly along a straight line, but rather along an irregular line with curves pointing outward (promontories) and inward

See Chapter 1: Geologic History for more on how siliciclastic deposition shaped the Coastal Plain.

(**embayments**). As the Cenozoic passed and erosion of the land continued, the embayments along the Atlantic coast became locations of **siliciclastic** deposition, as well as semi-restricted areas that developed their own particular kinds of organisms. Geologists and paleontologists studying the **Neogene** geology of the Atlantic Coastal Plain frequently study the area's sediments and fossils one embayment at a time, then attempt to connect them together to form a larger story. These shallow marine deposits contain many abundant and diverse fossil beds, especially mollusks (clams and snails), but also corals, barnacles, and many other organisms (*Figures 3.49–3.53*). In Florida, the geographic setting for sedi-ment accumulation included more carbonate, and its fossil-bearing deposits vary from shelly **sand** in the northern and central parts of the state to reef limestone in the far south and throughout the Florida Keys (*Figures 3.54 and 3.55*).

See Chapter 4: Topography to learn more about embayments.

See Chapter 7: Soils to learn about sandy Entisols, a common soil type found throughout the Coastal Plain.

siliciclastic • *pertaining to rocks that are mostly or entirely made of silicon-bearing clastic grains weathered from silicate rocks.*

Neogene • *the geologic time period extending from 23 to 2.6 million years ago.*

sand • *rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

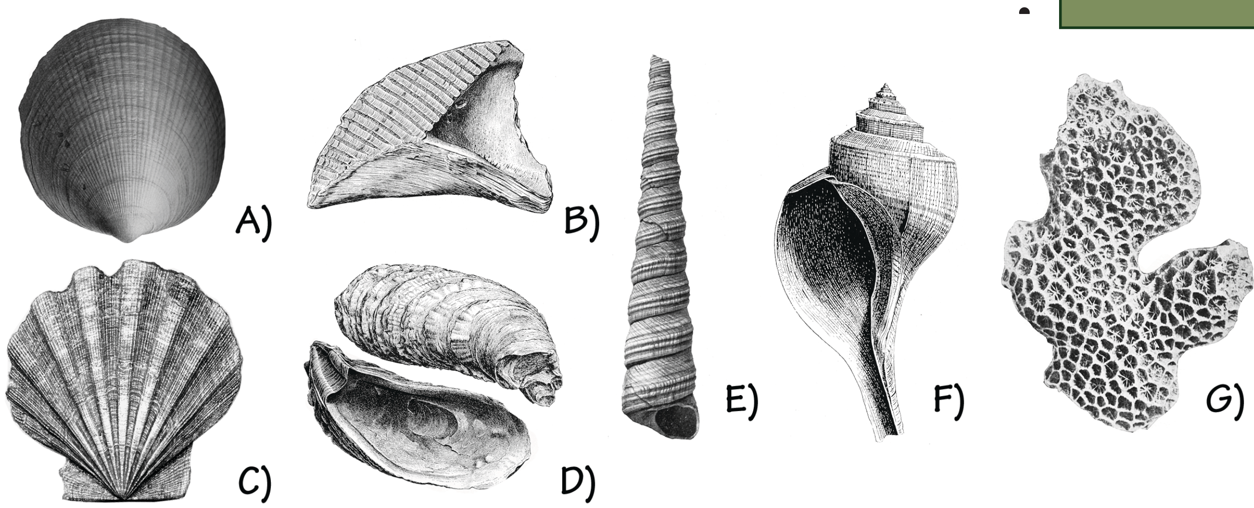


Figure 3.49: Miocene-Pliocene marine invertebrates from Virginia and the Carolinas. A) Bivalve, Glycymeris americana, *approximately 8.5 centimeters (3.5 inches) wide. B) Bivalve,* Isognomon maxillata, *approximately 16 centimeters (6.5 inches) tall/wide. C) Bivalve,* Chesapecten jeffersonius, *approximately 12 centimeters (5 inches) tall/wide. D) Bivalve,* Crassostrea virginica, *approximately 16 centimeters (6.5 inches) tall/wide. E) Gastropod,* Turritella eichwaldiella, *approximately 10 centimeters (4 inches) tall/wide. F) Gastropod,* Busycon canaliculatum, *approximately 20 centimeters (8 in) tall/wide. G) Scleractinian coral,* Septasrea marylandica, *approximately 7 centimeters (3 inches) tall.*

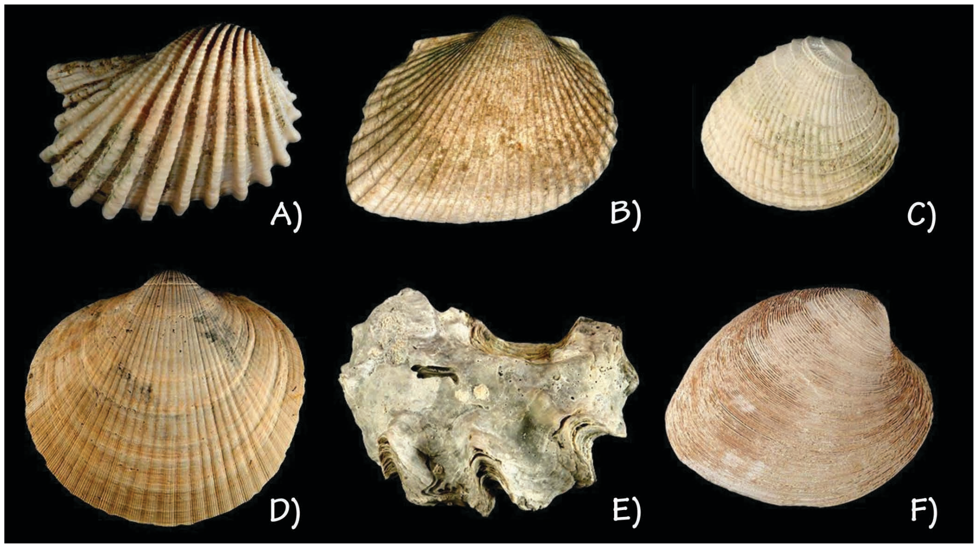


Figure 3.50: Pliocene-Pleistocene marine bivalves from Florida and the Carolinas. A) Anadara aequalitas*, approximately 3.5 centimeters (1.5 inches) wide. B)* Anadara callicestosa*, approximately 3 centimeters (1.2 inches) wide. C)* Chione erosa*, approximately 2 centimeters (0.8 inches) wide. D)* Glycymeris americana*, approximately 5 centimeters (2 inches) wide. E)* Undulostrea locklini*, approximately 4 centimeters (1.8 inches) wide. F)* Mercenaria campechiensis*, approximately 12 centimeters (7 inches) wide.*

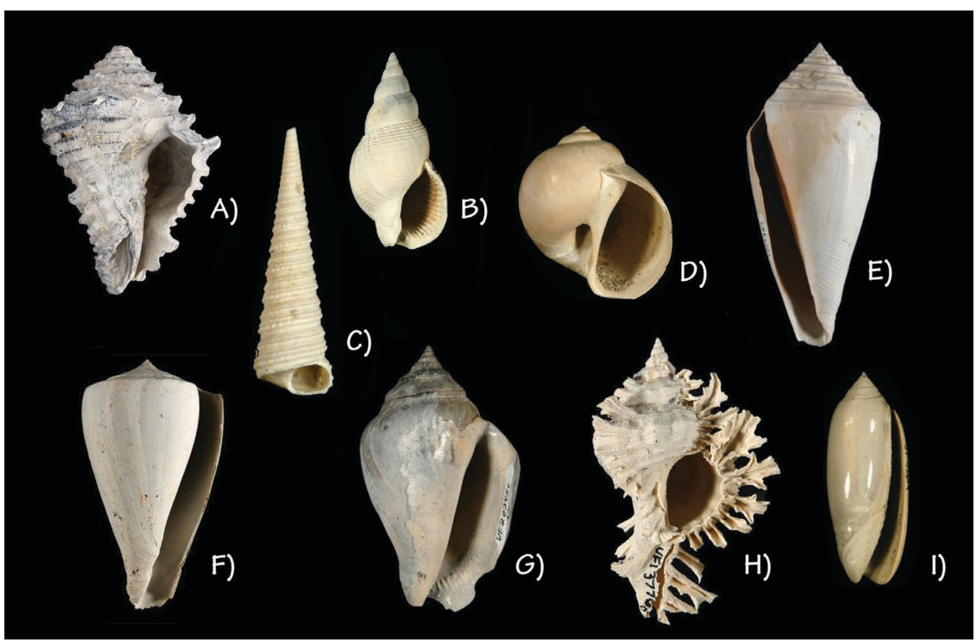


Figure 3.51: Pliocene-Pleistocene marine gastropods from Florida and the Carolinas. A) Vasum horridum*, 8 centimeters (4.5 inches) tall. B)* Calophos wilsoni*, 5 centimeters (2 inches) tall. C)* Turritella gladeensis*, 5 centimeters (2 inches) tall. D)* Euspira sayana*, 3.5 centimeters (1.5 inches) tall. E)* Contraconus adversarius*, 10 centimeters (4 inches) tall. F)* Conus haytensis*, 12 centimeters (5 inches) tall. G)* Strombus floridanus*, 6 centimeters (2.5 inches) tall. H)* Chicoreus floridanus*, 6 centimeters (2.5 inches) tall. I)* Oliva carolinensis*, 5 centimeters (2 inches) tall.*

Bivalves

Clams and their relatives, such as mussels, scallops, and oysters, are mollusks possessing a pair of typically symmetrical shells. Most are filter feeders, collecting food with their gills. Paleozoic bivalves typically lived on the surface of the sediment ("epifaunally"), but in the Mesozoic they evolved the ability to burrow more deeply into the sediment, becoming "infaunal." This innovation led to the rapid evolution of a large number of groups present in today's oceans.

Gastropods

Commonly known as snails, gastropod mollusks encompass terrestrial, freshwater, and marine species, and include varieties with and without shells (e.g., slugs). Gastropods are among the most diverse groups of organisms—only insects have more named species. The soft parts of gastropods are generally similar to those of bivalves, but the former typically have coiled shells and are usually much more active. Gastropods are present in Paleozoic and Mesozoic rocks, but are especially abundant and diverse in Cretaceous and Cenozoic sediments of the Coastal Plain.

Figure 3.52: Cluster of large barnacles, approximately 25 centimeters (10 inches) tall, Pliocene of Florida.

Figure 3.53: Pleistocene oyster reef at the Intracostal Waterway near Charleston, South Carolina.

Figure 3.54: Fossilized coral in the Key Largo Limestone, exposed at the Windley Key Fossil Reef Geological State Park in the Florida Keys.

Figure 3.55: Neogene corals from Florida. A) Silicified scleractinian coral (sawed in half to reveal "geodized" interior), late Miocene, Tampa Bay, approximately 9 centimeters (3.5 inches) in diameter. B) Manicina areolata*, approximately 15 centimeters (6 inches) wide. C)* Septastrea marylandica*, approximately 3 centimeters (1.25 inches) wide.*

archaeocete *• a member of a group of primitive whales that lived during the Eocene and Oligocene epochs.*

Marine Mammals

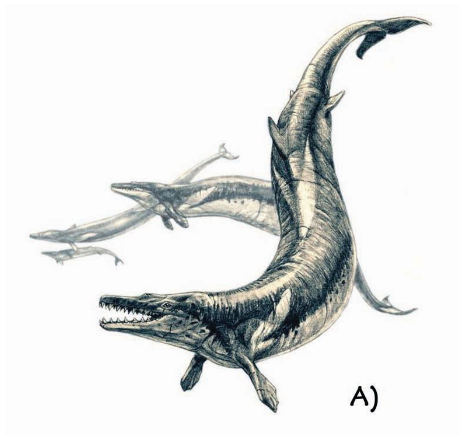
Whales evolved from four-legged, land-living mammals during the Eocene epoch, beginning around 55 million years ago. Fossils discovered over the past few decades in Pakistan and Egypt have revealed numerous extinct forms that show the evolutionary steps in this remarkable transition, from an animal resembling a wolf (but more closely related to an antelope) to a fully aquatic animal with an elongate body, nostrils on top of its head, and little or nothing in the way of hind limbs. The earliest whale-like forms are called **archaeocetes**, and these animals were first discovered in the Eocene sediments of Alabama's Coastal Plain during the early 1800s. Many different species of archaeocetes lived in warm, low-latitude seas around the world. Their multicusped teeth with distinctive, yolk-shaped roots, as well as their large vertebrae, can be found from Maryland to Mississippi (*Figures 3.56 and 3.57*). Archaeocetes became

Figure 3.56: Skeleton of the Eocene archaeocete whale Zygorhiza kochii *from Mississippi. This skeleton, mounted in the Mississippi Museum of Natural Sciences, is approximately 5.2 meters (17 feet) long.*

odontocete • *a member of the group of whales (cetaceans) that have baleen for feeding on fish, squid, and mammals.*

mysticete • *a member of the group of whales (cetaceans) that have baleen for feeding on plankton, krill, and small fish.*

extinct in the early Oligocene. From them evolved the two major groups of modern whales: the toothed whales or **odontocetes** (dolphins, porpoises, and the sperm whale), and the toothless baleen whales or **mysticetes** (the large plankton-feeding whales such as blue whales and right whales). Fossils of whales and dolphins can be found in Miocene and younger sediments along much of the Atlantic Coastal Plain and Gulf Coast of Florida (*Figure 3.58*).



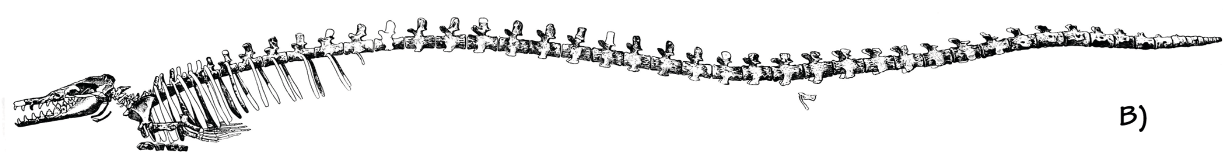
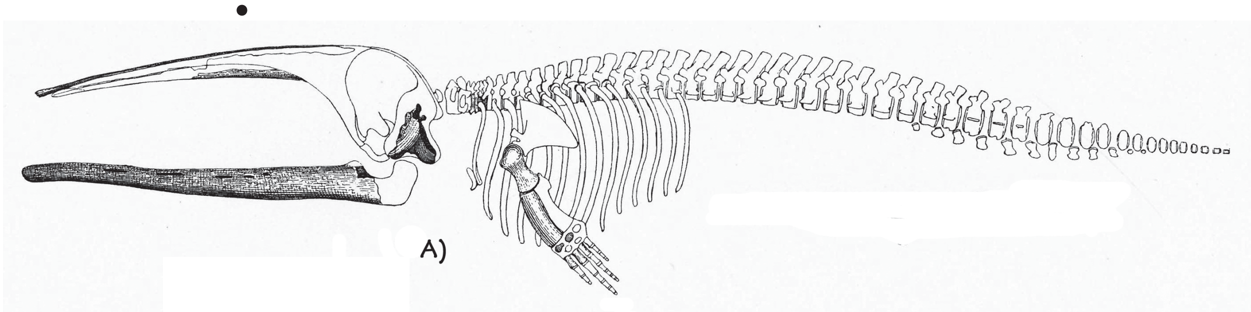


Figure 3.57: The giant archaeocete whale, Basilosaurus cetoides*, from the late Eocene of Alabama. A) Restoration and B) drawing of a skeleton mounted in the National Museum of Natural History in Washington, DC, found in Choctaw County. The skeleton is approximately 15 meters (50 feet) long.*



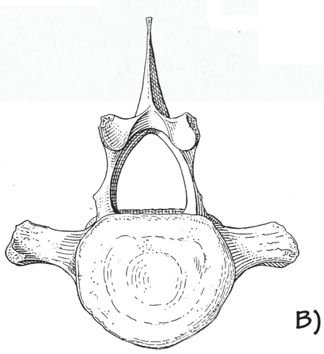


Figure 3.58: Neogene whales from the Coastal Plain. A) Skeleton of a small baleen whale, Miocene of Virginia, approximately 9 meters (29 feet) long. B) End view of a single whale vertebra, approximately 20 centimeters (8 inches) tall.

Manatees and dugongs belong to a group of aquatic mammals called **sirenians**. One species of manatee lives in Florida's rivers today. Many different kinds of sirenians, however, are represented by fossils found in the Coastal Plain, especially in Florida (*Figure 3.59*), where they are the most common fossil mammal. Manatees and dugongs are strict herbivores. Their bones tend to be easily recognized because of their high **density**, which provides them with ballast to counteract the buoyant blubber layer that covers their bodies.

sirenian *• an aquatic herbivorous mammal known as a sea cow, including dugongs and manatees.*

density *• a physical property of minerals, describing the mineral's mass per volume.*

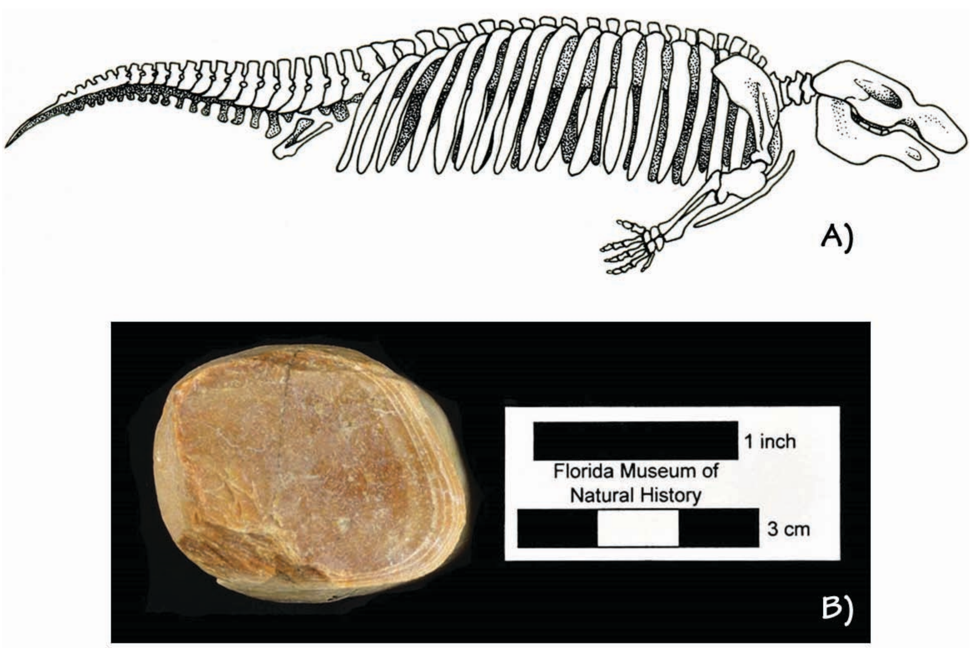


Figure 3.59: Fossil dugong, Metaxytherium floridanum, *middle to late Miocene of Florida. A) Skeleton, 3–3.5 meters (10 feet) in length. B) Cross-section through a rib, approximately 3 centimeters (1.5 inches) in diameter.*

Sharks and Rays

Sharks and rays have skeletons made of cartilage instead of bone, which means that their skeletons rarely are found as fossils. The teeth of sharks and rays, however, are much more resistant, and are common fossils in Cretaceous and Cenozoic sediments throughout the Coastal Plain. They are often found on beaches, where they may have washed in from offshore, or washed down in rivers from upland (*Figure 3.60*). Sharks shed their teeth constantly, and a single individual can produce as many as 35,000 teeth during its lifetime. You can tell the difference between fossil and modern shark teeth by their color: fossils are brown or black, whereas modern teeth are tan to white. Shark teeth come in many forms and sizes, but this can be misleading because not all teeth in the mouth of a single individual look alike.

The largest shark that ever lived was a species related to the modern great white shark, but much bigger. *Carcharocles megalodon* (frequently called just "megalodon") lived in the western Atlantic Ocean from approximately 16 to 2.6 million years ago (middle Miocene to late **Pliocene**). *C. megalodon* is regarded

__Pliocene__ • a geologic time interval extending from roughly 5 to 2.5 million years ago.

as one of the largest and most powerful predators ever (*Figure 3.61*). Because its fossil record consists almost entirely of teeth (which are common fossils in the Coastal Plain), size estimates have varied widely, but it seems reasonable to estimate that *C. megalodon* reached lengths of up to 18 meters (59 feet). It likely fed on large whales.

Rays and skates are close relatives of sharks, with cartilaginous skeletons and hard, easily fossilizable teeth. Many ray species feed on hard-shelled prey, such as clams that they dig up out of sand bottoms, and their teeth therefore frequently have flat, ridged surfaces suitable for grinding. Ray teeth are common fossils found on beaches throughout the Coastal Plain (*Figure 3.62*).

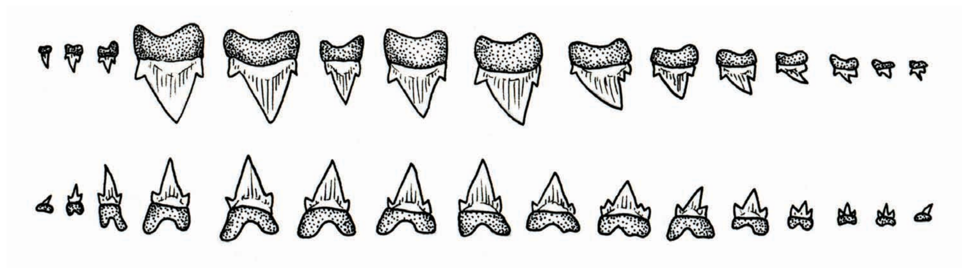


Figure 3.60: A generalized image of the teeth in a typical shark's upper and lower jaws, showing size and shape variation.

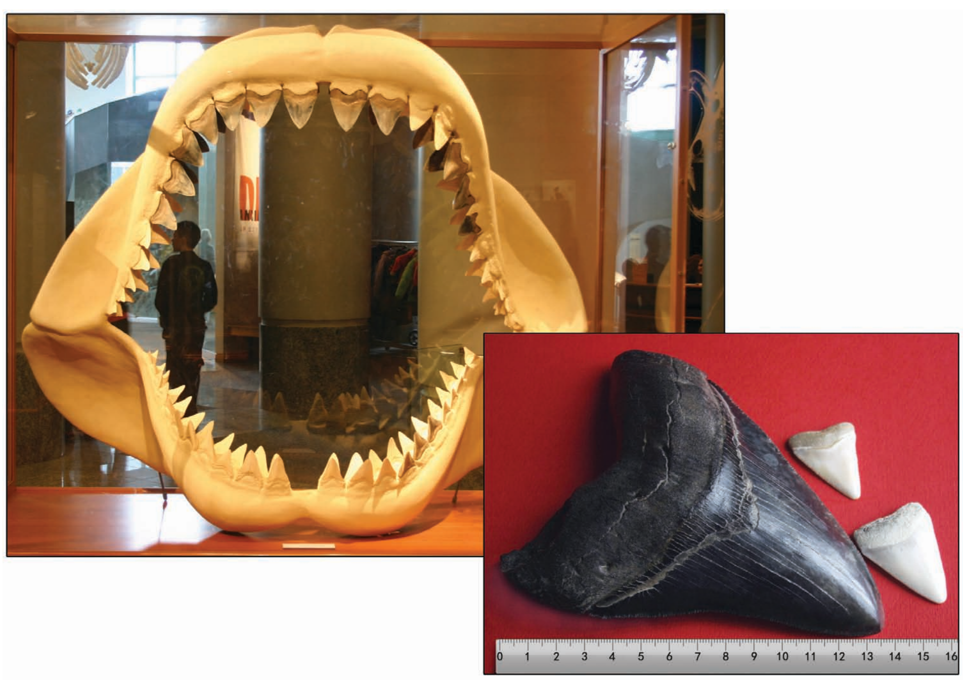


Figure 3.61: The giant great white shark, Carcharocles megalodon. *Reconstructed set of jaws, in the North Carolina Museum of Natural Sciences. Inset: Fossil tooth (left) next to two modern great white shark teeth* (Carcharodon carcharias).

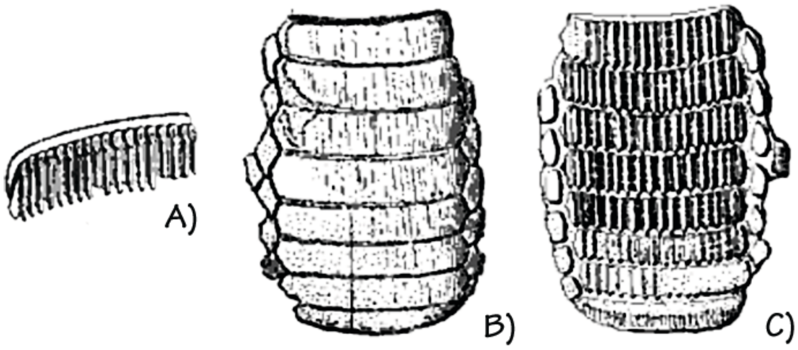


Figure 3.62: Dental plates of rays, adapted for grinding shells of mollusks. The "dental pavement" is made of numerous rows of plates, each with many ridges and grooves. A) Single plate, approximately 2 centimeters (0.8 inches) long. B and C) Entire pavement, upper and lower views, approximately 7 centimeters (3 inches) long.

Cenozoic Terrestrial Vertebrates (Birds & Mammals)

Many species of Pliocene birds are found in Florida. Most of these are marine (*Figure 3.63*), but some are among the largest land-living birds known. *Titanis walleri*, more commonly known as the North American "terror bird," is one of the largest known members of an extinct group of flightless carnivorous birds from the Cenozoic of South America. Of this group, the terror bird was the only one to migrate to North America, and probably the last known member of its lineage. Bones of this giant bird are found at several sites in Florida (*Figure 3.64*).

Figure 3.63: Bones of an extinct Pliocene species of cormorant from a shell pit near Sarasota, Florida. Hundreds of these skeletons were found in a single layer, apparently the result of a mass death due to red tide (a toxin-producing algal bloom that frequently kills fish and other marine life) followed by deposition in a storm.

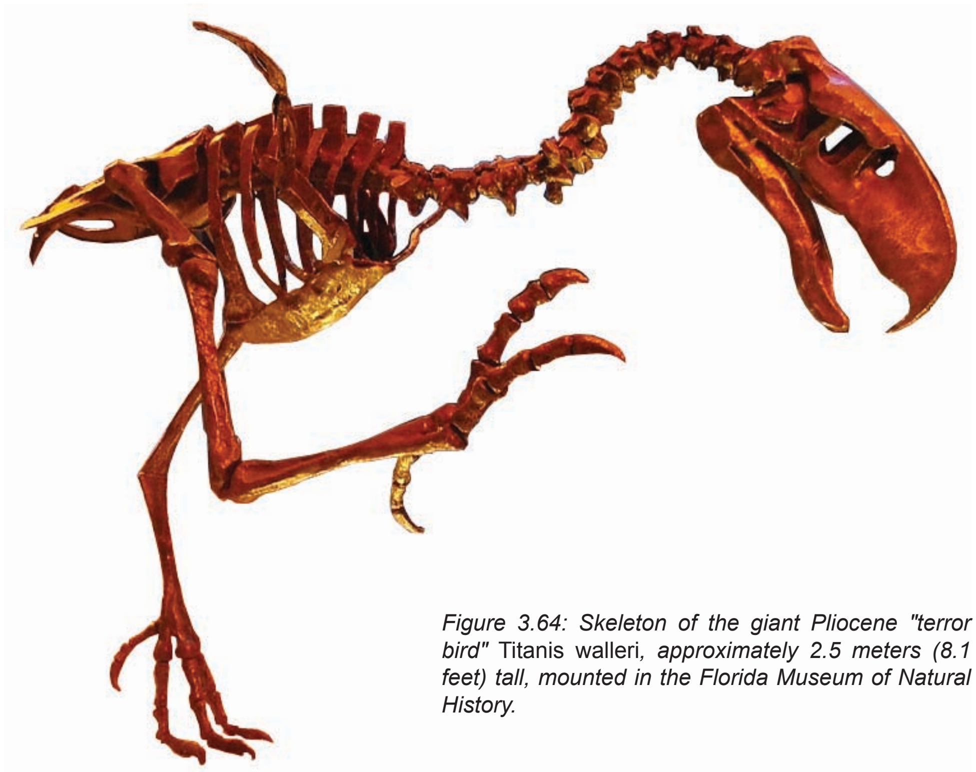


Figure 3.64: Skeleton of the giant Pliocene "terror bird" Titanis walleri*, approximately 2.5 meters (8.1 feet) tall, mounted in the Florida Museum of Natural History.*

Paleogene mammals are not common in the Coastal Plain, but a number of species have been identified from central Mississippi. These include a primitive primate and an early horse from the late Paleocene to early Eocene, and an early rhinoceros from the Oligocene. Fossils of Neogene mammals are abundant and diverse in the Coastal Plain—Florida has the richest fossil record of vertebrate animals in the eastern United States. For example, the Leisey Shell Pit in Hillsborough County, Florida (near Tampa Bay) has produced not only fossil shells, but was also one of the most important early Pleistocene fossil bone beds in the state. Fossils of many species of mammals and birds have been found there, including sabertoothed cats, tapirs, horses, and llamas (the quarry is now closed and flooded). Fossils of Pleistocene mammals are especially common throughout the Coastal Plain (*Figures 3.65 and 3.66*), from horse teeth on the coasts of the Carolinas to the bones of giant ground sloths, tapirs, horses, bison, and mastodons on the banks of the Mississippi River near Vicksburg, Mississippi. Among the most common Pleistocene vertebrate fossils in the Southeast are those of mastodons and mammoths (*Figure 3.67*). Both were common in the Southeast (and elsewhere in North America) during the Pleistocene, but they had different ecological preferences, and their fossils are usually found separately.

Figure 3.65 (AT RIGHT): Five genera of horses known from fossils from the Coastal Plain (mostly Florida). Restoration images all to same scale.

Fossils

3

Region 3

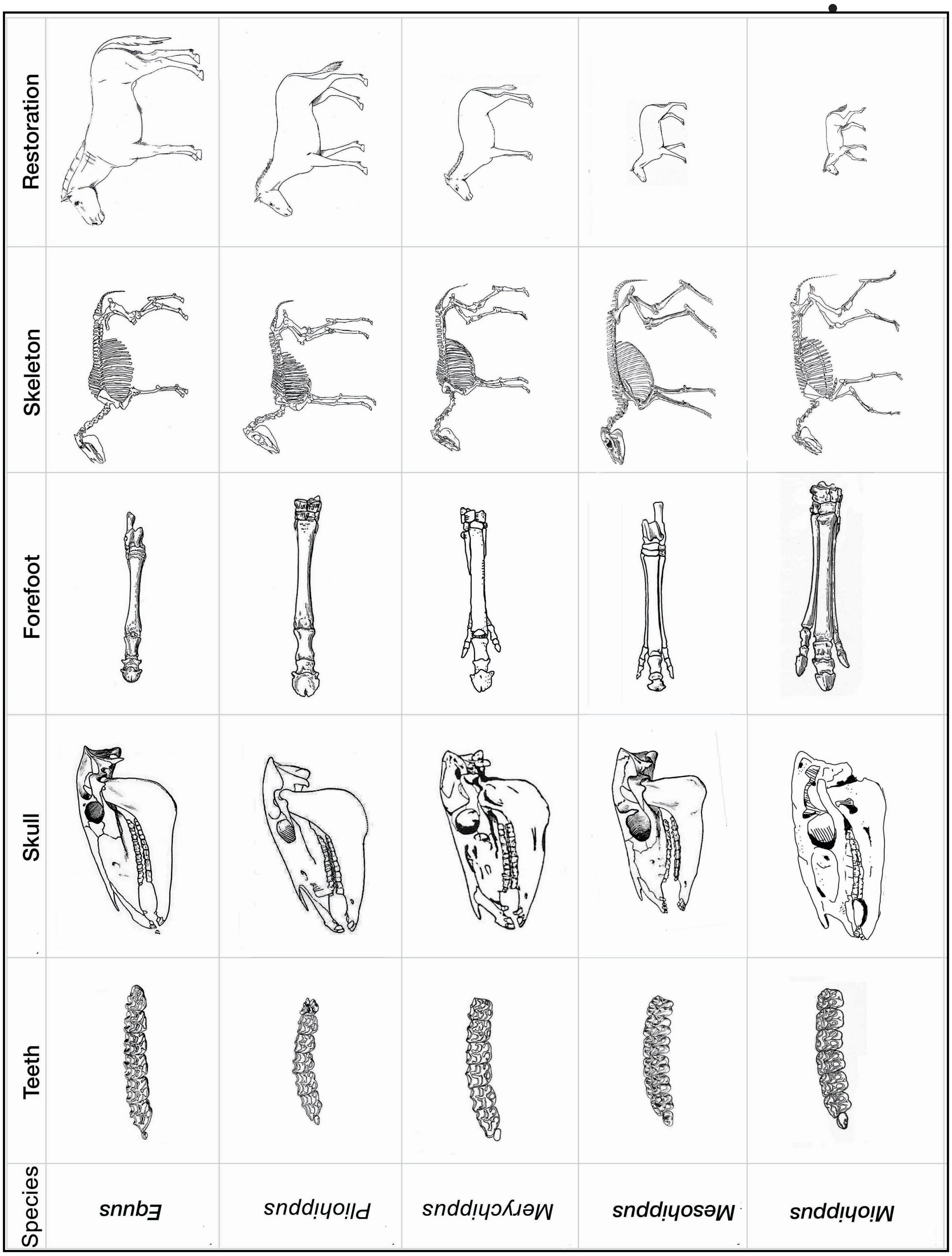


Figure 3.66: Skeletal cast of the giant sloth, Megalonyx jeffersoni, *Pleistocene of the Coastal Plain. Approximately 3 meters (10 feet) tall.*

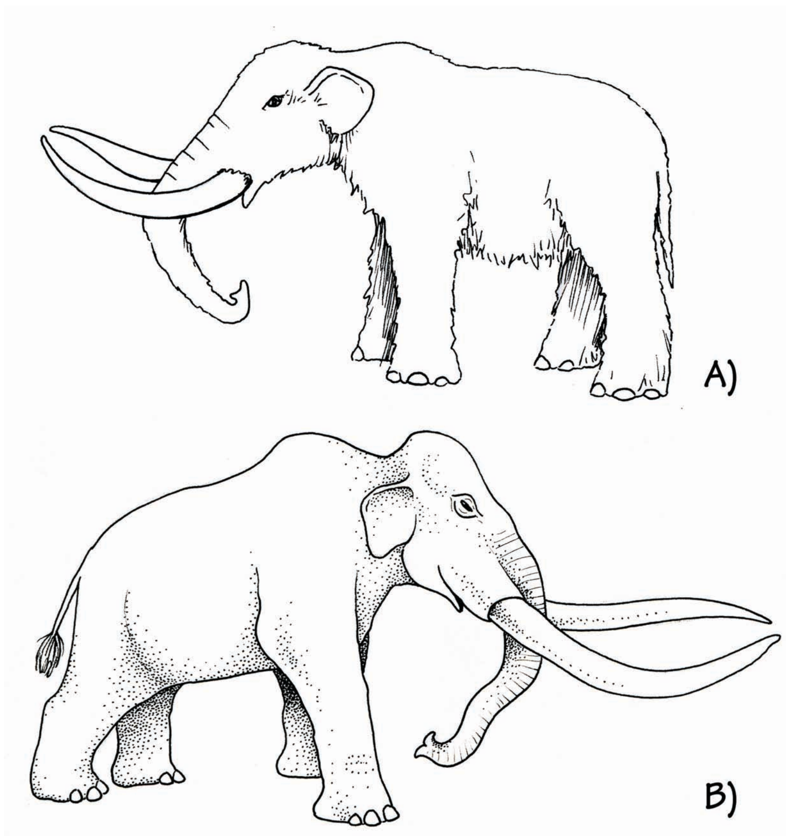
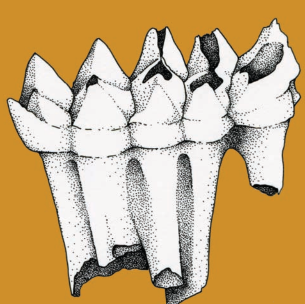


Figure 3.67: Restorations of A) American mastodon, Mammut americanum, *approximately 2.3 meters (7.5 feett) high at the shoulder. B) Columbian mammoth,* Mammuthus columbi, *approximately 4 meters (13 feet) high at the shoulder.*

Mastodons and Mammoths

These two kinds of ancient elephants (or, more technically, proboscideans) are frequently confused. Both were common during the Pleistocene, but they had different ecological preferences and are usually found separately. Mammoths are close cousins of modern African and Asian elephants; mastodons are more distant relatives, from a separate line of proboscideans that branched off from the modern elephant line in the Miocene. Mastodons have a shorter, stockier build and longer body; mammoths are taller and thinner, with a rather high "domed" skull. In skeletal details, the quickest way to tell the difference is by the teeth: mastodons have teeth with conical ridges, a bit like the bottom of an egg carton; mammoths, in contrast, have teeth with numerous parallel rows of ridges. The teeth are indicative of the two species' ecological differences. Mastodons preferred to bite off twigs of brush and trees, while mammoths preferred tough siliceous grasses. Thus, mastodon teeth are more suitable for cutting, while mammoth teeth are more suitable for grinding. Both mammoths and mastodons became extinct around 10,000 years ago.



A mastodon tooth, suitable for chewing twigs and tree leaves. Approximately 20 centimeters (8–9 inches) long.

A mammoth tooth, suitable for grinding grass and softer vegetation. Approximately 25 centimeters (1 foot) long.

State Fossils

Alabama
Basilosaurus cetoides (archaeocete whale; Eocene) (*Figure 3.57*)

Florida
Florida has no state fossil.

Georgia
Shark tooth (Cretaceous and Cenozoic) (*Figure 3.60*)

Kentucky
Brachiopod (Paleozoic) (*Figure 3.13*)

Mississippi
Basilosaurus cetoides and *Zygorhiza kochii* (archaeocete whales; Eocene) (*Figures 3.56 and 3.57*)

North Carolina
Carcharocles megalodon (shark; Miocene-Pliocene) (*Figure 3.61*)

South Carolina
Mammuthus columbi (Columbian mammoth; Pleistocene) (*Figure 3.67)*

Tennessee
Pterotrigonia (Scabrotrigonia) thoracica (bivalve; Cretaceous) (*Figure 3.35*)

Virginia
Chesapecten jeffersonius (bivalve; Miocene-Pliocene) (*Figure 3.49*)

West Virginia
Megalonyx jeffersonii (giant ground sloth; Pleistocene) (*Figure 3.66*)

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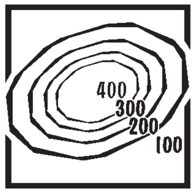

Chapter 4: Topography of the Southeastern US

Does your region have rolling hills? Mountainous areas? Flat land where you never have to bike up a hill? The answers to these questions can help others understand the basic topography of your region. The term **topography** is used to describe the changes in elevation over a particular area and is, generally speaking, the result of two processes: deposition and **erosion**. These processes can occur over an enormous range of timescales. For example, a flash flood can erode away tons of rock in a matter of hours, yet which rock is broken down and which remains can depend on how it was formed hundreds of millions of years ago. In the Southeast, topography is intimately tied to **weathering** and erosion as well as to the type and structure of the underlying bedrock, but it is also a story of **plate tectonics**, volcanoes, folding, **faulting**, **uplift**, and mountain building.

The Southeast's topographic zones are under the influence of the destructive surface processes of weathering and erosion. Weathering includes both the mechanical and chemical processes that break down a rock. There are two types of weathering: physical and chemical. Physical weathering describes the physical or mechanical breakdown of a rock, during which the rock is broken into smaller pieces but no chemical changes take place. **Wind**, water, temperature, and pressure are the main media by which physical weathering and erosion occur. Streams are constantly eroding their way down through bedrock to sea level, creating valleys in the process. Given sufficient time, streams can cut deeply and develop wide flat **floodplains** on valley floors. Streams, oceans, and ice also deposit the material they erode, creating new topographical features elsewhere. The pounding action of ocean waves on a coastline contributes to the erosion of coastal rocks and sediments, while the emptying of a river can lead to the formation of a **delta**.

Pressure release can cause rocks to crack. Growing plant roots can exert many pounds per square inch of pressure on rocks—think of **tree** roots uplifting and cracking a sidewalk. Additionally, since rocks buried miles beneath the surface are under considerable pressure, if those rocks become exposed at the Earth's surface (where the rock is under less pressure), the rock may expand and crack in a process called **exfoliation** (*Figure 4.1*). Ice can also change the landscape due to frequent episodes of freezing and thawing, causing both temperature and pressure differentials within a rock. On a small scale, as water trapped in **fractures** within the rock freezes and thaws, the fractures continue to widen (*Figure 4.2*). This alone can induce significant breakdown of large rock bodies.

topography • *the landscape of an area, including the presence or absence of hills and the slopes between high and low areas.*

erosion • *the transport of weathered materials.*

weathering • *the breakdown of rocks by physical or chemical means.*

plate tectonics • *the process by which the plates of the Earth's crust move and interact with one another at their boundaries.*

fault • *a fracture in the Earth's crust in which the rock on one side of the fracture moves measurably in relation to the rock on the other side.*

uplift • *upward movement of the crust due to compression, subduction, or mountain building.*

CHAPTER AUTHORS

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4 Topography

Review

mineral • *a naturally occurring solid with a specific chemical composition and crystalline structure.*

climate • *a description of the average temperature, range of temperature, humidity, precipitation, and other atmospheric/hydrospheric conditions a region experiences over a period of many years (usually more than 30).*

limestone • *a sedimentary rock composed of calcium carbonate ($CaCO_3$).*

marble • *a metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite.*

carbonate rocks • *rocks formed by accumulation of calcium carbonate, often made of the skeletons of aquatic organisms.*

cementation • *the precipitation of minerals that binds together particles of rock, bones, etc., to form a solid mass of sedimentary rock.*

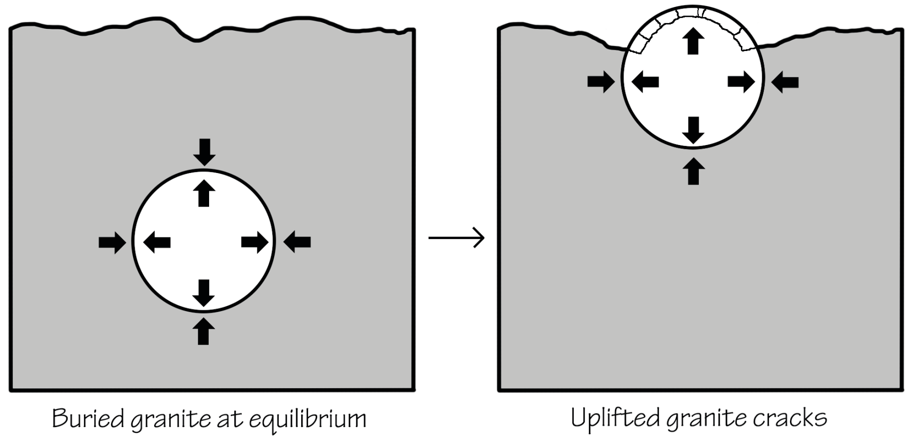


Figure 4.1: Exfoliation as a result of uplift and pressure release.

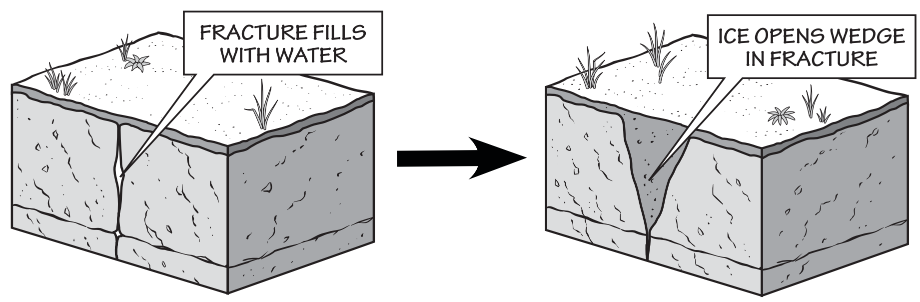


Figure 4.2: Physical weathering from a freeze-thaw cycle.

Working in conjunction with physical (mechanical) weathering, chemical weathering also helps to break down rocks through changes in the chemical composition of their constituent **minerals**. Some minerals contained in **igneous** and **metamorphic** rocks that are formed at high temperatures and pressures (far below the surface of the Earth) become unstable when they are exposed at the surface or placed in contact with water, where the temperature and pressure are considerably lower. unstable minerals transition into more stable minerals, resulting in the breakup of rock. Chemical weathering dominates in the Southeast due to its humid **climate**. Slightly acidic rainwater helps to form carbonic acid, promoting the disintegration of certain types of rocks. **Limestone** and **marble** may be chemically broken down as carbonic acid reacts with their **carbonate** mineral composition, forming cavities and caverns. Other **sedimentary rocks** held together by carbonate **cement** are also particularly susceptible to chemical weathering, which expedites the process of **soil** formation.

The specific rock type at the surface has an important influence on the topography of a region. Certain rocks are able to resist weathering and erosion more easily than are others; resistant rocks that overlie weaker layers act as caps and form ridges. The shallow **inland seas** that advanced across the face of the continent during the **Paleozoic** preserved sediments that became the sedimentary rocks seen today throughout the Inland Basin and Blue Ridge. Sedimentary rocks weather and erode differently than do crystalline (and generally harder) igneous and metamorphic rocks, such as those found throughout the Appalachian Mountains. **Silica**-rich igneous rocks have a crystalline nature and mineral composition that resists weathering far better than do the cemented grains of a sedimentary rock. The metamorphic equivalents of sedimentary and igneous rocks are often even more resistant due to **recrystallization**. There are exceptions, however, such as **schist**, which is much weaker than its pre-metamorphic limestone or **sandstone** state.

The underlying structure of rock layers also plays an important role in surface topography. Sedimentary rocks are originally deposited in flat-lying layers that rest on top of one another. The movement of tectonic **plates** creates stress and tension within the **crust**, especially at plate boundaries. **Intrusions** beneath the surface may also cause deformation of the crust. All these different sources of geological stress can deform the flat sediment layers through folding, faulting, or overturning. These terms are collectively used to describe rock structure, and they can also be used to determine which forces have affected rocks in the past. The folding of horizontal rock beds followed by erosion and uplift brings layers of rock to the surface. Tilted rocks expose underlying layers. Faulting likewise exposes layers at the surface to erosion, due to the movement and tilting of blocks of crust along the fault plane. For example, by the end of the Paleozoic, multiple phases of mountain building had produced the extensive Appalachian Mountain range, surrounded by folded and faulted strata that were deformed and wrinkled. For the last 200 million years, weathering has been dismantling the Appalachians and redistributing these sediments into extensive **clastic wedges** that form the wide Coastal Plain region. These sediment wedges are often over 15,000 meters (49,000 feet) thick and extend below current sea level to form the continental shelves. Above sea level, erosion continues to redistribute these sediments in multiple phases of **fluvial** erosion and deposition, ultimately depositing them along the coast to form barrier island complexes before ultimately transporting the sediment for final burial offshore; at least until the next tectonic phase of mountain building kick-starts the process all over again.

Just as we are able to make sense of the type of rocks in an area by knowing the geologic history of the Southeastern US, we are able to make sense of its topography (*Figure 4.3*) based on rocks and structures resulting from past geologic events. Topography is a central element of the broader concepts of geomorphology or **physiography**, which also include consideration of the shape (not just the height) of land forms, as well as the bedrock, soil, water, vegetation, and climate of an area, and how they interacted in the past to form the landscape we see today. A physiographic province is an area in which these features are similar, in which these features are significantly different from those found in adjacent regions, and/or is an area that is separated from adjacent regions by major geological features. The "regions" of the Southeast that we use in this book are examples of major physiographic provinces. The topography unique to each region thus provides a set of clues to its extensive geologic history.

Review

soil • *the collection of natural materials that collect on Earth's surface, above the bedrock.*

inland sea • *a shallow sea covering the central area of a continent during periods of high sea level.*

Paleozoic • *a geologic time interval that extends from 541 to 252 million years ago.*

silica • *a chemical compound also known as silicon dioxide (SiO_2).*

intrusive rock • *a plutonic igneous rock formed when magma from within the Earth's crust escapes into spaces in the overlying strata.*

fluvial • *see outwash plain: large sandy flats created by sediment-laden water deposited when a glacier melts.*

4 Topography

Region 1

compression • *flattening or squeezing as a result of forces acting on an object from all or most directions.*

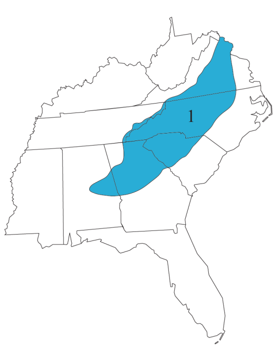
Pangaea • *supercontinent, meaning "all Earth," which formed over 300 million years ago and lasted for almost 150 million years.*

Pleistocene • *a subset of the Quaternary, lasting from 2.5 million to about 11,700 years ago.*

Figure 4.3: Digital shaded relief map of the Southeastern states.

Topography of the Blue Ridge and Piedmont

Region 1



The Blue Ridge and Piedmont represents a highly eroded ancient core of mountain building found along the spine of the Appalachians (*Figure 4.4*). Unlike the Southeast's other regions, which are dominated by sedimentary rocks, the Blue Ridge and Piedmont is underlain by crystalline metamorphic rock with localized igneous occurrences, including the remains of ancient volcanoes. Even though these mountains are highly eroded today, they can still top 1500 meters (4900 feet) in elevation. For example, Mount Rogers, an extinct volcano in Virginia, rises 1746 meters (5728 feet) above sea level.

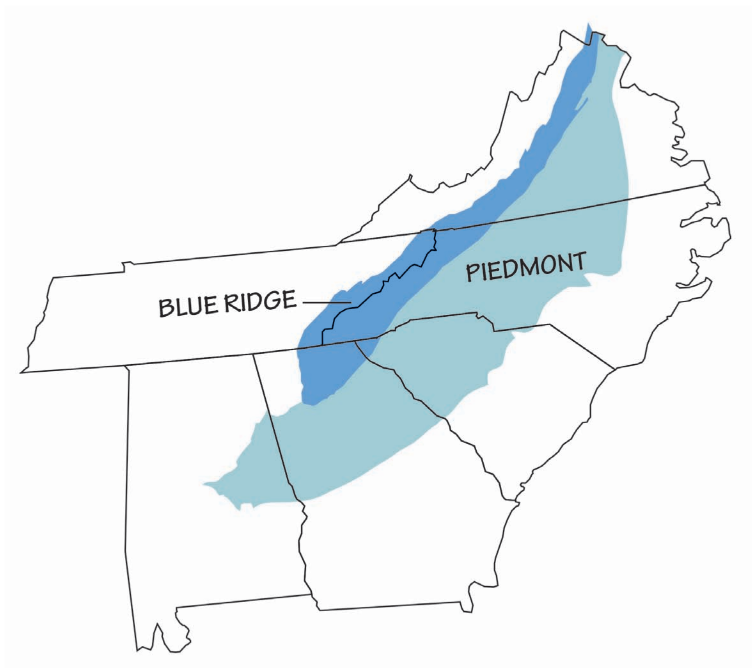


Figure 4.4: Physiographic divisions of the Blue Ridge and Piedmont.

Region 1

***periglacial zone** • a region directly next to an ice sheet, which, although never covered or scoured by ice, has its own distinctive landscape and features.*

***stratigraphy** • the branch of geology specifically concerned with the arrangement and age of rock units.*

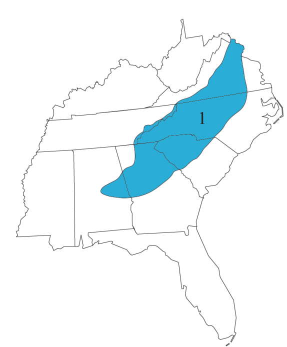
***anticline** • a layer of rock folded (bent) along an axis, concave side down (i.e., in an upside down "u" or "v" shape).*

The Blue Ridge

The elevated Blue Ridge formed from the **compressive** collision forces of several mountain-building episodes during the Paleozoic—essentially a block thrust northwest over the buried leading edge of the Valley and Ridge (directly west of the Blue Ridge). The boundary between the Valley and Ridge and Blue Ridge, the Great Appalachian Valley, is a major landform feature that stretches 1900 kilometers (1200 miles) from Quebec to Alabama. This gigantic trough, or chain of valley lowlands, reflects the late Paleozoic suturing of **Pangaea**. During this event, overthrusting juxtaposed contrasting lithologies, which have now been accentuated by subsequent erosion to produce the sharp boundary we use to divide the two physiographic regions. During glaciation in the **Pleistocene**, the Blue Ridge was also under the influence of **periglacial** processes, which further sculpted these landforms and influenced regional ecosystems.

The tectonic forces that built the Blue Ridge uplifted the oldest rocks in the Southeast (dating back to the Mesoproterozoic) and exposures older than 1.2 billion years old are common here. The region was pushed over 160 kilometers (100 miles) west, telescoping into a series of folded, thrusted crustal sheets that carried older rocks atop younger rocks, overturning the **stratigraphic** sequence (*Figure 4.5*). The Blue Ridge is actually one giant upward fold, or **anticline**, with many smaller folds superimposed upon it. This is known as an anticlinorium (*Figure 4.6*). The Blue Ridge anticlinorium is overturned to the west. The Eastern Continental Divide runs along the crest

A *hydrological divide* is a boundary between two drainage basins or watersheds.



Topography

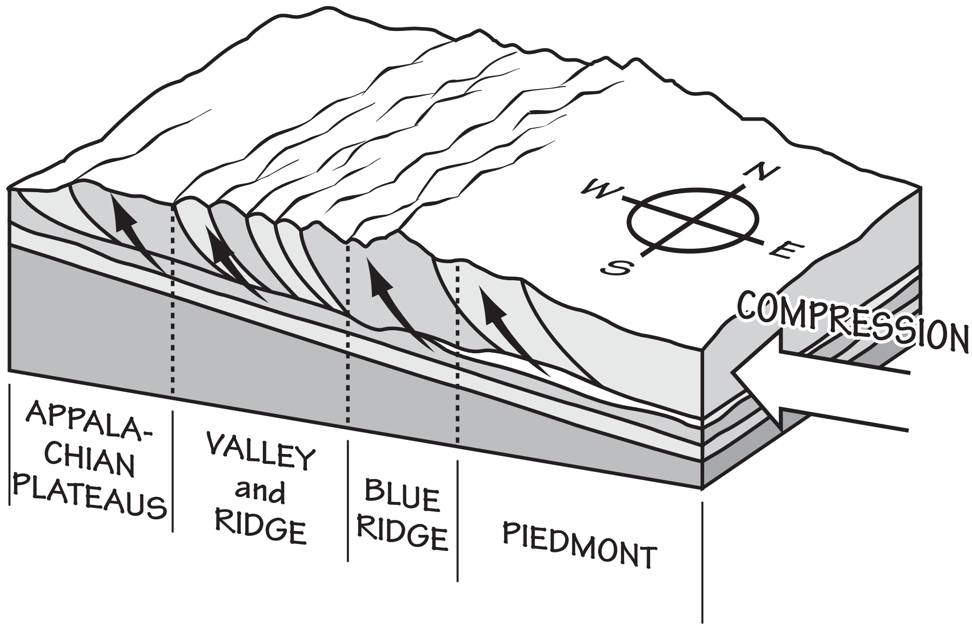


Figure 4.5: The crust of the Blue Ridge and Piedmont was "telescoped" by the compressional forces of Paleozoic mountain building. Slices of crust were thrust over top of each other, stacking like a deck of cards.

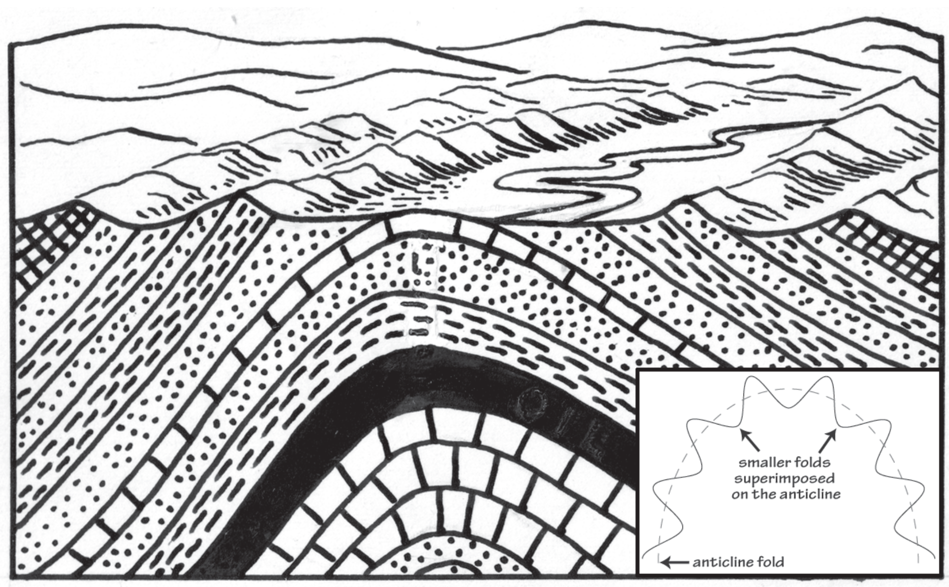
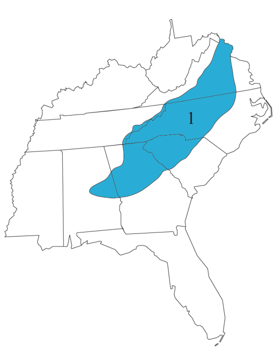


Figure 4.6: An anticline, an upward fold in layered rocks. Inset shows the structure of an anticlinorium.



of the eastern Blue Ridge, and separates the North American **watersheds** that flow east into the Atlantic Ocean from those that flow west and south toward the Gulf of Mexico. The Black Mountains, a part of the Blue Ridge in western North Carolina, are the highest mountains in the eastern United States, and their southern tip intersects the Eastern Continental Divide.

Heat generated by mountain building transformed the area's original sedimentary rock into the metamorphic rocks of the Blue Ridge Mountains, and it also allowed igneous intrusions to punch their way up through the crust. In Virginia's Shenandoah Mountains, many of the highest peaks are capped by greenstones—metamorphosed **basalt** flows that spilled out of the Earth during a **rifting** event about 570 million years ago. Over several million years, these **lava** flows spread out over the landscape, blanketing over 6000 square kilometers (4000 square miles) with basalt ranging from 6 meters (20 feet) to over 30 meters (100 feet) thick. Although these flows were metamorphosed into greenstone during the formation of the Appalachian Mountains, the original shape of the layers remains and has a noticeable effect on the landscape. Flat "benches" separate jagged cliffs and create stairstepped textures (*Figure 4.7*), while other areas are broad and flat. Already a subdivision of the larger

Figure 4.7: Stony Man mountaintop in Shenandoah National Park, Virginia.

Appalachian Mountain chain, the Blue Ridge has been further divided into many smaller ranges throughout its expanse. The Shenandoah Mountains of Virginia, the Great Smoky Mountains of Tennessee and the Carolinas, and the Blue Ridge Mountains of northern Georgia are a few such subdivisions, accompanying many smaller ranges with local topographic peculiarities. The Great Smoky Mountains, along the border of Tennessee and North Carolina, encompass a rugged terrain containing 16 peaks with elevations over 1800

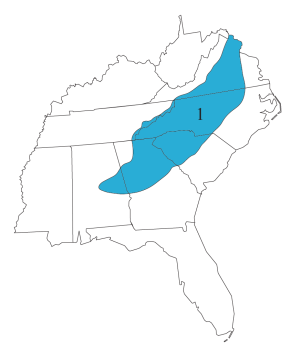
watershed • *an area of land from which all water under or on it drains to the same location.*

heat • *a form of energy transferred from one body to another as a result of a difference in temperature or a change in phase.*

basalt • *an extrusive igneous rock, and the most common rock type on the surface of the Earth.*

rift • *a break or crack in the crust that can be caused by tensional stress as a landmass breaks apart into separate plates.*

lava • *molten rock located on the Earth's surface.*



Region 1

quartzite • *a hard metamorphic rock that was originally sandstone.*

Precambrian • *a geologic time interval that spans from the formation of Earth (4.6 billion years ago) to the beginning of the Cambrian (541 million years ago).*

meters (6000 feet)—the highest elevations in the Southeast. The major peaks (Clingmans Dome is highest at 2025 meters [6644 feet], followed by Mount Guyot and Mount Le Conte) have smaller ridge spurs radiating from their central peaks, forming steep-sided, V-shaped valleys (*Figure 4.8*). Waterfalls are common throughout the steep valleys and gorges of the Blue Ridge.

In northwestern North Carolina, several smaller ranges are isolated from the main body of the Blue Ridge Mountains. The Brushy Mountains are separated from the Blue Ridge Mountains by the Yadkin River Valley and divide the waters of the Yadkin and Catawba rivers. The Sauratown Mountains, located within Stokes and Surry counties, rise sharply 240 to 520 meters (800 to 1700 feet) above the surrounding landscape and are known for some of the best rock climbing in the state. The range is home to many prominent peaks, including Pilot Mountain, an isolated erosional remnant of metamorphic **quartzite** (*Figure 4.9*).

Figure 4.8: Ridges and valleys of the Great Smoky Mountains, straddling North Carolina and Tennessee. The mountains' heavy forests release water vapor and other compounds that hang in the air, giving the range its name.

The overthrust rocks of the Great Smoky Mountains have been subjected to erosional processes spanning more than 200 million years. Along the Smokies' western leading edge, erosion has cut numerous geologic "windows" through the older rocks that form the overthrust upper sheet, exposing younger rocks within window valleys (usually referred to as coves.) Cades Cove in Tennessee is a roughly circular window eroded in **Precambrian** sandstone to expose the Paleozoic limestone beneath. A fault at the bottom completely encircles the

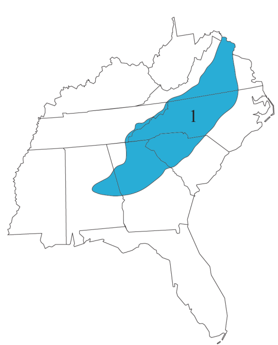


Figure 4.9: The bare rock walls of The Knob at Pilot Mountain, North Carolina, which rises about 430 meters (1400 feet) above the surrounding terrain.

cove. Weathering of the carbonate rocks in this and other similar topographic lows (e.g., Tuckaleechee and Wear coves) exposes **karstic** limestone and produces rich soils that were used for agricultural purposes by 18th-century settlers. Dissolution of the limestone has led to the formation of several caves—Bull Cave in Cades Cove, 281 meters (924 feet) deep, is the deepest cave in Tennessee. Tuckaleechee Caverns, a mile-long cave **system** near Townsend, Tennessee that reaches depths of 46 meters (150 feet), is another karstic cave estimated to be between 20 and 30 million years old.

See Chapter 2: Rocks to learn about the formation of geologic windows and where they can be found in the Southeast.

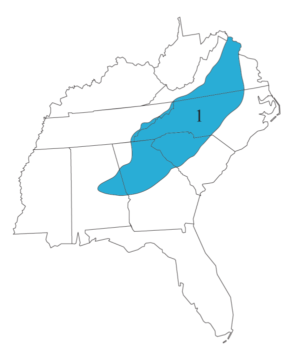
The boundary between the Blue Ridge and Piedmont provinces is often considered to be the Brevard Fault Zone, a 600-kilometer-long (370-mile-long) zone stretching from Alabama to Virginia, where the rocks were crushed and ground by the tremendous pressure of thrusting during the formation of Pangaea.

The Piedmont

East of the Blue Ridge mountain belt lies the upland Piedmont region. Here, a more humid climate has resulted in extensive weathering of the Piedmont's overthrusted rocks, producing a more subdued topography of low rolling

karst topography • *a kind of landscape defined by bedrock that has been weathered by dissolution in water, forming features like sinkholes, caves, and cliffs.*

system • *a set of connected things or parts forming a complex whole.*

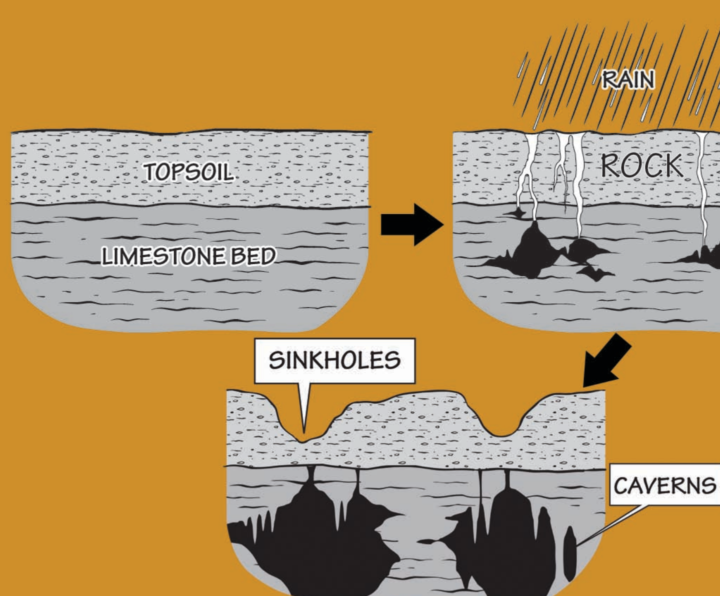


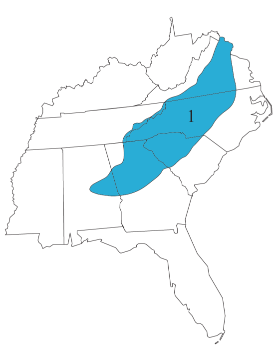
Region 1

atmosphere • *a layer of gases surrounding a planet.*

Karst Topography

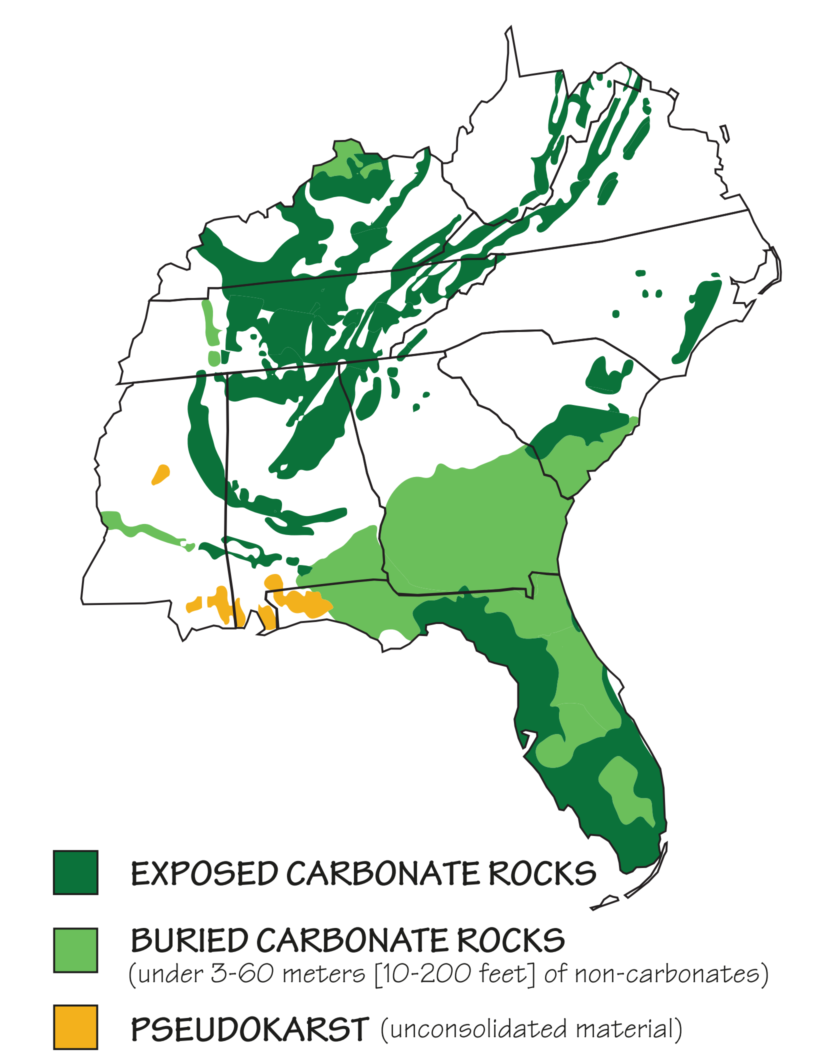
Karst topography refers to a region where the landscape's features are largely the result of chemical weathering by water, resulting in caves, sinkholes, disappearing and reappearing streams, cliffs, and steep-sided hills called towers. These structures form when water picks up carbon dioxide from the *atmosphere* and ground to form carbonic acid. Even this fairly weak and dilute acid dissolves carbonate rocks (such as limestone) relatively easily, resulting in dramatic features while other rock is comparatively unaffected. Karst is found in every state except Hawaii, and as an aquifer it is the source of a significant amount of our drinking water. While common, karst is not always easily identifiable since it is often not expressed at the surface or its topography has been affected by other factors. Karst topography is a relatively mature type of landscape, taking many tens of thousands of years to develop, and it can indicate that a region has been free of other forms of erosion, or deposition, for an extended period. Karst topography in the Southeast is present wherever water has eroded the limestone bedrock, especially throughout the Inland Basin and across the Florida Platform.





clay • *the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.*

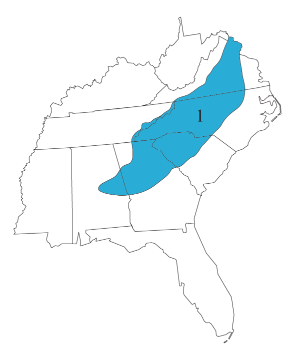
Karst Topography (continued)



(See TFG website for full-color version.)

hills. Elevations can reach several hundred meters (particularly in Alabama's northern Piedmont, which contains the highest peaks in the state), and the entire Piedmont gently slopes toward the east, draining toward the Atlantic Ocean. The near surface of the Piedmont is composed of saprolite, the **clay**-rich remains of decomposed rock that produces a rich soil for farming. Sporadically peeking up through this blanket of weathered metamorphics are erosional remnants called

The word Piedmont comes from the French for "foot of the mountain" reflecting the area's low rolling hills.



4 Topography

Region 1

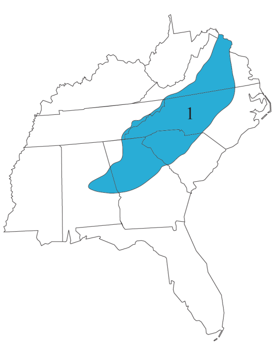
monadnock *• an isolated hill or small mountain on a plain, formed from rock more resistant to erosion than that of the surrounding landscape.*

pluton *• a body of intrusive igneous rock that formed under the Earth's surface through the slow crystallization of magma.*

granite *• a common and widely occurring type of igneous rock.*

iceberg *• a large chunk of ice, generally ranging in height from 1 to 75 meters (3 to 246 feet) above sea level, that has broken off of an ice sheet or glacier and floats freely in open water.*

Alleghanian Orogeny *• a Carboniferous to Permian mountain-building event involving the collision of the eastern coast of North America and the northwestern coast of Africa.*



monadnocks—resistant rocks that contrast with their surroundings in terms of topography and composition. In Georgia, an igneous **pluton** conspicuously rises 514 meters (1686 feet) above the surrounding landscape to form Stone Mountain, a massive **granite** dome that covers 236 hectares (583 acres) and has a physical volume of over 210 million cubic meters (7.5 billion cubic feet) (*Figure 4.10*). Despite its size, the mountain occupies only a small portion of the area underlain by the granite, like the tip of an **iceberg**. All of this granite formed around 300 million years ago, during the **Alleghanian Orogeny**, when it was intruded into the preexisting rock at a depth of about 12–16 kilometers (8–10 miles) below the surface. The granite was more resistant to weathering than was the surrounding rock, and as the layers of overlying rock slowly eroded away, the granite was finally exposed at the surface about 15 million years ago. There is also a Stone Mountain in North Carolina—another granitic monadnock—that formed at around the same time! Other monadnocks in the Piedmont include Little Mountain and Table Rock in South Carolina, Arabia Mountain in Georgia, and Kings Pinnacle in North Carolina.

See Chapter 7: Soils to learn more about the types of soils formed from weathered rock.

Figure 4.10: An aerial view of Stone Mountain, DeKalb County, Georgia.

A series of irregular linear basins, collectively referred to as **Mesozoic** Rift Basins or **Triassic** Basins (e.g., Dan River-Danville and Culpeper basins in Virginia and Wadesboro Basin in North Carolina), are exposed sporadically within the Piedmont. Topographically, these basins are hard to distinguish from the surrounding and enclosing terrain; however, they tend to have tilted sedimentary strata of sandstone and **shale** that erode to form low linear ridges on their eastern flanks. Where basalt flows occurred, these rocks are more resistant and form traceable topographic ridges.

See Chapter 1: Geologic History to learn about rifting during the Mesozoic.

At the westernmost edge of the Piedmont, called the Fall Line, the shift from crystalline rocks to loose sediment signals the beginning of the Atlantic Coastal Plain. A **fall line** (or fall zone) is a geomorphologic break between an upland region of relatively hard crystalline **basement rock** and a coastal plain of softer sedimentary rock (*Figure 4.11*). Rivers crossing such breaks typically display waterfalls and rapids, and were frequently sites of settlements that made use of water **power**. Numerous Southeastern cities are located on the Fall Line for this reason, including Great Falls, VA (on the Potomac River; *Figure 4.12*), Fredericksburg, VA (on the Rappahannock River), Richmond, VA (on the James River), Petersburg, VA (on the Appomattox River), Raleigh, NC (on the Neuse River), Columbia, SC (on the Congaree River), Augusta, GA (on the Savannah River), Macon, GA (on the Ocmulgee River), Columbus, GA (on the Chattahoochee River), and Belltown, AL (on the Tallapoosa River).

See Chapter 6: Energy for more information on the use of water as an energy source in the Southeast.

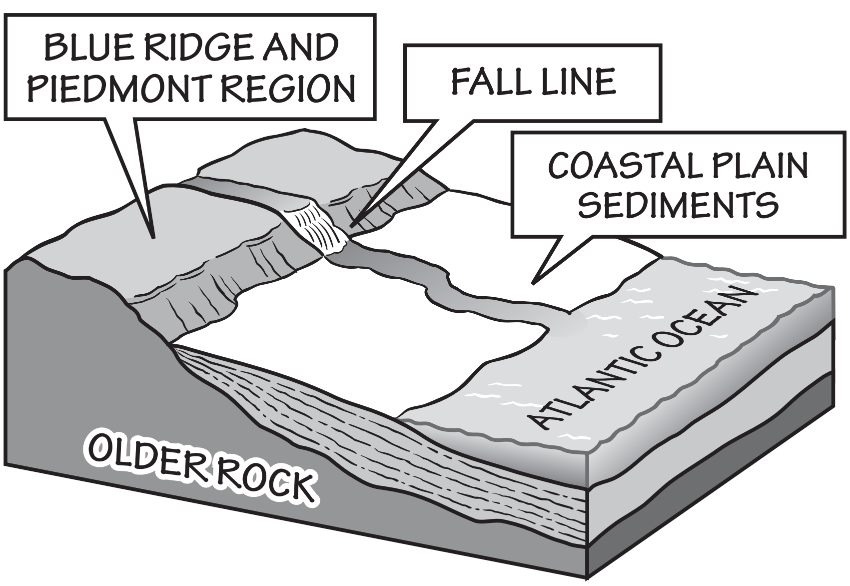


Figure 4.11: The Fall Line, between the Blue Ridge/Piedmont and Coastal Plain regions.

Region 1

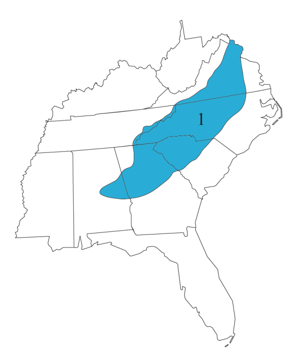
Mesozoic • *a geologic time period that spans from 252 to 66 million years ago.*

Triassic • *a geologic time period that spans from 252 to 201 million years ago.*

shale • *a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.*

basement rocks • *the foundation that underlies the surface geology of an area, generally composed of igneous or metamorphic crystalline rock.*

power • *the rate at which energy is transferred, usually measured in watts or, less frequently, horsepower.*



Mississippi Embayment • *a topographically low-lying basin in the south-central United States, stretching from Illinois to Louisiana.*

Figure 4.12: The Great Falls of the Potomac River, Virginia.

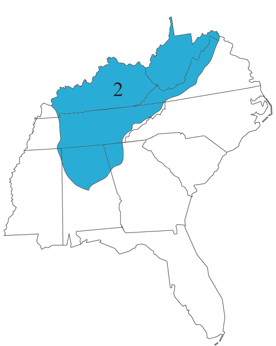
Topography of the Inland Basin
Region 2

The Inland Basin, occupying the landscape west of the Blue Ridge to the **Mississippi Embayment** and north of the Gulf Coastal Plain, can be thought of as the Southeast's geologically stable, ancient topographic nucleus. The Inland Basin is composed of a thick sequence of Paleozoic-aged carbonate sedimentary rock deposited during multiple ocean incursions into the continent's interior, punctuated by blankets of siliciclastic sediment from the erosion of newly uplifted mountains. This alternating stratigraphy of carbonates and clastics underlies the entire region, but it can be subdivided into several physiographic provinces based upon deformational characteristics associated with the formation of the Appalachian Mountains (*Figure 4.13*).

See Chapter 2: Rocks to learn how mountain building and erosion contributed to the Inland Basin's stratigraphy.

The Valley and Ridge

The easternmost part of the Inland Basin is a strip of linear, "wrinkled" ridges and valleys running northeast to southwest, adjacent to the Appalachians. This topography, characterized by long, even ridges with continuous valleys in between (*Figure 4.14*), is best developed in western Virginia and eastern Tennessee, but also extends into northeast Alabama and northwest Georgia. Individual ridge crests can run for extremely long distances—for example, Clinch Mountain in Tennessee is about 240 kilometers (150 miles) in length.



Region 2

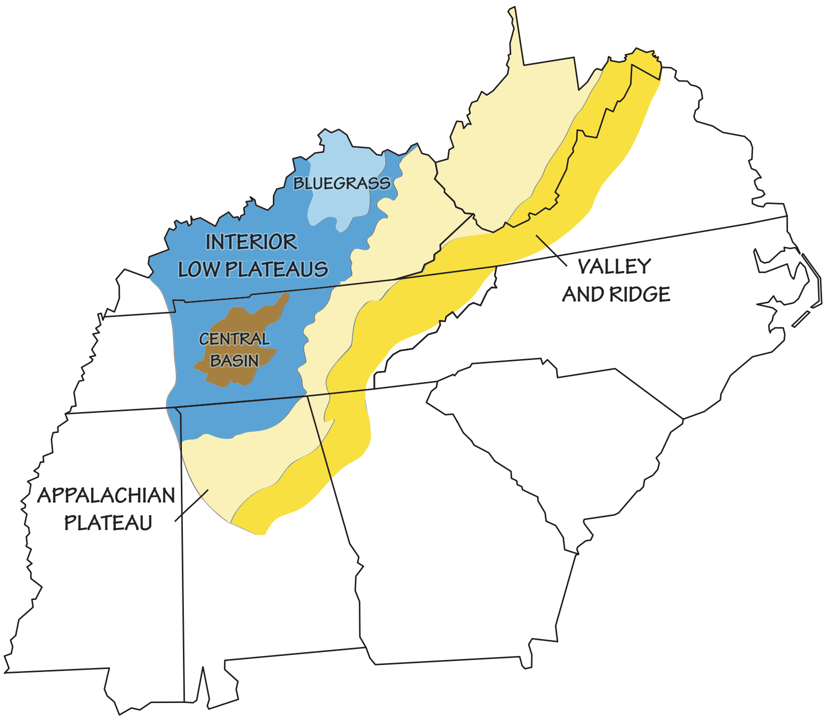
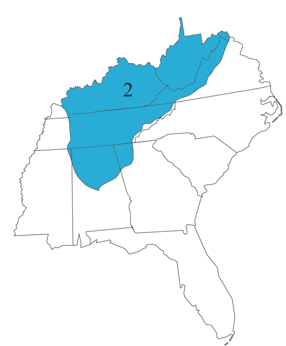
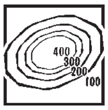


*Figure 4.13: The physiographic regions of the Inland Basin.
(See TFG website for full-color version.)*

Figure 4.14: Linear ranges of the Valley and Ridge adjacent to the Shenandoah River, Virginia.





Topography

Region 2

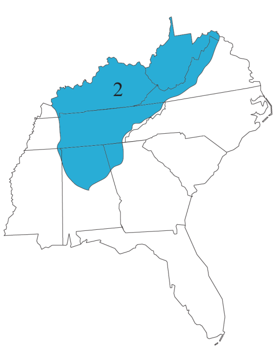
relief *• the change in elevation over a distance.*

The **relief** of ridges in this area can range from 400 to over 1100 meters (1300 to over 4000 feet) in height. Before the days of motorized transportation, the length and height of these ridges presented a major obstacle to east-west land travel, and settlers were able to cross the Valley and Ridge only near its endpoints or at erosional "gaps" created by wind and water.

The elongate and folded sedimentary rocks of the Valley and Ridge were deformed by thrust faulting during the Alleghanian Orogeny, which created an accordion-like repetition of strata as sheets of rock folded and then broke to slide over adjacent areas. The ridges represent the edges of erosion-resistant strata, while valleys formed under softer and easily-eroded layers. Differential weathering and the erosion of alternating resistant sandstones and weaker shale and limestone sharpens the area's topography (*Figure 4.15*). Cemented sandstones hold up the ridges, and valleys tend to be floored by shale and karst limestone, the latter easily recognized by the numerous depressions and sinkholes that develop as surface drainage is diverted below ground. Nestled between adjacent highland areas, well-developed soils have formed thanks to the erosion of numerous sedimentary rock types, generating highly fertile farmland in the valleys.

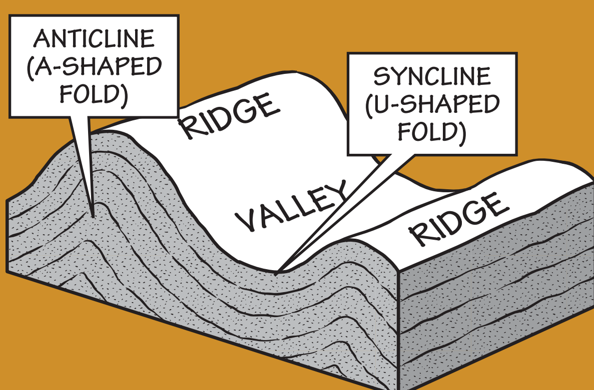
See Chapter 10: Earth Hazards for more information about the dangers associated with karst topography.

Figure 4.15: Sharp ridges of erosion-resistant sandstone are exposed in the Allegheny Mountains of Judy Gap, West Virginia, a popular rock-climbing destination.

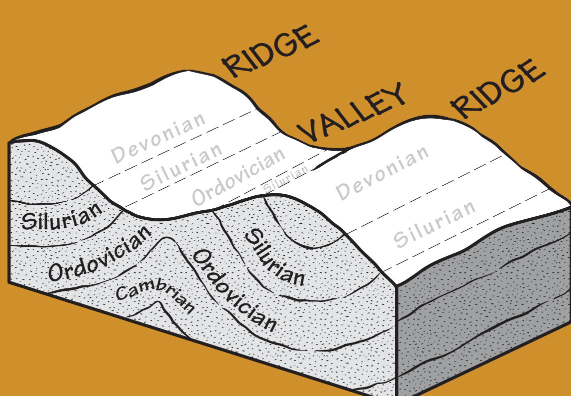


Topographic Inversions

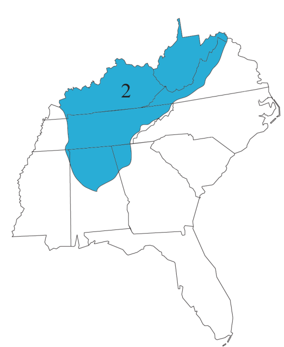
Typically, synclines (U-shaped folds) form valleys and anticlines (A-shaped folds) form ridges. However, the reverse is often true, especially in the Appalachians. In a phenomenon called topographic inversion, topographic lows (valleys) may form from the structural high (top of an anticline)—the term "structure" refers to the form of the rock layers. At the top of the anticline, a layer may erode away because of cracks caused by bending of the rock at the top of the fold. Fracturing at the top of the fold allows increased water penetration, and topographic highs are subjected to more severe weather. Once exposed, the less resistant layers below the eroded top quickly weather away to form a valley. The limbs of the resistant layer, however, are generally still intact. This leaves two ridges of resistant rock on either side of a valley floored by softer, less resistant layers.



Normal erosion of a fold.



Topographic inversion.



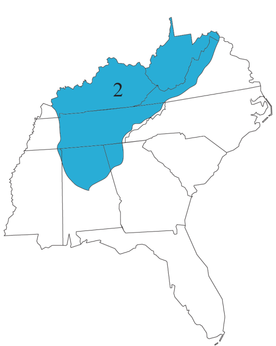
Region 2

iron • *a metallic chemical element (Fe).*

coal • *a combustible, compact black or dark-brown carbonaceous rock formed by the compaction of layers of partially decomposed vegetation.*

fuel • *a material substance possessing internal potential energy that can be transferred to the surroundings for specific uses.*

flux • *a mineral added to the metals in a furnace to promote fusing or to prevent the formation of oxides.*



Drainage within the Valley and Ridge typically follows the orientation of valleys, with most rivers meandering back and forth across valley floors in a northeast to southwest direction. Short tributaries flowing down the ridge slopes feed the rivers. This distinctive drainage pattern, controlled by the Valley and Ridge topography, is referred to as **trellis drainage** (*Figure 4.16*). Many small streams have developed in a manner consistent with the trellis pattern, but there are a few exceptions to this rule. The Tennessee River, for example, initially follows the Valley and Ridge, but abruptly doglegs westward through the Cumberland Plateau before heading west through northern Alabama. A few major rivers (including the Potomac and New rivers) have cut water gaps perpendicular to the ridges and are therefore thought to have been in place before the mountains were formed.

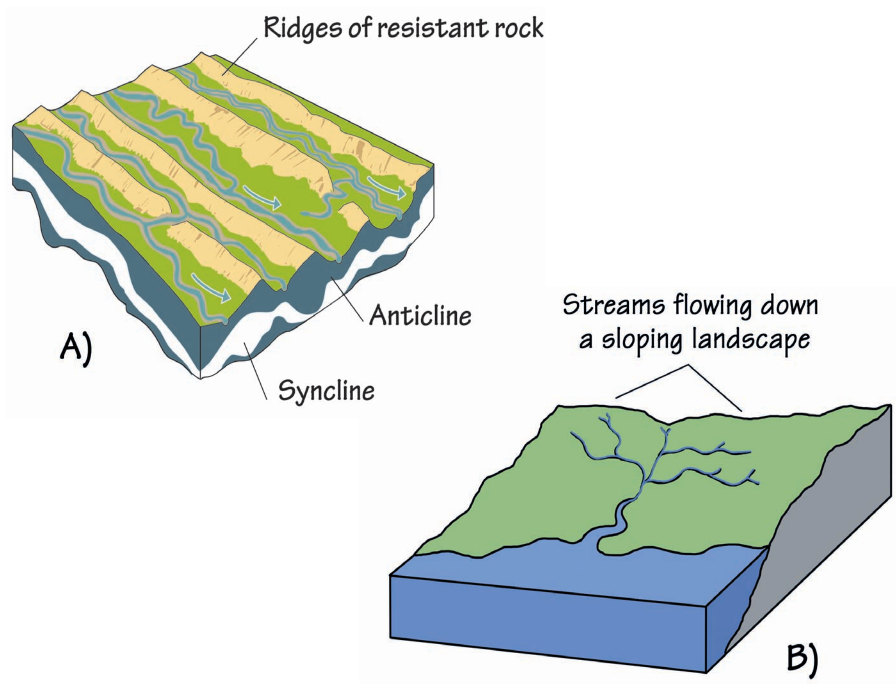


Figure 4.16: Common drainage patterns. A) Trellis drainage, in which tributaries feed into a river at right angles, forms between ridges of resistant rock. B) Dendritic drainage, in which many contributing streams join together like branches, follows the slope of the landscape.

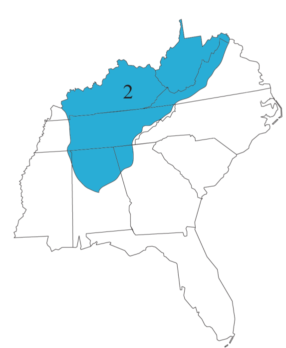
At its southernmost extent, the Valley and Ridge enters Alabama with several major ridges and their associated valleys: Birmingham-Big Canoe Valley and Cahaba, Coosa, Weisner, and Armuchee ridges (*Figure 4.17*). In the Birmingham area, Red Mountain towers above the city, exposing **iron**-rich sedimentary red beds that once gave the city the name "Iron and Steel Capital of the South" due to the proximity of **coal** for **fuel** and limestone for **flux**. In central Alabama, the entire Valley and Ridge terminates against the younger sediments of the Gulf Coastal Plain.

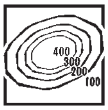
See Chapter 5: Mineral Resources to learn about Alabama's iron and steel industry.

The Contrary River

Most southeastern rivers follow a more or less direct path of least resistance from their headwaters downslope to the ocean. However, the Tennessee River seems to have a mind of its own. Its headwaters are in northeastern Tennessee on the west side of the Appalachians, which impede a direct eastern flow to the Atlantic Ocean. Rather, the Valley and Ridge trellis drainage pattern governs the Upper Tennessee, forcing it to follow valleys to the southwest. Instead of continuing its trek directly to the Gulf of Mexico, the Tennessee abruptly doglegs to the west at Chattanooga, forcing it to incise a deep canyon into Walden Ridge ("the Grand Canyon of Tennessee") before finally resuming a southwestward course. This is only temporary, however, for the Tennessee again changes course to head west through northern Alabama, forming rapids referred to as Muscle Shoals, then onward toward the Mississippi River. Here, the river once again confounds shortest-distance convention by turning at Pickwick to flow north across Tennessee and Kentucky before emptying into the Ohio River. The Tennessee River's circuitous course has proven useful to the Tennessee Valley Authority—damming the river allowed control of floods, and the construction of hydroelectric plants helped transform the south from poverty to riches after the Great Depression.

The Tennessee River and its tributaries.
(See TFG website for full-color version.)





Topography

Region 2

foreland bulge *• an area of uplift on the far side of an inland basin.*

conglomerate *• a sedimentary rock composed of multiple large and rounded fragments that have been cemented together in a fine-grained matrix.*

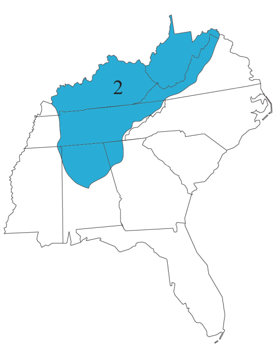
Figure 4.17: The Coosa River flows through the Coosa Valley, part of Alabama's Valley and Ridge.

The eastern margin of the Valley and Ridge is a structural trough—a series of valley lowlands—called the Great Appalachian Valley, and it has been used as an important north-south route of travel since prehistoric times (today, it is occupied by Interstate 81 as well as portions of I-40 and I-75). The valley, which extends from Canada all the way south to Alabama, is bounded by the Blue Ridge Mountains along its eastern edge. Regional names for the Great Appalachian Valley in the Southeastern states include the Shenandoah and James River valleys in Virginia, the Tennessee and Holston River valleys in Tennessee, and the Coosa Valley in Alabama.

The Appalachian Plateau

Westward of the Valley and Ridge, the highland rims rise and top out in a broad, high, flat plateau or "tableland" called the Appalachian Plateau. Although not as elevated as the Appalachian Mountains, these tablelands were slightly deformed into a broad, open fold, indicating their proximity to the "wrinkled carpet" deformation that made up the **foreland bulge** of the Appalachians. Southward, more extensive erosion has narrowed the plateaus, and the influence of underlying faulting and folding becomes more evident. The plateau's caprock is dominated by clastic Paleozoic rocks (e.g., **conglomerate**, sandstone, shale, and coal) formed in extensive swamps and coastal plains while the Appalachians rose. These relatively horizontal and undeformed caprocks lessened the rate of erosion, allowing the area to lag behind the more extensively eroded carbonates exposed in the Interior Low Plateaus to the west and creating the high tableland topography we see today. Erosion continues to eat away at the area from both sides, causing it to narrow as time passes.

The eastern side of the Appalachian Plateau is a major southeast-facing escarpment, the Appalachian Structural Front, formed in part by northeast- to southwest-trending thrust faults. The relief along this structure is steep, and



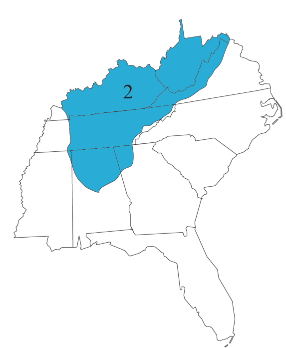
rockfalls and **landslides** are common environmental hazards. In West Virginia, the escarpment is called the Allegheny Front, and its highest point is Mt. Porte Crayon (1400 meters or 4700 feet). In Kentucky, it is the Pottsville Escarpment, a rugged sandstone belt of cliffs and valleys (*Figure 4.18*). In Tennessee, it is called the Cumberland Escarpment, and rises over 300 meters (980 feet), with grand vistas of the Valley and Ridge to the east.

***Escarpments*, or "scarps," form when faulting or erosion acts to create a cliff or steep slope that separates two level or gently sloping topographical surfaces.**

landslide • *the rapid slipping of a mass of earth or rock from a higher elevation to a lower level under the influence of gravity and water lubrication.*

Figure 4.18: A natural arch in the sandstone of the Pottsville Escarpment, Daniel Boone National Forest, Kentucky.

In West Virginia, the Appalachian Plateau is divided into the Parkersburg, Logan, and Allegheny plateaus. The highest tableland in Virginia is High Knob, which rises 1287 meters (4223 feet) above sea level and contains a mixture of topographical features common to the Valley and Ridge as well as the Appalachian Plateau. The southern portion of the tableland, stretching from Kentucky and Tennessee to Alabama, is called the Cumberland Plateau. In Kentucky, the Cumberland Plateau is dominated by forested hills and dissected by V-shaped valleys. A 201-kilometer-long (125-mile-long) thrusted ridge, Pine Mountain, extends across the area. In the northern part of the Tennessee Plateau, an unusual pattern of late Paleozoic thrust faults has created a raised and tilted uplift called the Wartburg Basin, deforming the strata into the



topographic inversion • *a landscape with features that have reversed their elevation relative to other features, most often occurring when low areas become filled with lava or sediment that hardens into material that is more resistant to erosion than the material that surrounds it.*

topographically higher Cumberland Mountains—a mountain range that lies on top of the plateau. In southern Tennessee, the Cumberland Plateau is bisected by a breached anticline, the Sequatchie Anticline, that later eroded to form Sequatchie Valley—also an example of **topographic inversion** (*see box on p. 167*). This northeast-trending valley resembles a deep knife slice into the southern Cumberland Plateau extending into Alabama (*Figure 4.19*).

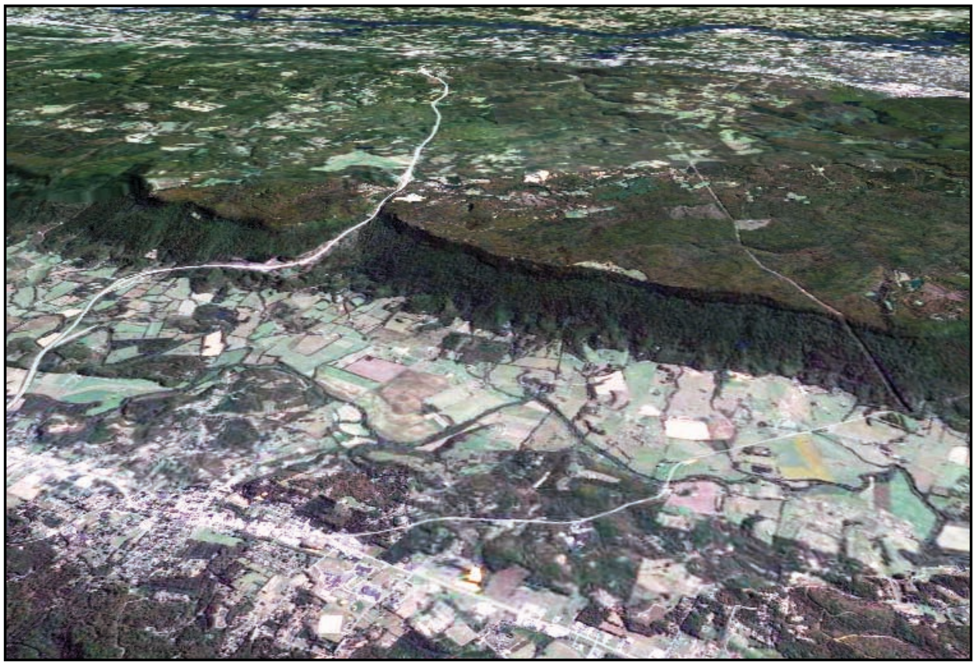
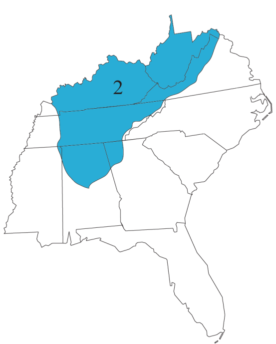


Figure 4.19: A steep escarpment, Walden Ridge, rises from the eastern edge of the Sequatchie Valley near Chattanooga, Tennessee.

The Sequatchie Valley represents the western extent of thrust faulting from the adjacent Valley and Ridge—the last of the tight wrinkles of folded strata from the continental collision that formed the Appalachians. The thrust fault shallows as it nears the surface, and was therefore more easily reached by erosion. The older Paleozoic strata exposed within the Sequatchie Valley show the classic northeast to southwest "grain" typically found in rocks farther east and at lower elevations. Sinkholes and caverns occur in the valley where its protective caprock is breached. Grassy Cove, an enclosed valley at Sequatchie's northern tip, contains notable karst formations. Eventually, once the remaining higher layers of rock separating Grassy Cove from the rest of Sequatchie Valley are removed by erosion, it will become a northeastern extension of the main valley.

The Appalachian Plateau narrows into Alabama to become an area of flat-topped plateaus, including Sand Mountain and Blount Mountain, separated by steep-sided valleys. These plateaus, which slope gently toward the southwest, flank an extensive geologic basin—the Black Warrior Basin—that lies at the southern tip of the Appalachians. The Black Warrior Basin's topography is mostly



horizontal, with tablelands formed by coal-rich clastic rocks. The eastern edges of this basin were impacted by Appalachian mountain building to become part of the adjacent Valley and Ridge topography.

See Chapter 6: Energy for more about coal resources in the Inland Basin.

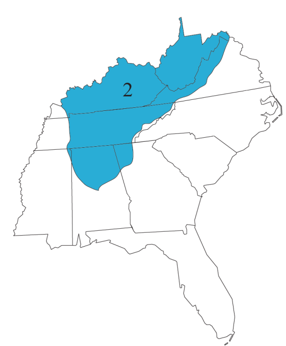
dendritic drainage • *a drainage pattern where many smaller streams join and contribute to ever larger streams.*

The western margin of the Appalachian Plateau has an irregular geographic outline, modified by west-flowing creeks and rivers that erode the west edge of the plateau. The drainage pattern here is dominantly **dendritic** (*see Figure 4.16*), flowing northwest into the basins of the Interior Low Plateaus. Differential weathering of slightly tilted sedimentary strata has formed stair-stepped topography in the valleys, and waterfalls are a common occurrence. Fall Creek Falls in Tennessee is considered the highest waterfall east of the Mississippi River, with a plunge of 78 meters (256 feet). Cumberland Falls in Kentucky is another large waterfall, 21 meters (68 feet) high and 38 meters (125 feet) wide, that spans the Cumberland River on the border of McCreary and Whitley counties (*Figure 4.20*).

Figure 4.20: Cumberland Falls, McCreary and Whitley counties, Kentucky.

The Interior Low Plateaus

Broad, gently folded basins and domes with surrounding highland rims dominate the basic structure that controls the topography of the Interior Low Plateaus. Here, largely flat-lying sedimentary bedrock is close to the surface, and the area's topography is dependent on its resistance to erosion. Rolling



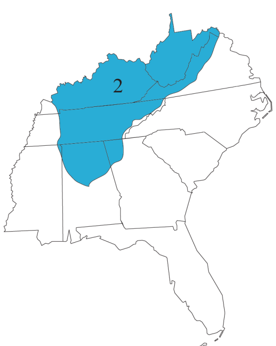
4 Topography

Region 2

__Cincinnati Arch__ • an uplifted region that existed between the Illinois Basin, the Michigan Basin, and the Appalachian Basin during the late Ordovician and Devonian.

__Cambrian__ • a geologic time period lasting from 541 to 485 million years ago.

__Ordovician__ • a geologic time period spanning from 485 to 443 million years ago.



limestone plains are punctuated with occasional rugged hills, swampy valleys, and expanses of karst. Streams and rivers cut deeply into the softer bedrock.

An extensive dome-like area, the slightly curved **Cincinnati Arch**, dominates the central portion of the Interior Low Plateaus (*Figure 4.21*). This foreland bulge parallels the trend of the Appalachians and stretches through Ohio, Kentucky, and Tennessee much like a slightly wrinkled rug. Erosion has breached the Cincinnati Arch's crest in several areas, forming rounded topographic basins over the otherwise dome-like uplifted strata—examples of inverted topography. The Bluegrass area of Kentucky and the Central Basin of Tennessee are prime examples of this phenomenon. These uplifted structural domes, now eroded into topographic basins, create bowl-shaped depressions that influence surface drainage. Except where large rivers cut the landscape, like the Tennessee and Cumberland rivers in Tennessee and the Kentucky and Licking rivers in Kentucky, drainage occurs toward the centers of the topographic basins. For example, the extensive "1000-year flooding" in Central Tennessee in 2010 occurred as rainwater filled the Central Basin faster than it could find its way out down the nearby rivers.

See Chapter 9: Earth Hazards to learn more about major floods in the Southeastern states.

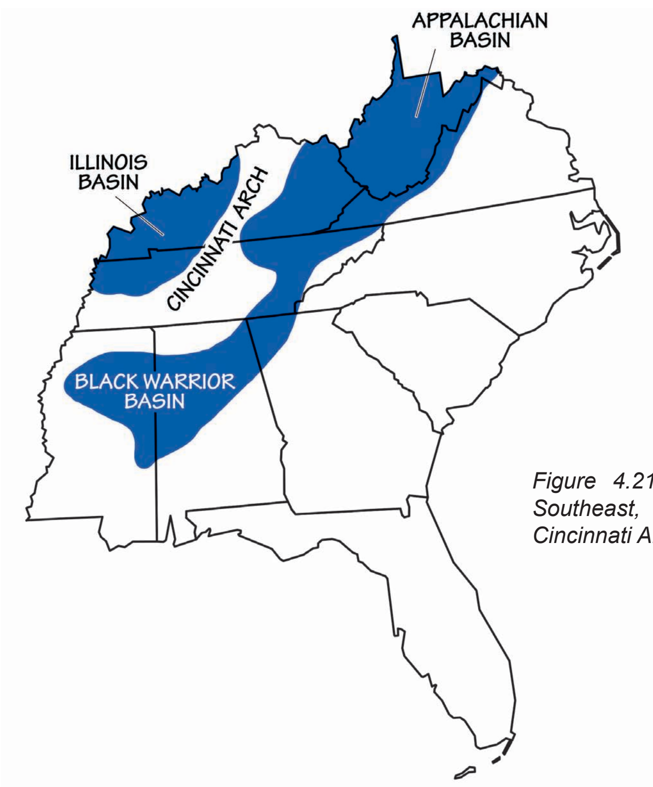


Figure 4.21: Sedimentary basins of the Southeast, separated by the uplifted Cincinnati Arch.

The rims of these basins are generally steep drainage divides that expose cuts of younger to older Paleozoic strata. The bottoms of the basins expose rocks of **Cambrian** to **Ordovician** age, surrounded by the middle and late

Paleozoic rocks of the rims. For example, the Central Basin is surrounded by a ridge called the Highland Rim, a hilly area that extends south into Alabama, north to the border of Kentucky, east to the Cumberland Plateau, and west to the Tennessee River (*Figure 4.22*). The rocks of the Highland Rim are largely **Carboniferous** in age, while those exposed at the bottom of the Central Basin are Ordovician. Differences in the rock layers' durability have resulted in slight differences in the basins' internal topography, such that that they can be divided into "inner basins" of nearly horizontal strata with low rolling landscapes surrounded by "outer basins" of slightly more dissected rolling hill terrain. The Kentucky Bluegrass is an excellent example—the Inner Bluegrass is an area of gently rolling hills and rich soils of weathered limestone (*Figure 4.23*), while the Outer Bluegrass is characterized by deep erosional valleys. Exposed rocks in the basins are predominantly carbonates that have undergone chemical dissolution to form extensive karst topography (*Figure 4.24*). Sinkholes and cavern systems are common features, as are streams that disappear into the ground.

Carboniferous • *a geologic time period that extends from 359 to 299 million years ago.*

Illinois Basin • *an inland basin centered in the state of Illinois, which formed when Baltica approached North America in the Ordovician.*

Figure 4.22: The Buffalo River Valley in central Tennessee marks a major tributary of the Duke River, which cuts through the Western Highland Rim and enters the Tennessee River.

Flanking the Cincinnati Arch and its inverted erosional basins are true down-warped geologic basins that have been centers of deposition for most of their existence. These basins, which escaped the deformational mountain building processes that formed the Appalachians, accumulated and were eventually filled with thick layers of sediment. Today, the topographic expression of these horizontal layers of deposited sediment masks the basins' true structural down-warped shape. The Western Kentucky Coal Field is one such basin and is an extension of the much larger **Illinois Basin** that stretches into the midcontinent.

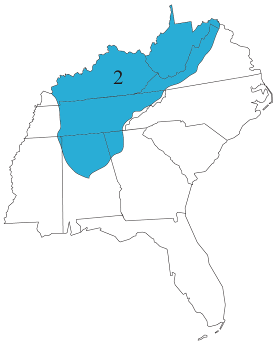


Figure 4.23: The rolling hills of the Inner Bluegrass in Scott County, Kentucky are underlain by shales and limestones.

Figure 4.24: Delicate formations called speleothems grace the walls and ceiling of Mammoth Cave in Kentucky, the longest known cave system in the world. These formations, deposits of dissolved calcium carbonate, grow extremely slowly—about one cubic inch every 100 years! The cave developed in dissolved limestone underlying a layer of resistant sandstone, so its passages are remarkably stable.

Impact Craters

Most Southeastern topography is directly attributable to tectonic forces, deposition, and erosion acting over millions of years. There are a few topographic features that are "extraterrestrial" in origin. Impact craters of varying sizes occur in many areas of the Southeast. The Wells Creek Crater in northwestern Tennessee is an ancient scar produced by an impact that probably occurred during the Paleozoic. The fault-bounded circular pattern, easily visible as a basin surrounded by ridges, is over 12 kilometers (7 miles) in diameter. The Middlesboro Crater on the Cumberland Plateau at the border of Kentucky, Virginia, and Tennessee is also visible at the surface and contains the entire town of Middlesboro, Kentucky. Fracturing of the rocks on the edge of the Middlesboro Crater helped to form the Cumberland Gap, through which Dr. Thomas Walker and Daniel Boone opened up westward expansion beyond the Cumberland Mountains. Other craters in the Southeast include the Wetumpka impact structure in Alabama and the Flynn Creek Crater in Tennessee. See Chapter 2: Rocks for a map of major impact craters in the Southeast.

Topography of the Coastal Plain
Region 3

The entire eastern and southern margin of the Southeast consists of relatively flat to gently-sloped loose **gravel**, **sand**, and clay sediments of Mesozoic and **Cenozoic** age. The Coastal Plain begins at the Fall Line, where slow erosion of the Piedmont's crystalline rocks forms numerous waterfalls and rapids, and extends east to the Atlantic Ocean and south to the Gulf of Mexico. Rivers flowing east out of the Piedmont over the Fall Line quickly deepen and widen as they erode the Coastal Plain's looser materials. The region's sediments form a thickening "clastic wedge" nearly 15,000 meters (49,000 feet) thick, which extends below sea level to become the continental shelf-slope-rise system. Most of the Atlantic states subdivide the Coastal Plain into an upper hilly and dissected plain and a flatter, sloping lower plain (*Figure 4.25*). From the Atlantic Seaboard, the Coastal Plain wraps around into the Gulf of Mexico, the Gulf Coastal Plain, and up into the Mississippi Embayment at the region's western margin. To the south, the Florida peninsula represents the carbonate Florida Platform.

gravel *• unconsolidated, semi-rounded rock fragments larger than 2 millimeters (0.08 inches) and smaller than 75 millimeters (3 inches).*

sand *• rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

Cenozoic *• the geologic time period spanning from 66 million years ago to the present.*

last glacial maximum • *the most recent time the ice sheets reached their largest size and extended farthest toward the equator, about 26,000 to 19,000 years ago.*

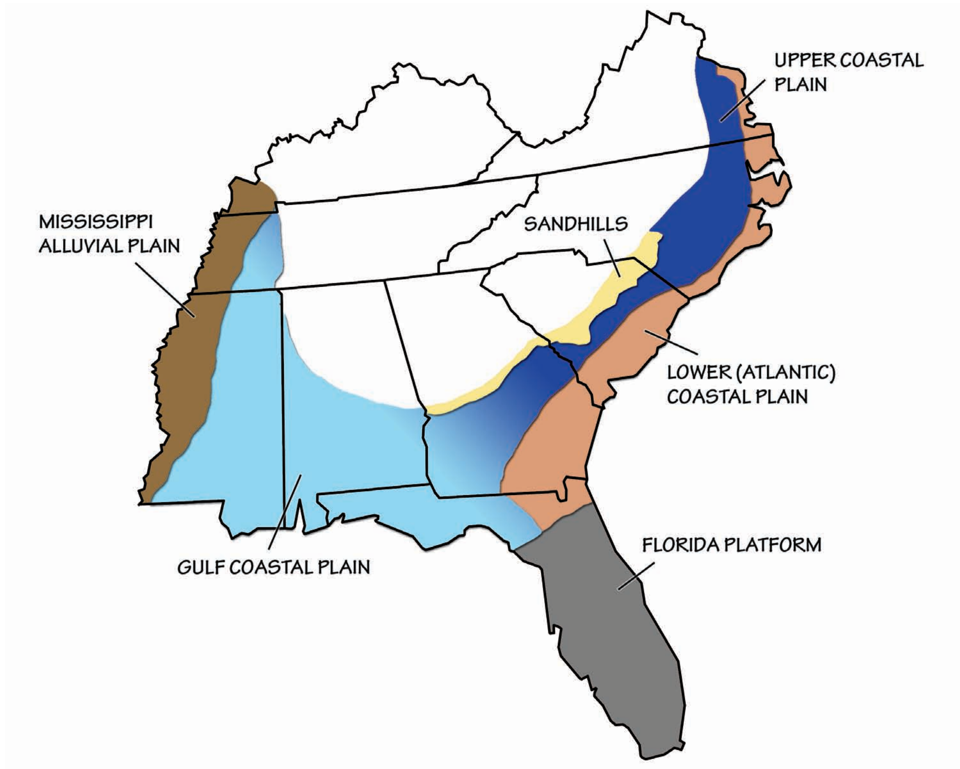


Figure 4.25: Physiographic subdivisions of the Coastal Plain. (See TFG website for full-color version.)

The Gulf and Atlantic Coastal Plain

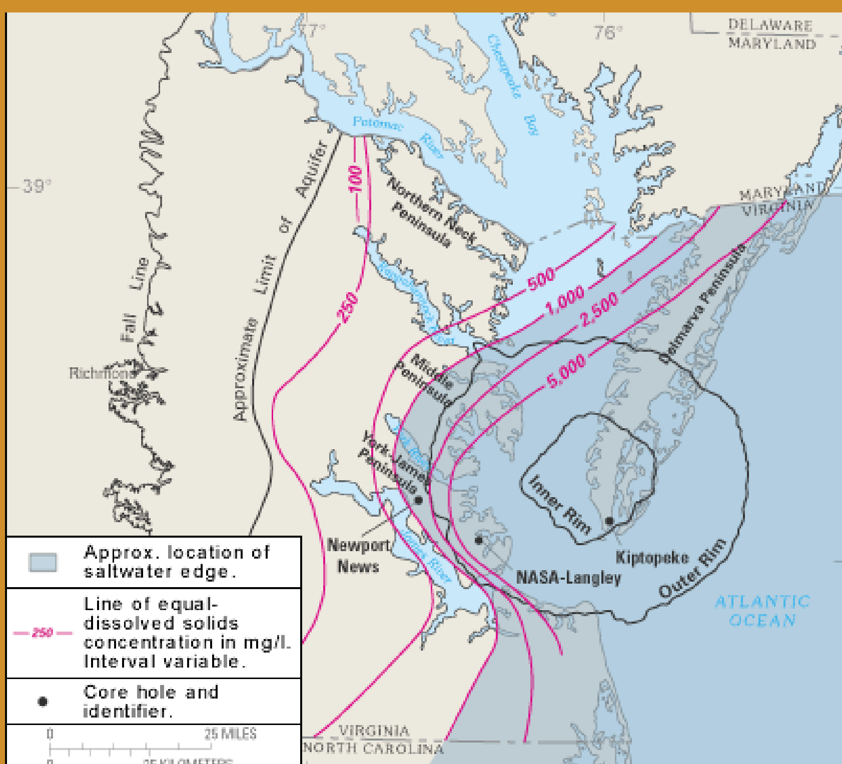
The interior portions of the Coastal Plain are topographically broad uplands displaying low slopes toward the sea and gentle drainage divides with mostly dendritic drainage structures (*see Figure 4.16*). These rivers, such as the Chattahoochee in Georgia, have their headwaters in the Blue Ridge and Piedmont region (*Figure 4.26*). Where stream erosion has incised more deeply—drainage slopes may show elevations of 20 to 75 meters (60 to 250 feet). Closer to the coast, relief is much more subdued, with elevations ranging from 0 to 20 meters (0 to 60 feet). Coastal boundaries become very irregular with multiple drowned river valleys—broad, deeply indented coastal inlets that represent the original course of a river. In Virginia, the eastward-flowing rivers crossing the Piedmont (e.g., Potomac, Rappahannock, York, and James rivers) become tidal estuaries that empty into the Chesapeake Bay, itself a uniquely large drowned river, which then empties into the Atlantic Ocean (*Figure 4.27*). For example, the Susquehanna River flows through the Chesapeake lowland region for more than 90 kilometers (56 miles) before emptying into the modern Chesapeake Bay, which was submerged about 5000 to 6000 years ago with the drowning of the Susquehanna's lower reaches.

Several drops in sea level since the **last glacial maximum** have resulted in topography that preserves relict shorelines traceable into the Gulf and Atlantic coasts. In fact, much of the currently drowned continental shelf was emergent

Region 3

Chesapeake Bay

The Chesapeake Bay owes its original existence to an impact event that occurred 35 million years ago. The circular Chesapeake Bay Crater (over 85 kilometers [53 miles] in diameter and 1.3 kilometers [0.8 miles] deep) is not currently visible at the surface because it was modified by later processes of erosion and deposition; however, the deep depression of the impact topographically influenced the drainages that produced the present-day Chesapeake Bay—explaining why it is the only drowned river of its size on the East Coast.



Boundaries of the Chesapeake Bay Impact Crater

low coastal plain during the last **ice age**. Relatively low, wide, and flat **terraces** stairstep downward in elevation toward the coast (*Figure 4.28*). Narrow steps that mark former shorelines, known as scarps, are recognized by narrow contour lines traceable at the same elevation throughout the Southeast. Higher terraces to the west represent older and higher shorelines formed when sea level was higher, during **interglacial** periods; lower terraces formed when sea

ice age • *a period of global cooling of the Earth's surface and atmosphere, resulting in the presence or expansion of ice sheets and alpine glaciers.*

terrace • *a flat or gently sloped embankment or ridge occurring on a hillside, and often along the margin of (or slightly above) a body of water, representing a previous water level.*

interglacial • *a period of geologic time between two successive glacial stages.*

4 Topography

Region 3

Figure 4.26: From its source in Georgia's Blue Ridge Mountains, the Chattahoochee River flows southwest to form the southern half of the Alabama/Georgia state line before entering the Florida Panhandle.

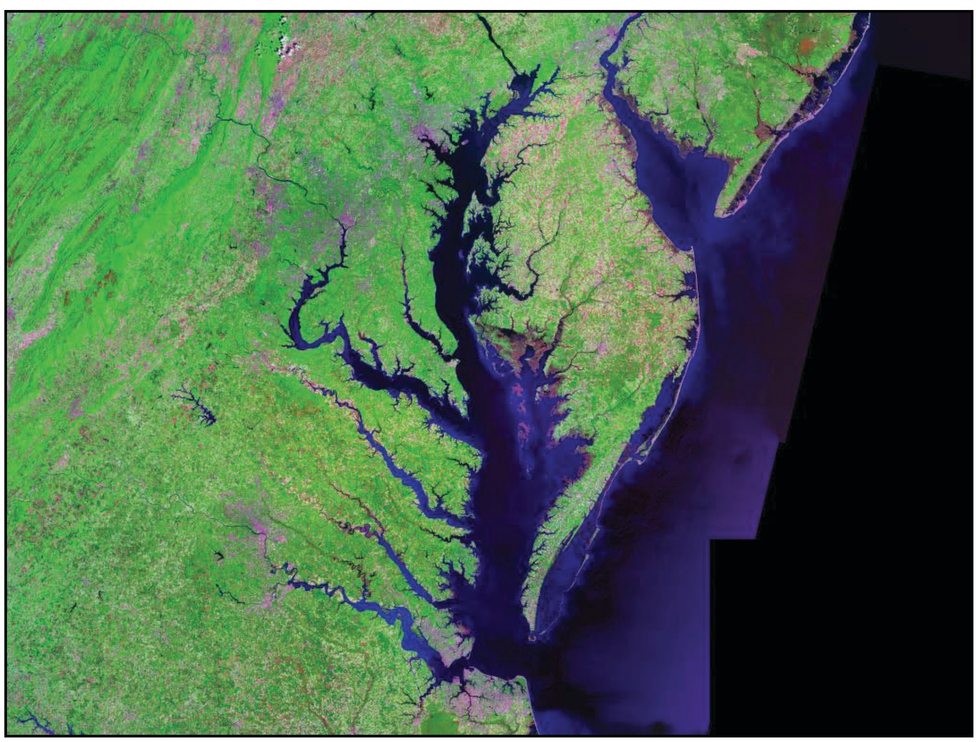


Figure 4.27: A satellite image of Chesapeake Bay on Virginia's Atlantic coast.

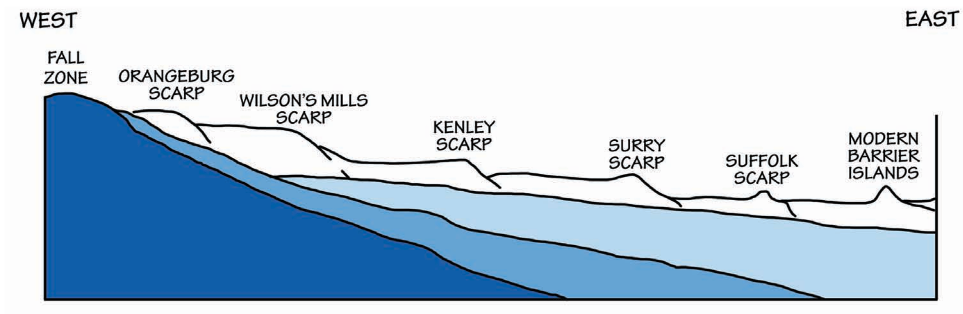


Figure 4.28: The scarps and intervening terraces of North Carolina's Coastal Plain.

level dropped during glaciations. In South Carolina, seven terrace-scarp pairs stairstep the topography of the lower Coastal Plain, representing seven cycles of the receding ocean levels. These seven sea level shifts are traceable along the Atlantic seaboard and include two that occurred during the **Pliocene** epoch, followed by four during the Pleistocene epoch and the current Holocene shift. For example, the Orangeburg Scarp, extending from central North Carolina to northeast Florida, formed from wave erosion during an interval of high sea level during the mid- to late Pliocene (3.5–2.5 million years ago).

See Chapter 8: Climate to learn about sea-level change throughout Earth history and its implications for the future.

The Sandhills, a strip of ancient beach dunes, are a distinctive feature of the Upper Coastal Plain and stretch from North Carolina into Georgia along the Fall Line. This formation of broad flat ridges and rolling hills formed from a combination of fluvial **Cretaceous** sediments deposited around 90 million years ago by meandering streams, and marine sediments deposited about 45 million years ago during a sea level highstand (*Figure 4.29*). These sandy sediments are highly **permeable**, easily absorbing precipitation; as a result, the Sandhills are not highly eroded. A portion of South Carolina's peach industry thrives in the area's sandy soils.

An unusual topographic feature of the Lower Coastal Plain, best seen in North and South Carolina, are the Carolina Bays. These are not actually marine coastal bays, but large, elliptical inland depressions whose long axes are aligned in the same general northwest to southeast direction (*Figure 4.30*). The bays are often difficult to visualize from land, as their rims can be only a few centimeters in height. They can be as large as thousands of acres, and nearly 500,000 of them occupy the Atlantic Coastal Plain. They are visible on maps and photographs from space, especially where lakes, boggy swamps, or savannahs occupy the bays. Several theories have been proposed for the Bays' formation, including sea currents, groundwater seepage, **aeolian** processes, and even extraterrestrial impact.

Pliocene *• a geologic time interval extending from roughly 5 to 2.5 million years ago.*

Cretaceous *• a geologic time period spanning from 144 to 66 million years ago.*

permeability *• a capacity for fluids and gas to move through fractures within a rock, or the spaces between its grains.*

aeolian *• pertaining to, caused by, or carried by the wind.*

Figure 4.29: The Sandhills of Peachtree Rock Preserve in South Carolina support a scrubby forest of longleaf pine and oak.

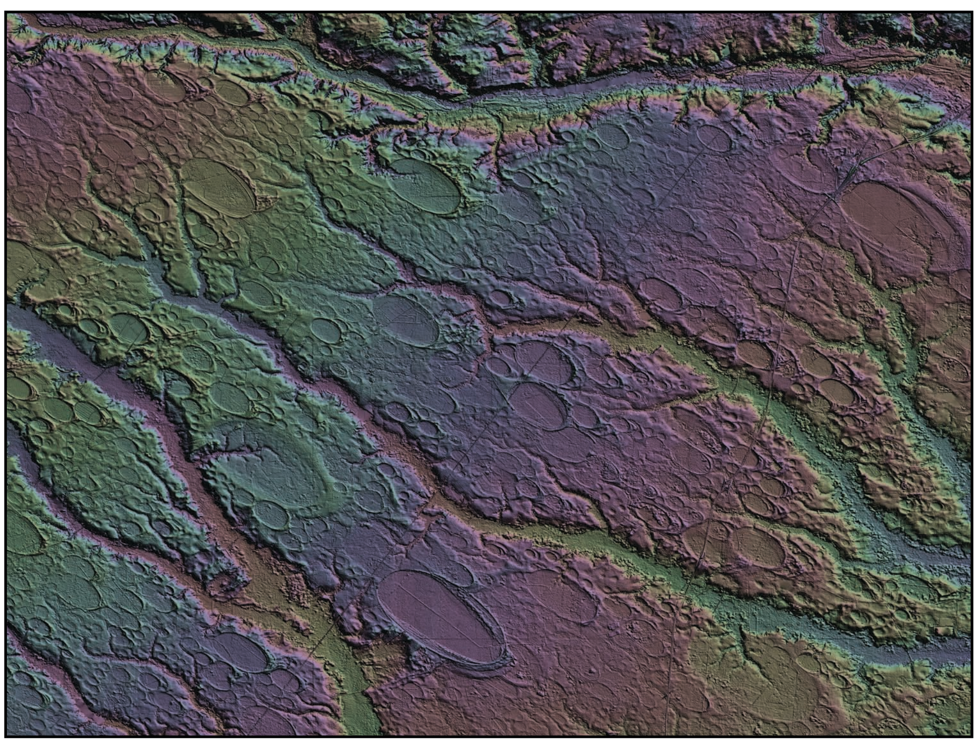


Figure 4.30: Digital elevation map data collected by remote sensing LIDAR technology reveals the presence of hundreds of Carolina Bays in a 600-square-kilometer (230-square-mile) segment centered on Robeson County, North Carolina.

Extending from the eastern Shore of Virginia along the coasts of North and South Carolina, Georgia, and portions of Florida is an extensive **barrier island** complex. Locally, the shapes of barrier islands can change from submergent coastlines protected by relatively linear, thin ribbons of island (Outer Banks, North Carolina) to beach-fronted mainlands with smaller barriers (South Carolina, Georgia, and south into Florida). Along the Gulf Coast, barrier islands also extend to the Mississippi River Delta. Barrier islands of the Atlantic region are zoned ribbons of mostly **quartz** sand, dynamically sculpted into beaches, dune fields (e.g., Kitty Hawk, North Carolina), marshes, and protected sounds. In North Carolina, the linear stretches of the Outer Banks separate the Atlantic Ocean from the much more irregularly shaped marshes and protected bays of Pamlico and Albemarle sounds. Thanks to the protection of the Outer Banks, Pamlico and Albemarle sounds have the distinction of being the two largest "landlocked" bays on the East Coast. At Capes Hatteras, Lookout, and Fear, the direction of the Outer Banks shift, making sharp, prominent turns. Storm systems and shifting sand bars have caused hundreds of shipwrecks, and North Carolina's barrier islands are sometimes called "The Graveyard of the Atlantic."

Most topography in the eastern Gulf Coast mimics that of the Atlantic Coast; however, beginning at Mobile Bay in Alabama, some notable coastal changes occur. Mobile Bay is a submerged, drowned river valley. East of the bay, barrier islands form close to the mainland or occur as long spits attached to the mainland (e.g., Fort Morgan Peninsula, Alabama) with only small estuarine bays behind them. West of Mobile Bay, a long line of thin, offshore barrier islands (e.g., Dauphin, Petit Bois, Ship, and Horn islands) stretches latitudinally to the Mississippi River Delta, protecting an extensive waterway called the Mississippi Sound (*Figure 4.31*). Gulf barrier islands are similar in topography and zonation to the Outer Banks, but tend to be shorter and narrower. They constantly change shape due to storms entering the Gulf.

The Florida Platform

The majority of Florida is situated much farther south than the rest of the Coastal Plain, stretching toward the subtropics. While most topography in northern Florida and the Florida Panhandle resembles that of the Atlantic and Gulf coasts (especially in terms of terracing), middle peninsular and southern Florida is a relatively flat carbonate platform, originally formed underwater and now exposed barely above sea level (*Figure 4.32*). The Florida Platform divides the Gulf of Mexico from the Atlantic Ocean, and on its western margin (the Florida Escarpment) steep undersea cliffs drop off sharply to over 3000 meters (10,000 feet) in depth. The terrestrial Florida peninsula is located toward the eastern side of the platform, which terminates as few as 5 to 6.5 kilometers (3 to 4 miles) from the land's edge. The Florida Platform's carbonate rocks have easily eroded to produce a flat, subdued topography throughout central and southern Florida. The platform's bedrock is overlain by a layer of **porous** karst limestone, which has eroded to produce extensive systems of caves, sinkholes, and springs.

Florida's karst contains the most productive **aquifer** in the US, called the Floridian Aquifer. It is composed largely of Paleocene and Miocene limestone.

barrier island *• a long, thin island next to and parallel to a coastline.*

quartz *• the second most abundant mineral in the Earth's continental crust (after the feldspars), made up of silicon and oxygen (SiO_2).*

porosity *• the percentage of openings in a body of rock such as pores, joints, channels, and other cavities, in which gases or liquids may be trapped or migrate through.*

aquifer *• a water-bearing formation of gravel, permeable rock, or sand that is capable of providing water, in usable quantities, to springs or wells.*

4 Topography

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Figure 4.31: Mobile Bay, Alabama, with associated barrier islands.

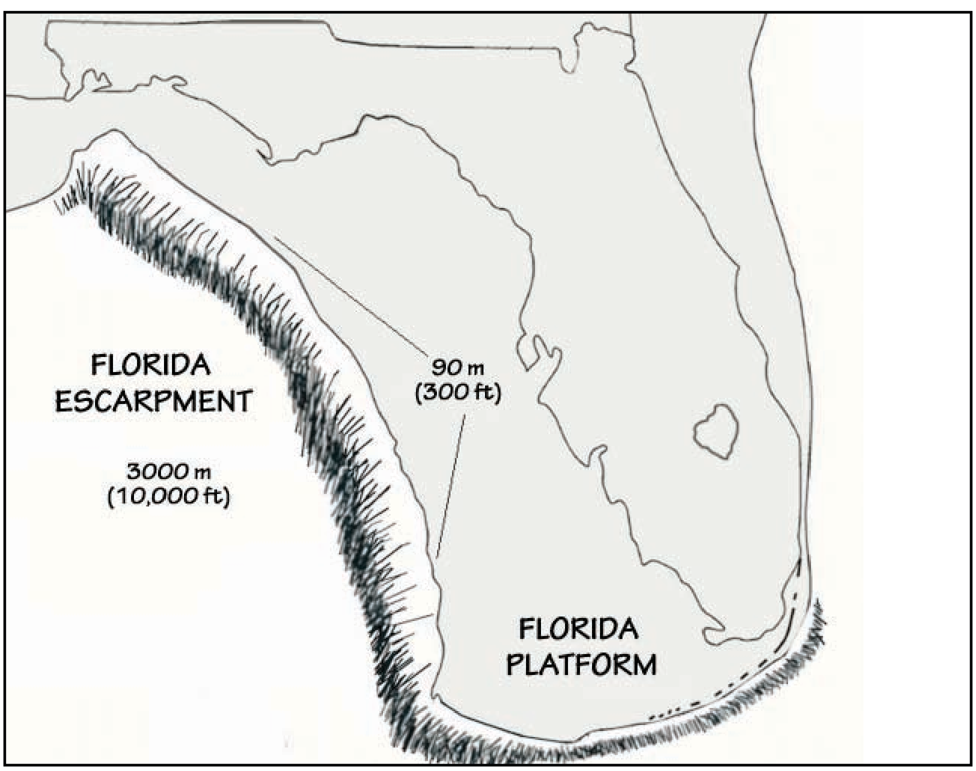

Figure 4.32: The extent of the Florida Platform and surrounding water depths.

This aquifer underlies all of Florida, as well as parts of South Carolina, Georgia, and Alabama. In the northwest part of peninsular Florida, between Tampa Bay and Tallahassee, the aquifer is *unconfined*, meaning water can flow directly between it and the surface. Elsewhere, it is *confined* beneath a less permeable layer, and thus under pressure. One result of this is that Florida has numerous springs (more than 700, including large ones, such as Wakulla Springs in Wakulla County, and Weeki Wachee Springs in Hernando County), which are natural **artesian** outflows from the Floridian Aquifer (*Figure 4.33*). Water temperatures in these springs are usually relatively constant (generally around 24°C [75°F]), and as a result some of them provide unique habitat for several species of plants and animals, including manatees.

artesian *• a channel that releases pressure from an aquifer, allowing the aquifer's internal pressure to push the water up to the surface without the aid of a pump.*

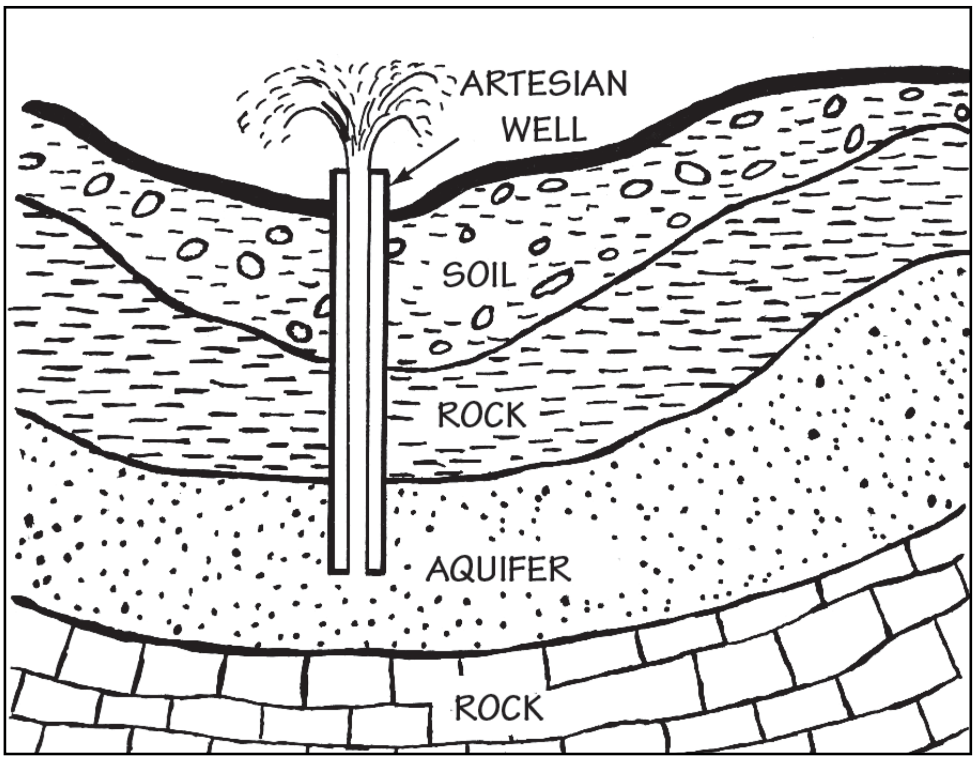

Figure 4.33: Diagram of an artesian well, following the same principle as a natural artesian spring. Water beneath an impermeable layer of rock is frequently under pressure. When a well or natural channel opens into the aquifer, the internal pressure pushes the water up to the surface without the aid of a pump.

Lake Okeechobee (in the lower half of peninsular Florida; *see Figure 4.32*) is the largest freshwater lake in Florida and the seventh largest in the US, covering 1900 square kilometers (730 square miles). The lake sits in a shallow trough underlain by compacted clay deposits; water flowing into the topographical low originally built up wetlands that were later drowned as water level increased. Lake Okeechobee is extremely shallow, with an average depth of only 3 meters (9 feet), but it can hold 3.8 trillion liters (1 trillion gallons) of water at its fullest capacity, and it is the headwaters of the Everglades. The Everglades are the "World's Largest Sawgrass Swamp"—rarely more than 2 meters (6.5 feet)

Groundwater

Groundwater is the water present beneath Earth's surface in pore spaces in the soil and in fractures in subsurface rock. A unit of rock or an unconsolidated deposit is called an aquifer if it can yield a usable quantity of water. The level below which groundwater saturates the aquifer is called the water table. All groundwater ultimately comes from precipitation, which percolates into the aquifer from the surface in a process called recharge. Groundwater naturally comes to the surface in springs, seeps, and wetlands. It is also withdrawn through wells for agricultural, industrial, or municipal use.

Groundwater supplies approximately 25% of the fresh-water used by humans each year in the US. (the rest comes from surface water, such as rivers and lakes). This varies geographically; in Florida and Mississippi, more than 60% of all freshwater used comes from groundwater, whereas in most of the other Southeastern states it is less than 10%.

The amount of water that can be removed from an aquifer depends on its recharge rate and permeability. Recharge depends on precipitation and human use, both of which are affected by climate. Permeability refers to the ease with which water can move through the aquifer. This property varies widely, depending on the type of materials that constitute the aquifer. Fine-grained material such as clay or silt is less permeable than sand and gravel. Crystalline rocks such as granite have a very low permeability unless they have been fractured, creating openings through which groundwater can move.

in relief, but covering 13,000 square kilometers (5000 square miles) of land. The Everglades swamp is really a river flowing south from Lake Okeechobee to Florida Bay. Slight topographic highs, called "hammocks," punctuate the swamp (*Figure 4.34*).

Figure 4.34: Mangroves and hardwood hammocks punctuate the Florida Everglades' vast tall-grass swamp.

At the southern tip of Florida lies a curved island archipelago, the Florida Keys, extending out toward the southwest. The Keys are the exposed remnants of an ancient coral **reef** chain, and reefs continue to grow in the warm, tropical waters to the south. At the western tip of the Keys are the Dry Tortugas islands, a cluster of smaller islets. The majority of the Florida Keys occur in the Florida Straits, which separate the Gulf of Mexico and the Atlantic Ocean.

Florida has the longest coastline in the contiguous United States, at a length of about 2170 kilometers (1350 miles).

The Mississippi Embayment

The Mississippi Embayment, stretching from Illinois to Louisiana, actually originated in the Precambrian during the breakup of **Rodinia**. Many smaller rifts in the crust formed adjacent to the major rift that split North America away from the supercontinent. One of these smaller rifts is located beneath the modern day Mississippi Embayment. During parts of the Paleozoic era, a proto-Mississippi Embayment existed above the rift. During the Cretaceous, the ocean flooded the **embayment**, and when sea level fell, the Mississippi River was born. Thousands of meters of sediment were deposited in the river valley. Mississippi's major aquifers are found within and beneath these thick beds of sediment. Recurrent activity along faults associated with the deeply buried ancient rifts beneath the embayment caused the 1811–1812 New Madrid Earthquake, one of the largest **earthquakes** ever recorded in North America.

See Chapter 1: Geologic History for more information about the rifting of early supercontinents.

See Chapter 9: Earth Hazards to learn more about the New Madrid Seismic Zone.

reef • *a feature lying beneath the surface of the water, which is a buildup of sediment or other material built by organisms, and which has positive relief from the sea floor.*

Rodinia • *a supercontinent that contained most or all of Earth's landmass, between 1.1 billion and 750 million years ago, during the Precambrian.*

embayment • *a bay or recess in a coastline.*

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earthquake *• a sudden release of energy in the Earth's crust that creates seismic waves.*

oxbow *• a stream meander in the shape of a "U," named after the U-shaped collar of an ox yoke.*

levee *• a deposit of sediment built up along the sides of a river's floodplain, or an artificial embankment along a waterway to prevent flooding.*

progradation *• outward building of strata toward the sea in the form of a beach, fan, or delta.*

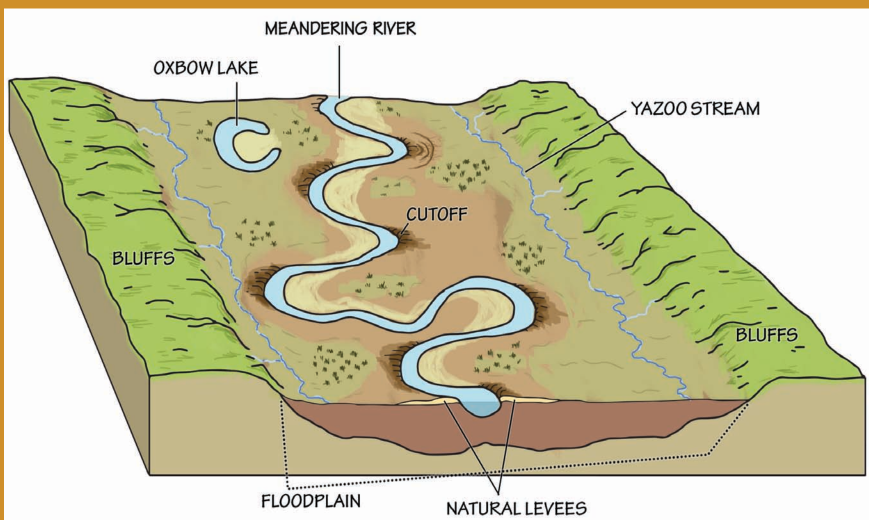
The Mississippi River Valley is bounded by a bluff line paralleling the river course, marking the extent of its meandering river path. The Mississippi is an archetypical meandering river system, and has a very low topographic profile within the valley. Maps show that the river's meandering, snake-like path that has shifted periodically, cutting off some of its loops to produce **oxbows**. Flanking the river itself is a pair of high, linear ridges called **levees**, naturally deposited during flood events, which confine the river course. These are usually the highest elevations of the otherwise wide extensive floodplain. Occasionally, "yazoo tributaries"—small tributary streams running parallel to the larger river—develop on the floodplains.

The extensive Mississippi River Delta, an extremely important coastal area in North America, marks the Southeast's western coastal margin. It is the United States' largest drainage basin, creating a very active depositional environment. The deposits become increasingly younger toward the gulf, due to a depositional process called **progradation**. During this process, the river forms a deposit at its margin, and then overflows it and deposits material on the far side in a continual outward movement. Typical of deltas, the topography here consists of low swampland and lakes. The delta's overall shape is a series of rounded lobes extending out in a "birdfoot" form as they are built up through deposition (*Figure 4.35*). In front of the delta, barrier islands are found in a more north-south orientation (e.g., Cat Island and Chandeleur Islands). The Mississippi River Delta is the terminus for the Mississippi River floodplain system that extends north to Cairo, Illinois.

Figure 4.35: The Mississippi River Delta and sediment plumes from the Mississippi and Atchafalaya rivers.

Meandering Rivers and Streams

A meandering river forms when moving water erodes its banks, widening the river valley and taking on a sinuous shape. Sediments are swept up from the outside edge of river bends, where water flows more swiftly, and deposited back on the bank's inside. Over time, the river or stream forms a snaking pattern across its valley, resulting in a wide, flat floodplain and other representative features such as oxbow lakes. An oxbow lake forms when erosion cuts a meander off from the main stream, creating a U-shaped, freestanding body of water.



Highest and Lowest Elevations by State

Alabama
Alabama's highest point is Cheaha Mountain, a 735-meter-high (2413-foot-high) mountain in the Talladega Mountains, the southernmost segment of the Blue Ridge. Thanks to its tall relief, today the mountain is host to a variety of radio antennas and TV transmitters. The state's lowest point is the shore of the Gulf of Mexico, which lies at sea level.

Florida
Britton Hill, rising 105 meters (345 feet) above sea level, is Florida's highest natural point. The hill, located in Walton County about a half mile south of the Alabama border, is the lowest state high point in the US. The lowest points in Florida are found at sea level along the state's Atlantic and Gulf coastlines.

4 Topography

Elevations

Georgia

The Chattahoochee-Oconee National Forest is home to Brasstown Bald, Georgia's highest mountain. At 1458 meters (4784 feet) in elevation, the peak offers 360 degree views of four states—Georgia, North Carolina, Tennessee, and South Carolina—and on clear days, even the skyline of Atlanta is visible. Georgia's lowest points are found at sea level along the coast, where the shoreline meets the Atlantic Ocean.

Kentucky

At 1263 meters (4139 feet) above sea level, Black Mountain is Kentucky's highest point, located in the Appalachians near the Virginia border in Harlan County. The mountain is located near rich coal veins and was threatened by mountaintop removal mining until the state purchased rights to the summit in 1999. The Mississippi River at Kentucky Bend in southwestern Kentucky is the lowest point in the state, with an elevation of 78 meters (257 feet).

Mississippi

Mississippi's highest point is Woodall Mountain, with an elevation of 246 meters (807 feet). The mountain was originally called Yow Hill, and it was the scene of the 1862 Battle of Iuka during the American Civil War. It is located near Mississippi Highway 25 in the state's northeastern corner. The lowest points in Mississippi are found along the coast, where the shoreline meets the Gulf of Mexico.

North Carolina

At 2037 meters (6684 feet) in elevation, Mt. Mitchell is the highest peak in North Carolina as well the tallest mountain in mainland eastern North America. Mt. Mitchell is part of the Black Mountain subrange of the Appalachians, and is located about 31 kilometers (19 miles) northeast of Asheville. The mountain is named for professor Elisha Mitchell, who first explored the Black Mountains in 1835, and fell to his death at nearby Mitchell Falls when he returned in 1857 to verify his measurements. North Carolina's lowest points are along its coastline, where the shore is at sea level.

South Carolina

Sassafras Mountain, in the Blue Ridge Mountains of northern Pickens County, is South Carolina's highest point. Although the mountain stands 1083 meters (3554 feet) above sea level, it is accessible from a parking lot at the summit. South Carolina's coast, where the shoreline meets the Atlantic Ocean, is the state's lowest point.

Tennessee

Tennessee's highest point is Clingmans Dome, the highest mountain in the Great Smoky Mountains as well as the highest point along the 3499-kilometer (2174-mile) Appalachian Trail. At 2025 meters (6643 feet), it is the third highest mountain east of the Mississippi River, and on clear days offers a panoramic view of seven states: Tennessee, North Carolina, South Carolina, Kentucky, Virginia, Alabama, and Georgia. The Mississippi River at Tennessee's western border is the state's lowest point at 54 meters (178 feet) above sea level.

Elevations

Virginia
Mt. Rogers, located in Jefferson National Forest on Virginia's border with North Carolina, is the state's highest point, with an elevation of 1746 meters (5729 feet). The mountain is named for William Barton Rogers, Virginia's first State Geologist who also went on to found the Massachusetts Institute of Technology. Virginia's lowest points are along the coast where the Atlantic Ocean touches the shore.

West Virginia
In the Appalachians, the highest point on a ridge is often called a "knob" or "dome." Spruce Knob—the summit of Spruce Mountain, the highest peak in the Allegheny Mountains—is West Virginia's highest point at 1482 meters (4863 feet) above sea level. The lowest point in West Virginia is the Potomac River at Harpers Ferry in Jefferson County, with an elevation of 73 meters (240 feet).

4 Topography

Elevations

Resources

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Topoquest, https://www.topoquest.com/.

Websites

OpenLandform Catalog, Education Resources, OpenTopography, http://www.opentopography.org/index.php/resources/lidarlandforms. (High resolution topographic images that may be useful in teaching.)

Teaching Geomorphology in the 21st Century, On the Cutting Edge' Strong Undergraduate Geoscience Teaching, SERC, http://serc.carleton.edu/NAGTWorkshops/geomorph/index.html. (A set of resources for college level, some of which may be adaptable to secondary education.)

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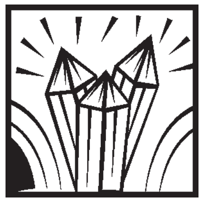

Chapter 5: Mineral Resources of the Southeastern US

What is a mineral?

A **mineral** is a naturally occurring inorganic solid with a specific chemical composition and a well-developed crystalline structure. Minerals provide the foundation of our everyday world. Not only do they make up the rocks we see around us in the Southeast, they are also used in nearly every aspect of our lives. The minerals found in the rocks of the Southeast are used in industry, construction, machinery, technology, food, makeup, jewelry, and even the paper on which these words are printed.

Minerals provide the building blocks for rocks. For example, **granite**, an **igneous rock**, is typically made up of crystals of the minerals feldspar, quartz, **mica**, and **amphibole**. In contrast, **sandstone** may be made of **cemented** grains of feldspar, quartz, and mica. The minerals and the bonds between the crystals define a rock's color and resistance to **weathering**.

Several thousand minerals have been discovered and classified according to their chemical composition. Most of them are **silicates** (representing approximately a thousand different minerals, of which quartz and feldspar are two of the most common and familiar), which are made of silicon and oxygen combined with other elements (with the exception of quartz, SiO_2). Carbonate rocks are made of carbon and oxygen combined with a metallic element; **calcium carbonate** ($CaCO_3$) is the most common example, and most of it today originates as skeletal material precipitated by organisms. Other mineral categories include native elements (such as gold), oxides and **sulfur**-bearing minerals, and **salts**.

Metallic minerals are vital to the machinery and technology of modern civilization. However, many metals occur in the **crust** in amounts that can only be measured in parts per million (ppm) or parts per billion (ppb). A mineral is called an **ore** when one or more of its elements can be profitably removed, and it is almost always necessary to process ore minerals in order to isolate the useful element. For example, **chalcopyrite** ($CuFeS_2$), which contains copper, **iron**, and sulfur, is referred to as a copper ore when the copper can be profitably extracted from the iron and sulfur. Ores are not uniformly distributed in the crust of the Earth, but instead occur in localized areas where they are concentrated in amounts sufficient for being economically extracted by mining.

Non-metallic minerals do not have the flash of a metal, though they may have the brilliance of a **diamond** or the silky appearance of **gypsum** ($CaSO \cdot 2H_2O$). Generally much lighter in color than metals, non-metallic minerals can transmit light, at least along their edges or through small fragments.

granite • *a common and widely occurring type of igneous rock.*

igneous rocks • *rocks derived from the cooling of magma underground or molten lava on the Earth's surface.*

mica • *a large group of sheetlike silicate minerals.*

amphibole • *a group of dark colored silicate minerals, or either igneous or metamorphic origin.*

sandstone • *sedimentary rock formed by cementing together grains of sand.*

weathering • *the breakdown of rocks by physical or chemical means.*

CHAPTER AUTHORS

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5 Mineral Resources

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quartz • *the second most abundant mineral in the Earth's continental crust (after the feldspars), made up of silicon and oxygen (SiO_2).*

copper • *a ductile, malleable, reddish-brown metallic element (Cu).*

gold • *a soft, yellow, corrosion-resistant element (Au), which is the most malleable and ductile metal on Earth.*

feldspar • *an extremely common group of rock-forming minerals found in igneous, metamorphic and sedimentary rocks.*

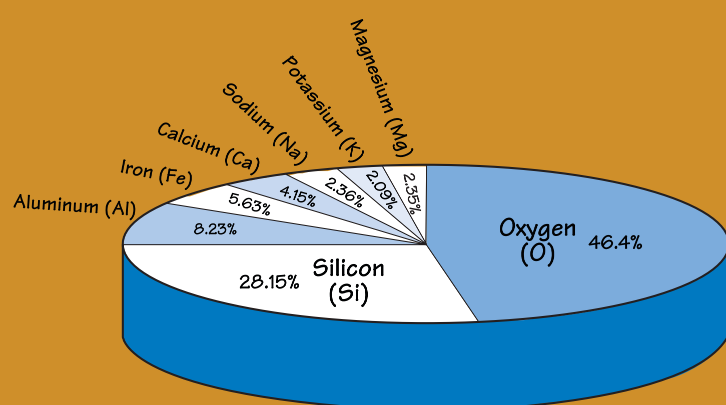
hardness • *a physical property of minerals, specifying how hard the mineral is, and its resistance to scratching.*

erosion • *the transport of weathered materials.*

calcite • *a carbonate mineral, consisting of calcium carbonate ($CaCO_3$).*

Elements: The Building Blocks of Minerals

Elements are the building blocks of minerals. The mineral *quartz*, for example, is made of the elements silicon and oxygen, and, in turn, is also a major component of many rocks. Most minerals present in nature are not composed of a single element, though there are exceptions such as gold. Elements such as *copper* (Cu), lead (Pb), zinc (Zn), and even silver (Ag), *gold* (Au), and diamond (C) are not rare, but they are usually widely dispersed throughout rocks and occur at very low average concentrations. Eight elements make up (by weight) 99% of the Earth's crust, with oxygen being the most abundant (46.4%). The remaining elements in the Earth's crust occur in very small amounts, some in concentrations of only a fraction of one percent. Since silicon (Si) and oxygen (O) are the most abundant elements in the crust by mass, it makes sense for silicates (e.g., *feldspar*, quartz, and garnet) to be some of the most common minerals in the Earth's crust and to therefore be found throughout the Southeast.



Mineral percentage by mass in the Earth's crust.

Mineral Identification

Although defined by their chemical composition and crystal structure, minerals are identified based on their physical properties. A variety of properties must usually be determined when identifying a mineral, with each such property eliminating possible alternatives.

Hardness is a very useful property for identification, as a given mineral can only exhibit a narrow range of hardnesses, and since it is easily testable, this property can be used to quickly and simply minimize the number of possibilities. Hardness is important because it helps us understand why some rocks are more or less resistant to weathering and **erosion**. Quartz, with a rating of 7 on the **Mohs scale**, is a relatively hard mineral, but the mineral **calcite** ($CaCO_3$), rating 3 on the Mohs scale, is significantly softer. Therefore, it should be no surprise that quartz sandstone is much more resistant to erosion and weathering than is **limestone**, which is primarily made of calcite. Quartz is a very common mineral in the Earth's crust, and it is quite resistant due to its hardness and relative insolubility. Thus, quartz grains are the dominant mineral type in nearly all types of **sand**.

Mohs Scale of Hardness

In 1824, the Austrian mineralogist Friedrich Mohs selected ten minerals to which all other minerals could be compared to determine their relative hardness. The scale became known as the Mohs scale of hardness, and it remains very useful as a means for identifying minerals or for quickly determining their hardness. Everyday items can be used to determine hardness if the minerals in the scale are not available. These include a streak plate or piece of unglazed porcelain (hardness 7), a piece of glass (hardness 5), a penny (hardness 3), and a fingernail (hardness 2).

1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

Color is helpful in identifying some minerals such as sulfur, but it is uninformative or even misleading in others such as garnet. **Luster** describes how light is reflected from a mineral's surface, and it can range from adamantine, seen in diamonds, to dull or earthy (effectively no luster), such as in **kaolinite**. **Crystal form**, if visible, can also be diagnostic. For example, **fluorite** and calcite may appear superficially similar, but fluorite forms cubic crystals while calcite forms trigonal-rhombohedral crystals.

Relatedly, crystals may have planes of weakness that cause them to break in characteristic ways, called **cleavage**. Or they may not, but instead display **fracture** when broken. For example, mica and **graphite** have very strong cleavage, allowing them to easily be broken into thin sheets, while quartz and

Review

limestone *• a sedimentary rock composed of calcium carbonate ($CaCO_3$).*

sand *• rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

color (mineral) *• a physical property determined by the presence and intensity of certain elements within the mineral.*

luster *• a physical property of minerals, describing the appearance of the mineral's surface in reflected light, and how brilliant or dull it is.*

kaolinite *• a silicate clay mineral, also known as china clay.*

crystal form *• a physical property of minerals, describing the shape of the mineral's crystal structure.*

fluorite *• the mineral form of calcium fluoride (CaF_2).*

Review

density • *a physical property of minerals, describing the mineral's mass per volume.*

streak • *a physical property of minerals, obtained by dragging the mineral across a porcelain plate and effectively powdering it.*

luminescence • *the emission of light.*

radioactivity • *the emission of radiation by an unstable atom.*

marble • *a metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite.*

jade • *a word applied to two green minerals that look similar and have similar properties: jadeite (a kind of pyroxene) and nephrite (a kind of amphibole).*

soapstone • *a metamorphic schistose rock composed mostly of talc.*

glass (the latter not being a mineral) have no cleavage, instead displaying a distinctive curved fracture form known as conchoidal. The **density** of a mineral may also aid in identifying it (e.g., metals tend to be very dense). Finding the exact density is straightforward, but it does require measuring the volume of the sample. Placing an unknown mineral in water (or other liquid) to find its volume by displacement can be a risky undertaking since several minerals react violently with water, and many more break down with exposure. A mineral's **streak** is obtained by dragging it across a porcelain plate, effectively powdering it. The color of the powder eliminates conflating variables of external weathering, crystal habit, impurities, etc. Some minerals are **magnetic** (affected by magnetic fields), while a few are natural magnets (capable of producing a magnetic field).

Most minerals can be identified through the process of elimination after examining a few of these properties and consulting a mineral identification guide. Mineral testing kits often include several common objects used to test hardness: a porcelain streak plate, a magnet, and a magnifying glass. Some minerals have rare properties, which may be more difficult to test. For example, there are minerals that exhibit **luminescence** of all types, giving off light due to a particular stimulus. Some minerals are **radioactive**, usually due to the inclusion of significant amounts of uranium, **thorium**, or potassium in their structure. Carbonate minerals will **effervesce** when exposed to hydrochloric acid. **Double refraction** describes the result of light passing through a material that splits it into two polarized sets of rays, doubling images viewed through that material. For example, a single line on a sheet of paper will appear as two parallel lines when viewed through a clear calcite crystal.

There are many more interesting and distinguishing properties that minerals may possess, and there are many more elaborate and precise means for identifying them. The branch of geology that studies the chemical and physical properties and formation of minerals is called *mineralogy*.

What Are Minerals Used For?

Mineral resources fall into many different categories, including industrial minerals, construction materials, **gemstones**, and metallic and non-metallic ores. Some minerals and rocks are abundant and are used in the construction industry or in the manufacturing of many of the products we commonly find in stores. Construction materials include **dimension stone** (e.g., sandstone, limestone, and granite), which is used for the exterior or interior of structures.

Minerals used in manufacturing include kaolinite for ceramics, gypsum for wallboard, fluorite for the fluoride in toothpaste, and halite for common table and rock salt. We also seek out specific rock types and sediment to use in the construction of buildings, highways, and bridges. Decorative statues are commonly constructed of **marble**, **jade**, or **soapstone**. Granite, travertine, and other decorative stones are increasingly used to beautify our home interiors and to make art, in addition to being used in public buildings. Some minerals are considered to be precious or semi-precious and are used in jewelry, including diamond and some crystalline forms of quartz.

What distinguishes a regular mineral from a gem?

Minerals are assigned to the category of gemstones based primarily on our interpretation of what has value. Typically, the beauty, durability, and rarity of a mineral qualify it as a gemstone. Beauty refers to the luster, color, transparency, and brilliance of the mineral, though to some degree it is dependent on the skillfulness of the cut. Not all gems are prized for these reasons; for example, scarcity may be artificially inflated, or a mineral may be valued for its unusual color.

Gemstones can be further categorized as precious or semiprecious stones. Precious stones, including diamond, topaz, and sapphire, are rare and translucent to light. They are more durable because they are hard, making them scratch resistant. On the Mohs scale of hardness, the majority of precious gemstones have values greater than 7. Semi-precious stones are generally softer, with hardness scale values between 5 and 7. The minerals peridot, jade, garnet, amethyst, citrine, rose quartz, tourmaline, and turquoise are examples of semi-precious stones that can be cut and used in jewelry.

Gems may have common names that differ from their geological ones, and these names may be dependent on mineral color. For example, the mineral beryl is also referred to as emerald, aquamarine, or morganite depending on its color. Corundum can also be called sapphire or ruby, and peridot is another name for olivine.

Metallic minerals have many applications and are used to manufacture many of the items we see and use every day. For example, iron comes from **hematite** and **magnetite**, and from it we make steel. **Lead**, from the mineral **galena**, is used in the manufacture of batteries and in the solder found in electronic devices. **Titanium**, from the mineral **ilmenite**, is used in airplanes, spacecraft, and even white nail polish. **Aluminum** comes from **bauxite** and is known for being both lightweight and strong—many of the parts that make up today's

Review

hematite *• a mineral form of iron oxide (Fe_2O_3), with vivid red pigments that make it valuable as a commercial pigment.*

magnetite *• a mineral form of iron oxide (Fe_3O_4) with naturally occurring magnetic properties.*

lead *• a metallic chemical element (Pb).*

galena *• an abundant sulfide mineral with cubic crystals.*

titanium *• a metallic chemical element (Ti) that is important because of its lightweight nature, strength and resistance to corrosion.*

ilmenite *• an ore of titanium, produced for use as a white pigment in paint.*

aluminum *• a metallic chemical element (Al), and the most abundant metal in the Earth's crust.*

Review

magma • *molten rock located below the surface of the Earth.*

intrusive rock • *a plutonic igneous rock formed when magma from within the Earth's crust escapes into overlying strata.*

rift • *a break or crack in the crust that can be caused by tensional stress as a landmass breaks apart into separate plates.*

volcanism • *the eruption of molten rock onto the surface of the crust.*

felsic • *igneous rocks with high silica content and low iron and magnesium content.*

gabbro • *a coarse-grained, mafic and intrusive igneous rock.*

mafic • *igneous rocks that contain a group of dark-colored minerals, with relatively high concentrations of magnesium and iron.*

automobiles are made of this metal. Copper comes from a variety of copper-bearing minerals, including chalcopyrite, and is used to make electrical wire, tubing, and pipe.

Mineral Formation

Economically recoverable mineral deposits are formed by geologic processes that can selectively concentrate desirable elements in a relatively small area. These processes may be physical or chemical, and they fall into four categories:

Magmatic processes separate minor elements of **magma** from the major elements and concentrate them in a small volume of rock. This may involve either the early crystallization of ore minerals from the magma while most other components remain molten or late crystallization after most other components have crystallized. Magmatic processes responsible for the formation of mineral deposits are usually associated with igneous **intrusions** (formed during mountain building events, **rifting**, and **volcanic** activity), which can range in composition from granite (**felsic**) to **gabbro** (**mafic**). **Metamorphism** may also cause **recrystallization** of minerals and concentration of rare elements. Under conditions of extreme high-temperature metamorphism, minerals with the lowest melting temperatures in the crust may melt to form small quantities of **pegmatite** magmas.

Hydrothermal processes involve **hydrothermal solutions** that dissolve minor elements dispersed through large volumes of rock, transport them to a new location, and precipitate them in a small area at a much higher concentration. Hydrothermal solutions are commonly salty, acidic, and range in temperature from over 600°C (~1100°F) to less than 60°C (140°F). Some of these fluids may travel very long distances through **permeable sedimentary rock**. Eventually, the hydrothermal fluids precipitate their highly dissolved load of elements, creating concentrated deposits.

Sedimentary processes gather elements dispersed through large volumes of water and precipitate them in a sedimentary environment, such as in sedimentary layers on the ocean floor or on lakebeds. Sedimentary mineral deposits form by direct precipitation from the water.

Weathering and erosion break down large volumes of rock by physical and chemical means and gather previously dispersed elements or minerals into highly concentrated deposits. **Residual weathering deposits** are mineral deposits formed through the concentration of a weathering-resistant mineral, as a result of surrounding minerals being eroded and dissolved. In contrast, mineral deposits formed by the concentration of minerals in moving waters are called **placer deposits**.

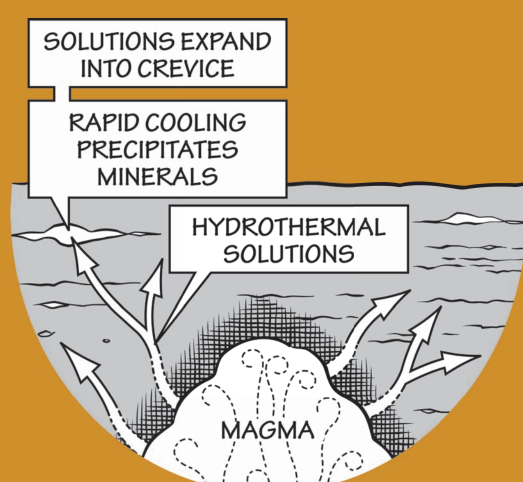
Mineral Resources 5

What are hydrothermal solutions?

Hot water enriched in salts such as sodium chloride ($NaCl$), potassium chloride (KCl), and calcium chloride ($CaCl_2$) is called a hydrothermal solution, or simply "brine." The brine is as salty or even saltier than seawater, and may contain minute bits of dissolved minerals such as gold, lead, copper, and zinc. The presence of salt in the water stops the metallic minerals from precipitating out of the brine because the chlorides in the salt preferentially bond with the metals. Additionally, because the brine is hot, the minerals are more easily dissolved, just as hot tea dissolves sugar more easily than cold tea does.

Hot water brines can have varying origins. Most bodies of magma contain mineral-enriched, superheated water, which is released into the surrounding rock as the magma cools. Rainwater can become a hydrothermal solution as it filters through rocks and picks up soluble materials along its path. Seawater, which is already enriched in salt, often becomes a hydrothermal solution in the vicinity of volcanic activity on the ocean floor where tectonic *plates* are pulling apart.

Hydrothermal solutions move away from their source of heating through cracks, faults, and solution channels into the adjacent cooler rocks. As the water moves quickly through fractures and openings in the rock (where it experiences changes in pressure or composition and dilution with groundwater), it can cool rapidly. This rapid cooling over short distances allows concentrations of minerals to be deposited. When a hydrothermal solution cools sufficiently, the dissolved salts form a precipitate, leaving behind minerals in a vein or strata-bound deposit.



Review

metamorphic rocks • *rocks formed by the recrystallization and realignment of minerals in pre-existing sedimentary, igneous, and metamorphic rocks when exposed to high enough temperature and/or pressure.*

recrystallization • *the change in structure of mineral crystals that make up rocks, or the formation of new mineral crystals within the rock.*

pegmatite • *a very coarse-grained igneous rock that formed below the surface.*

hydrothermal solution • *hot, mineral-rich water moving through rocks.*

permeability • *a capacity for fluids and gas to move through fractures within a rock, or the spaces between its grains.*

sedimentary rock • *rock formed through the accumulation and consolidation of grains of broken rock, crystals, skeletal fragments, and organic matter.*

5 Mineral Resources

A mineral is not necessarily restricted to one method of concentration or environment of formation. For example, economically important deposits of gypsum may form as a precipitate from evaporating water. However, gypsum formation may also be associated with volcanic regions where limestone and sulfur gases from the volcano have interacted, or from other areas as a product of the chemical weathering of pyrite.

Minerals in the Southeast

The Southeast's mineral resources contributed significantly to Colonial economies, the struggle for independence, and the rise of the United States as a world power. The first metals mined by Europeans in the United States were extracted in 1621 from a lead deposit in Virginia. This same deposit supplied shot for the Continental Army during the American Revolution, and was a point of contention during the Civil War. In the early 19th century, the first gold rush in North America spread across the southern Appalachian Piedmont from a small farm in central North Carolina.

During the 17th, 18th, and early 19th centuries, mines in the Southeast were generally numerous and small, often producing minerals for local use. Mines were fewer in number but larger in scale during the late 19th and early 20th centuries, serving mostly regional and national markets. Today, there are relatively few mines in the Southeast, but the area's existing mines are commonly large or highly specialized operations that produce minerals for the global marketplace. The Southeast is currently a major supplier of **zinc**, cadmium, germanium, **lithium**, pyrophyllite, **olivine**, mica, and feldspar.

Mineral Resources of the Blue Ridge and Piedmont

Region 1

The Blue Ridge and Piedmont contains many distinct types of mineral deposits, which formed by different geologic processes throughout the Southeast's geologic history. Over the last billion years, these processes and their associated geologic environments have operated to produce the abundance and diversity of mineral deposits found in the region today (*Figure 5.1*).

Metallic Resources

Iron and titanium **oxide** deposits, associated with igneous intrusions that occurred during the **Grenville Orogeny**, can be found scattered throughout the Grenville rocks that stretch from Virginia to Georgia. These rocks formed one billion years ago as the supercontinent **Rodinia** formed and ocean floor

Region 1

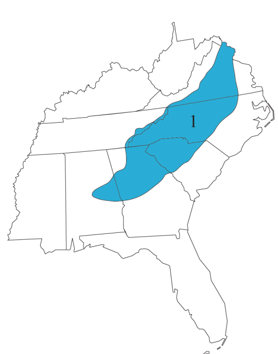
zinc • *a metallic chemical element (Zn, atomic number 30).*

lithium • *a metallic chemical element (Li) used in the manufacture of ceramics, glass, greases, and batteries.*

olivine • *an iron-magnesium silicate mineral ($(Mg,Fe)_2SiO_4$) that is a common constituent of magnesium-rich, silica-poor igneous rocks.*

oxidation • *a chemical reaction involving the loss of at least one electron when two substances interact.*

Grenville Orogeny • *a mountain-building event, about 1.3 to 1 billion years ago, that played a role in the formation of the supercontinent Rodinia.*



Mineral Resources

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Region 1

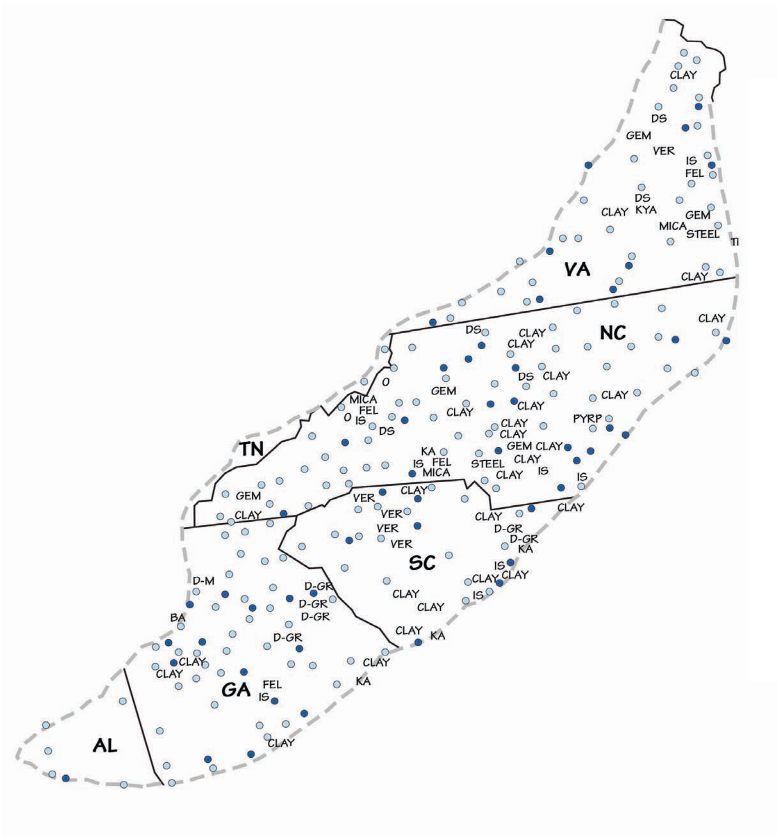


Figure 5.1: Principal mineral resources of the Blue Ridge and Piedmont.

Rodinia • *a supercontinent that contained most or all of Earth's landmass, between 1.1 billion and 750 million years ago, during the Precambrian.*

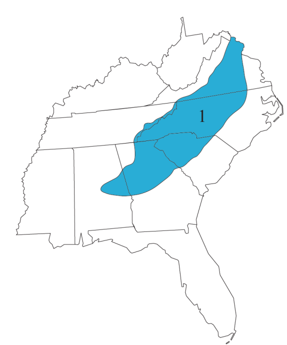
rutile • *a typically reddish brown mineral formed of TiO_2.*

phosphate • *an inorganic salt of phosphoric acid, and a nutrient vital to biological life.*

sediment was pushed onto ancient North America. The tectonic processes that formed the Grenville rock and mineral deposits are often obscured by strong metamorphism and deformation.

See Chapter 1: Geologic History to learn more about ancient supercontinents and building events.

The titanium oxide minerals **rutile** and ilmenite were mined in the Roseland District of central Virginia (western Amherst and Nelson counties) between 1900 and 1971. This area once supplied a large percentage of the rutile consumed in the United States, used largely as a white pigment and an ingredient in refractory ceramics (*Figure 5.2*). During the milling process, significant tonnages of the **phosphate** mineral apatite were also recovered, from which phosphorous chemicals were produced. From 1931 to 1971, the American Cyanamid Company operated a plant at Piney River, which refined the titanium ore and produced titanium dioxide for paint pigment. After the plant closed, its waste disposal sites remained behind. Today, the 20-hectare (50-acre) area is classified as a Superfund site due to the leaching of highly acidic iron sulfate, which has degraded the Piney River's water quality, destroyed vegetation, and contaminated local groundwater. More than



5

Mineral Resources

Region 1

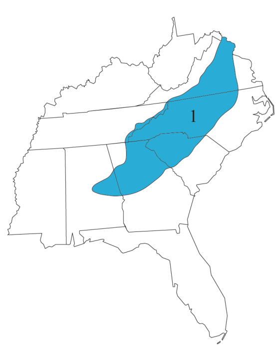
sphalerite • *zinc sulfide (ZnS), the chief ore mineral of zinc.*

pyrite • *the iron sulfide mineral (FeS_2) with a superficial resemblance to gold, known commpnly as "fool's gold."*

Precambrian • *a geologic time interval that spans from the formation of Earth (4.6 billion years ago) to the beginning of the Cambrian (541 million years ago).*

rift basin • *a topographic depression caused by subsidence within a rift.*

heat • *a form of energy transferred from one body to another as a result of a difference in temperature or a change in phase.*



200,000 fish died between 1977 and 1981 as a result of runoff from the plant's waste piles; today, about 200 people live within one mile of the site.

A Superfund site is a heavily polluted location, designated by the government to receive a long-term clean-up response in order to remove environmental hazards and contamination.

Figure 5.2: A crystal of rutile, composed primarily of titanium dioxide (TiO_2). Although it appears dark in color, when powdered it becomes a brilliant white. Specimen is 4.4 centimeters (1.7 inches) in width.

Small but rich magnetite (iron oxide) deposits at Cranberry, North Carolina occur in a 40-kilometer-long (24-mile-long) area associated with a large intrusion of gabbro, a dark-colored igneous rock. Around 1.5 million tons of high-purity magnetite was produced in this area of North Carolina from 1882 to 1930.

Sulfides, including iron, zinc, lead, and copper sulfides (galena, **sphalerite**, chalcopyrite, and **pyrite**), make up the majority of ore minerals in the Southeast's **Precambrian rift basins**, which formed during the breakup of Rodinia. These minerals were largely deposited by hydrothermal processes. Seawater circulating through thick sequences of sediments, some of which were volcanic in origin, was **heated** by geothermal **energy** from subsurface magma. These hydrothermal fluids dissolved base metals, sulfur, and other elements from the sediments through which they migrated. Because the mineral-laden solutions were hot, they rose upward to the surface of the rift basins. As the hydrothermal fluids cooled at the surface, minerals precipitated from the solutions to form blankets of sulfides (including iron, copper, and zinc sulfides) within the rift basin sediments. During the **Taconic** and **Acadian orogenies**, these deposits were folded to form thick lenses, and recrystallized into coarse crystals that are easily extracted. Numerous small sulfide deposits are present from southwest Virginia to northeast Georgia. The region's largest deposits are those found in the Gossan Lead District in the Ashe Formation of Virginia, with 28 kilometers (17 miles) of iron sulfide deposits, and the Ducktown District in Tennessee's Ocoee Basin, which contains nine separate sulfide bodies totaling almost 200 million tons of ore (*Figure 5.3*).

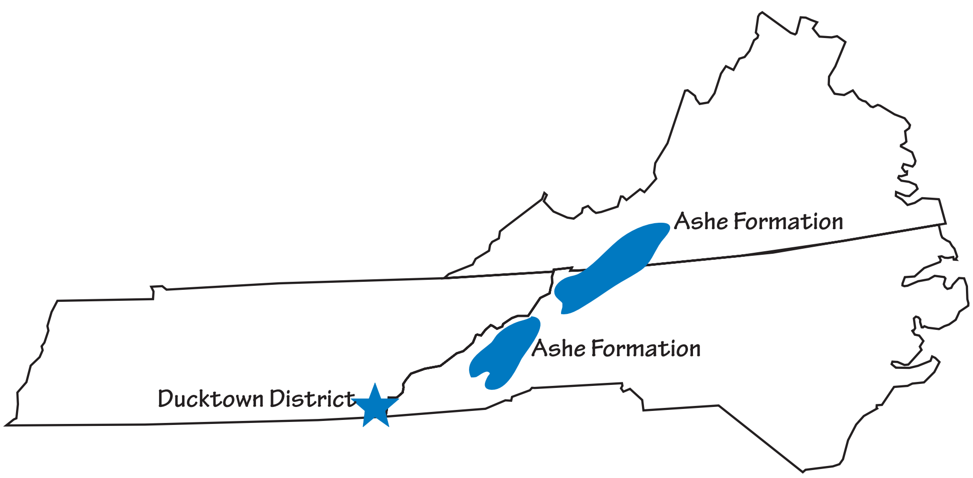


Figure 5.3: The Gossan Lead District is in the Ashe Formation of Virginia; the Ducktown District is in southeastern Tennessee.

The Ducktown District was first worked in the early 1840s, initially for iron and later for gold formed by surface weathering of the sulfide ore bodies. The district also produced zinc and **silver**. Rich secondary copper ores were discovered below the **gossans** and mined from 1847 to 1879. Initially, the rich ore was piled on huge stacks of cordwood and set to burn for several weeks to oxidize the sulfur. The roasted ore was then placed in smelters fired by charcoal to recover the copper metal. The entire valley was stripped of **trees** to fuel the roasters and smelters, consuming over 600 hectares (1500 acres) of mature timber each year by 1876. By 1878, 122 square kilometers (47 square miles) of forest had been consumed in and around the valley. Sulfur gases released by roasting and smelting fell with rain as sulfuric acid, killing virtually all remaining vegetation in the valley. High rainfall resulted in extensive erosion and gullying, producing terrain similar to a desert (*Figure 5.4*). Mining of the primary sulfide ore bodies underground began in 1890, and continued until the end of the district's mining in 1987. Cleaner smelting technologies and extensive reclamation and planting efforts from the 1970s through the 1990s restored vegetation in much of the valley, an effort that continues to the present.

Manganese oxide deposits are locally present in the Blue Ridge and Piedmont's Precambrian rift basin sediment, especially in the Ashe Formation near the North Carolina-Virginia border. These include the deposits at Bald Knob, North Carolina, which are composed of manganese oxides, **carbonates**, and silicates. The formation of these manganese deposits is similar to that of the sulfide deposits described previously, but here they took place at lower temperatures.

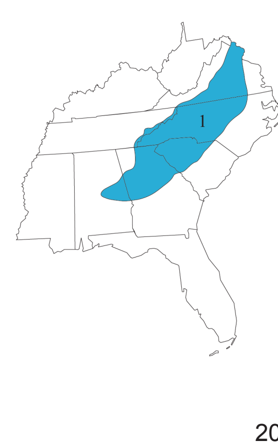
***Taconic Orogeny* • a late Ordovician mountain-building event involving the collision and accretion of a volcanic island arc along the eastern coast of North America.**

***Acadian Orogeny* • a Devonian mountain-building event involving the collision of the eastern coast of North America and the accreted terrane of Avalon.**

***orogeny* • a mountain-building event generally caused by colliding plates and compression of the edge of the continents.**

***silver* • a metallic chemical element (Ag).**

***gossan* • the near-surface, oxidized portion of a sulfide-rich ore body.**



Cambrian • *a geologic time period lasting from 541 to 485 million years ago.*

Ordovician • *a geologic time period spanning from 485 to 443 million years ago.*

fault • *a fracture in the Earth's crust in which the rock on one side of the fracture moves measurably in relation to the rock on the other side.*

barite • *a usually white, clear, or yellow mineral ($BaSO_4$) found in limestone, clay-rich rocks, and sandstones.*

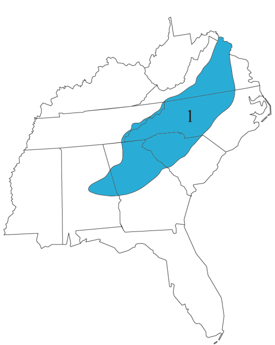
Avalon • *an early Paleozoic microcontinent offshore of what is now the eastern coast of North America.*

Figure 5.4: A train brings copper ore out of the Tennessee Ducktown mines in 1939. Fumes from the burning of sulfide ores caused severe erosion and loss of the area's vegetation.

During mountain building in the **Cambrian** and **Ordovician**, hydrothermal fluids migrated along fractures and thrust **faults**, following units of permeable rock. Minor occurrences of zinc and lead sulfides from this time period are present in the Blue Ridge, and there are several large **barite** deposits formed along thrust faults—for example, the barite deposits found in the Hot Springs District of Madison County, North Carolina. Because it is heavy, soft, and chemically inert, barite is widely used as an additive and filler, largely to increase the density of lubricating muds used in oil and gas drilling.

The rocks of the Inner and Outer Piedmont host numerous hydrothermal sulfide and gold deposits, although most were relatively small and largely mined out in the 19th century. Many of the region's high-grade gold deposits are concentrated within quartz veins. In the Outer Piedmont, numerous deposits of sulfides (copper, lead, and zinc), gold, iron, manganese, barite, and tungsten are associated with Precambrian to Cambrian volcanic activity and igneous intrusions that occurred before the **Avalon terrane** was attached to North America. The Carolina Slate Belt, a weak to moderately metamorphosed section of Avalon rocks that stretches over 970 kilometers (600 miles) from Georgia to Virginia, is thought to contain significant quantities of undiscovered gold and silver (*Figure 5.5*).

See Chapter 2: Rocks for more on Avalon and other exotic terranes that accreted to North America during the Paleozoic.



Over 300 different minerals have been found in North Carolina—a greater variety than in any other state.

Figure 5.5: A lead-rich ore with patches of silver, from the Silver Hill Mine in the Carolina Slate Belt, Davidson County, North Carolina. Specimen is 8.8 centimeters (3.5 inches) wide.

Many of these deposits also contain abundant pyrite, sometimes in crystals up to 20 centimeters (8 inches) across. The deposits were modified, and in some cases further concentrated, by hydrothermal processes accompanying the Acadian and **Alleghanian** orogenies. Subsequent weathering and erosion formed rich placer and residual gold deposits that were the initial target of mining in the Piedmont. **Alluvial** mining gave way to **lode** mining as placer deposits were exhausted and the gold was traced to its source in the bedrock. Although much of the Blue Ridge and Piedmont's gold has already been commercially extracted, gold panning and sluicing (*Figure 5.6*) is a popular recreational activity in many parts of the region.

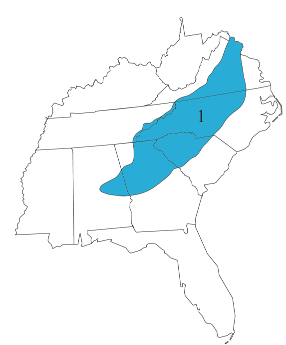
Gold was first reported in North Carolina in 1774, but the Carolina Gold Rush began after 12-year-old Conrad Reed found an 8-kilogram (17-pound) gold nugget on the family farm in 1799. Mining had begun at deposits in five North Carolina counties by 1820, and 14 kilograms (500 ounces) of North Carolina gold arrived at the US Mint in Philadelphia in 1824. Mining experts and engineers were recruited from Britain, Germany, Italy, and South Africa, and miners came to the Southeast from more than a dozen countries. The Carolina Gold Rush spread through the southeastern Piedmont from Virginia to Alabama and westward across the Blue Ridge by 1830, and included the deposits of the Inner Piedmont.

terrane • *a piece of crustal material that has broken off from its parent continent and become attached to another plate.*

Alleghanian Orogeny • *a Carboniferous to Permian mountain-building event involving the collision of the eastern coast of North America and the northwestern coast of Africa.*

alluvial • *a layer of river-deposited sediment.*

lode • *an ore deposit that fills a fissure or crack in a rock formation.*



How is gold mined?

Gold can be extracted using a wide variety of methods. Placer mining searches stream bed deposits for minerals moved from their original source by water. Placer deposits can be mined in several different ways: panning, which uses a small, hand-held pan to manually sort the gold from sand and rock fragments; sluicing, in which water is sent through a man-made stepped channel that traps particles of gold; or dredging, where a large machine uses mechanical conveyors or suction to pull loads of material from the river bottom and then dump smaller fragments into a sluice box. Gold that is trapped in layers of rock may be excavated through underground mining, where tunnels or shafts are used to locate the ore, or by open pit mining, which is used when deposits are relatively close to the surface.

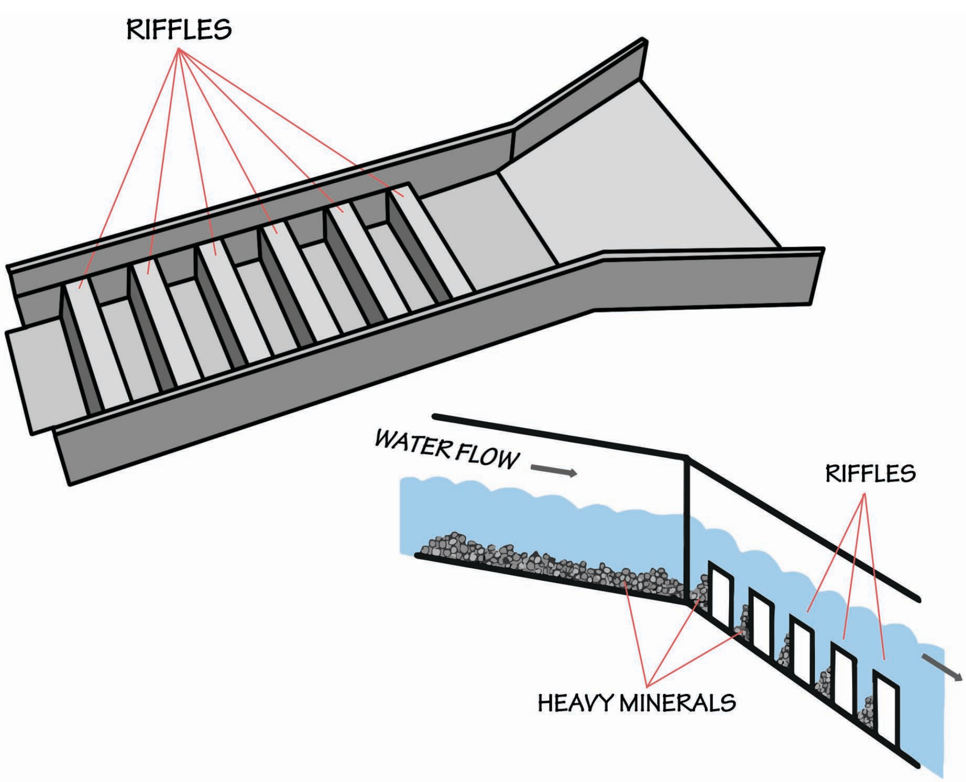
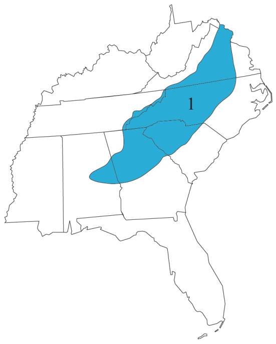


Figure 5.6: A sluice is a long tray through which water that contains gold is directed. The sluice box contains riffles, or raised segments, which create eddies in the water flow. Larger and heavier particles, such as gold, are trapped by the eddies and sink behind the riffles where they can later be collected.



There are over 300 known gold, silver, and base metal mines and prospects in Virginia, but the most important are clustered in a narrow zone of volcanic rocks called the Virginia Gold-Pyrite Belt, which extends for about 160 kilometers (100 miles) (*Figure 5.7*). At least 100 old gold mines are present along this trend, opened along veins and sulfide deposits of hydrothermal origin. Total gold production from Virginia from 1804 through 1947 was 9300 kilograms (330,000 ounces). Copper, zinc, and lead from sulfide deposits also were mined in this area.

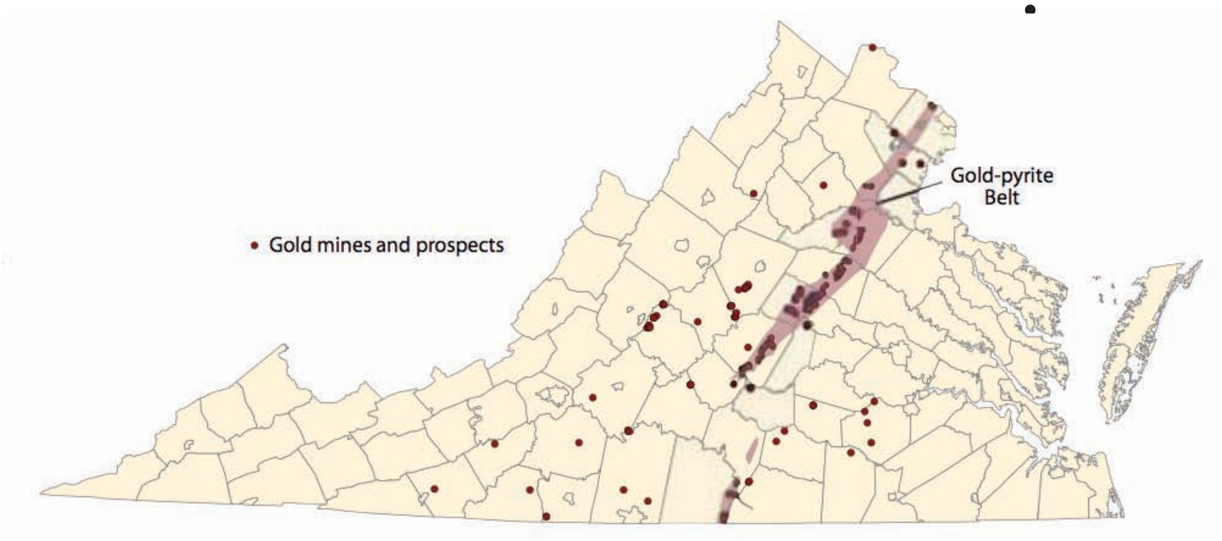
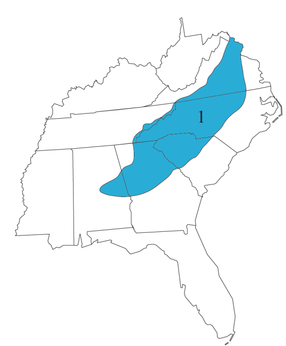


Figure 5.7: The Virginia Gold-Pyrite Belt, and associated gold mines and prospects.

banded iron formation • *rocks with regular, alternating thin layers of iron oxides and either shale or silicate minerals.*

Northern Georgia's Dahlonega Belt—volcanic rocks containing rich hydrothermal gold-bearing quartz veins and sulfide deposits—produced over 14,000 kilograms (500,000 ounces) of gold between 1838 and 1941 (*Figure 5.8*). Gold was first discovered in the Dahlonega area in 1828, leading to a period of feverish prospecting known as the Georgia Gold Rush. A branch of the US Mint operated in Dahlonega between 1838 and 1861, striking United States coins from Dahlonega gold.

South Carolina was the scene of a modern-day gold rush between 1985 and 1999, with four major open-pit mines—the Ridgeway Mine (Fairfield County), Barite Hill Mine (McCormick County), Brewer Mine (Chesterfield County), and Haile Mine (Lancaster County)—in operation. Total gold production from the entire Southeastern Piedmont through 1969 is estimated at 77,000 kilograms (2.7 million ounces). South Carolina's production from 1985 to 1999 increases this figure to about 123,000 kilograms (4.35 million ounces) of gold.



A **banded iron formation** extends for almost 137 kilometers (85 miles) through the Avalon rocks in North and South Carolina. Hydrothermal in origin, the iron was originally deposited in sediments on the ancient seafloor. These deposits were first mined just before 1760, and supplied iron for the weapons of the Continental Army during the American Revolution. The same banded iron formations were also a major source of iron for the weapons of the Confederate

Region 1

Triassic • *a geologic time period that spans from 252 to 201 million years ago.*

Jurassic • *the geologic time period lasting from 201 to 145 million years ago.*

Pangaea • *supercontinent, meaning "all Earth," which formed over 300 million years ago and lasted for almost 150 million years.*

gneiss • *a metamorphic rock that may form from granite or layered sedimentary rock such as sandstone or siltstone.*

beryl • *a white, blue, yellow, green, or pink mineral, found in coarse granites and igneous rocks.*

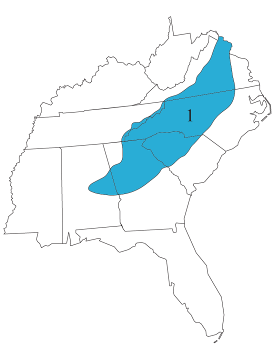


Figure 5.8: A view into the tunnels of the Consolidated Gold Mine, Dahlonega, Georgia. This mine was the site of one of the world's largest gold-bearing quartz veins, and it is the largest hard rock gold mine east of the Mississippi.

Dahlonega and the Trail of Tears

The "official" discovery of gold in Georgia was made in 1828 by Frank Logan in present-day White County, well within the territory of the Cherokee Nation. The Cherokee were aware of the presence of gold on their lands, and gold mines were operated illegally in Cherokee Territory as early as 1819. As word of the discovery spread, a systematic campaign to remove the Cherokee and open the area to gold mining was crafted in Georgia and Washington, DC. In 1830, Congress quickly passed the Indian Removal Act. In December 1835, the US government signed a treaty with a small group of disaffected Cherokee, none of whom were elected officials of the Cherokee Nation. Twenty signed the treaty, ceding all Cherokee territory east of the Mississippi to the US, in exchange for $5 million and new homelands in the Indian Territory (Oklahoma). More than 15,000 Cherokees protested the illegal treaty, but the US Senate ratified it by one vote. Most of the Cherokee people were forced to leave their ancestral home in northern Georgia and adjacent states, and relocate to the Indian Territory in the winter of 1838–1839. Over 4000 Cherokee died as a result of the removal, nearly a fifth of the Cherokee population. Their journey is called "The Trail of Tears."

armies during the Civil War, including shot, cannonballs, and armor plates for naval ironclads. Production declined after the war and ended around 1900.

Uranium ore is found in **Triassic-Jurassic** rift basin sediments that were deposited as **Pangaea** began to split apart. The uranium was transported in dissolved form by groundwater, then concentrated in the sediments and deposited. In 1982, the Marline Uranium Corporation announced the discovery of a 30-million ton deposit of uranium ore in Pittsylvania County, Virginia. The ore body is developed in an intrusion of **gneiss** in the Danville rift basin. This uranium deposit was never commercially developed, due to a drop in uranium ore prices and local opposition to the project.

Non-Metallic Resources

During the Taconic and Acadian orogenies, numerous pegmatites intruded Precambrian rift rocks throughout the Blue Ridge. Many of these pegmatites have been mined for feldspar, kaolinite, quartz, and mica (*Figure 5.9*). Among the most important districts for pegmatite mining are the Franklin-Sylva and Spruce Pine districts in North Carolina, where hundreds of pegmatites intrude into the Ashe Formation (*see Figure 5.3*). These two districts have produced over half of all US sheet and scrap mica and feldspar since mining began there in 1868, and North Carolina remains the nation's top producer. Ancient mine pits and shafts in the Blue Ridge Mountains of North Carolina were long thought to be pre-colonial silver and gold prospects attributed to early Spanish explorers, but these old prospects are now thought to be the work of Native Americans who mined the pegmatites for sheets of muscovite mica. **Beryl** is a common mineral in some pegmatites, and mines in the Spruce Pine District have produced gem quality aquamarine and emerald (varieties of beryl). Pegmatites are also widespread in the Inner Piedmont, although they are generally no longer mined there. An unusual group of lithium-bearing pegmatites in Alexander County, North Carolina produces gem-quality emeralds and hiddenite, a gem form of **spodumene** (*Figure 5.10*). Lithium-rich pegmatite deposits between Lincolnton, North Carolina and Gaffney, South Carolina represent one of the largest concentrations of silicate lithium in the world.

Two of the most common mica minerals are muscovite (light-colored) and biotite (black). Mica minerals are used in heating and insulating.

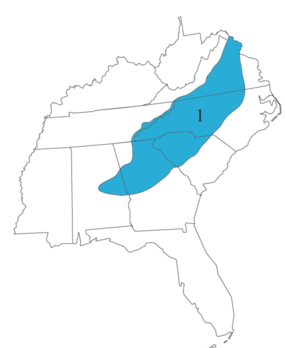
The mineral olivine, concentrated in the **ultramafic** igneous rocks dunite and **peridotite**, is present throughout the Blue Ridge from Virginia to Alabama. It occurs in highly deformed Precambrian rift rocks that were thrust westward onto the margin of North America during the Taconic Orogeny.

The fibrous mineral asbestos is a very slow conductor of heat, and was commonly used as a fireproofing material and as electrical insulation. Concerns over health effects on the lungs have led to its removal from common use.

spodumene • *a translucent pyroxene mineral (lithium aluminum inosilicate) occurring in prismatic crystals, and a primary source of lithium.*

ultramafic rocks • *igneous rocks with very low silica content (< 45%), which are composed of usually greater than 90% mafic minerals.*

peridotite • *a coarse-grained plutonic rock containing minerals, such as olivine, which make up the Earth's mantle.*



Region 1

asbestos *• a fibrous silicate mineral that is resistant to heat, flames, and chemical action.*

Paleozoic *• a geologic time interval that extends from 541 to 252 million years ago.*

corundum *• an aluminum oxide mineral (Al_2O_3) that is, after diamond, the hardest known natural substance.*

aggregate *• crushed stone or naturally occurring unlithified sand and gravel.*

talc *• hydrated magnesium silicate, formed during hydrothermal alteration accompanying metamorphism.*

silt *• fine granular sediment most commonly composed of quartz and feldspar crystals.*

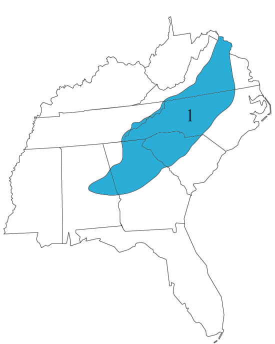


Figure 5.9: A portion of a feldspar-rich pegmatite from Pine Mountain Mine in Mitchell County, North Carolina, with inclusions of muscovite mica and garnet. Specimen is 13 centimeters (5 inches) wide.

Figure 5.10: A crystal of hiddenite, a varity of spodumene, from the Adams Hiddenite and Emerald Mine in North Carolina. Hiddenite was first discovered in Alexander County, North Carolina in 1879. A nearby community was also named after the mineral.

Mineral Resources

5

Region 1

Western North Carolina leads the nation in olivine production; the Webster-Balsam District in Jackson County and the Spruce Pine District in Yancey and Mitchell counties have produced commercial quantities of this mineral for use in industry and as the gemstone peridot. Ultramafic deposits in the Blue Ridge have also produced minor quantities of **asbestos** and chromite.

Paleozoic mountain building altered the Blue Ridge and Piedmont's ultramafic rocks, resulting in the formation of distinctive localized deposits. In the Blue Ridge, deposits of **corundum** are common. Corundum is used as an abrasive, and in gem form is known as ruby (red) or sapphire (blue). The Macon County area continues to produce gem-quality forms of corundum, especially rubies and sapphires—in 1985, two rubies totaling almost 1000 carats with an uncut value of around $40,000 were found there. In the Inner Piedmont, Paleozoic metamorphism formed deposits of vermiculite, used in lightweight concrete **aggregates**, insulation, agriculture, and other products. The United States is one of the two largest producers of vermiculite in the world; all US production comes from deposits in the Inner Piedmont of Virginia and South Carolina.

Talc deposits are associated with the Murphy Marble in a belt extending through Cherokee and Swain counties, North Carolina. The talc formed through tectonic-metamorphic alteration of **silty dolomite** or associated sediments during one of the Paleozoic orogenic events. While talc can form from a variety of **parent materials**, including ultramafic rocks rich in olivine, talc formed from dolomitic marbles tends to be cleaner and more pure, making the Murphy deposits economically viable. These deposits were mined as early as 1859 and well into the 1980s, but are currently inactive. The district has produced over 200,000 tons of high-grade talc.

See Chapter 2: Rocks to learn more about the Murphy Marble and other metamorphosed rocks of the Southeast.

The Blue Ridge and Piedmont also produces numerous industrial minerals in the form of crushed stone, sand and **gravel**, and common **clays**. **Holocene** sand and gravel deposits found along streams and **terraces** are locally quarried for use as construction aggregate, which is used to strengthen concrete, make blacktop, produce building materials, and as road and dam foundations. Limestone, and to a lesser extent dolomite (**dolostone**), is also mined and crushed for use as aggregate, and Georgia is the national leader in the production of granite used as crushed stone. Some types of sand are quartz-rich, which makes them useful for other industrial purposes. This "industrial sand" is used in sandblasting, filtering, and the manufacturing of glass, and is mined from quartz-rich Paleozoic sandstones and **quartzites**.

Dimension stone is the commercial term applied to quarried blocks of rock that are cut to specific dimensions and used for buildings, monuments, curbing and facing. Granite, limestone, and sandstone are often quarried as dimension stone. The largest open-face granite quarry in the world is located at Mt. Airy, North Carolina (*Figure 5.11*). Polished granites from Georgia (in particular the Elberton area) and North Carolina have been used in many government

dolomite • *a carbonate mineral, consisting of calcium magnesium carbonate* ($CaMg(CO_3)_2$).

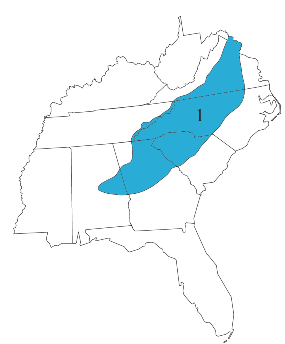
parent material • *the original geologic material from which soil formed.*

gravel • *unconsolidated, semi-rounded rock fragments larger than 2 millimeters (0.08 inches) and smaller than 75 millimeters (3 inches).*

clay • *the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.*

dolostone • *a rock primarily composed of dolomite, a carbonate mineral.*

quartzite • *a hard metamorphic rock that was originally sandstone.*



buildings and monuments, including the US Capitol building and the Jefferson Memorial in Washington, DC.

Figure 5.11: The open-faced granite quarry at Mt. Airy, North Carolina, produces over 610,000 meters (2 million feet) of white granite each year for use in construction and facing. The quarry was opened in 1743, and covers an area of roughly 372,000 square meters (4 million square feet).

Mineral Resources of the Inland Basin
Region 2

The major mineral deposits of the Inland Basin include sulfide and non-sulfide minerals associated with hydrothermal processes (*Figure 5.12*). Occurrences of lead and zinc are widespread throughout much of the **Appalachian Basin** and Valley and Ridge, where thrust faults and fractures provided pathways for fluid migration and sites for ore deposit formation during the Acadian and Alleghanian orogenies to the east. In addition, a vast reservoir of sedimentary rocks was deposited in the Paleozoic **inland sea** that covered the western half of the Inland Basin. Extensive precipitation of **evaporite** salts in this shallow sea occurred during the **Silurian**, and locally at other time periods. Weathering and erosion have also been

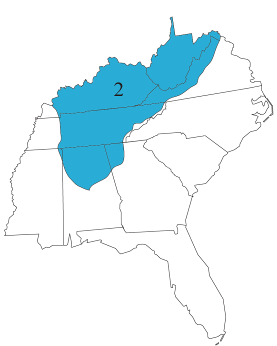
See Chapter 4: Topography for more information on the Appalachian Basin, Valley and Ridge, and other physiographic subregions of the Inland Basin.

Appalachian Basin • *an inland basin, formed by the Taconic and Acadian mountain-building events.*

inland sea • *a shallow sea covering the central area of a continent during periods of high sea level.*

evaporite • *a sedimentary rock created by the precipitation of minerals directly from seawater, including gypsum, calcite, dolomite, and halite.*

Silurian • *a geologic time period spanning from 443 to 419 million years ago.*



important processes in the formation of mineral deposits in the Appalachian Basin. Chemical weathering of limestone and dolostone have formed numerous small deposits of iron, manganese, and bauxite at the surface, and concentrated lower-grade hydrothermal deposits of barite.

__karst topography__ • a kind of landscape defined by bedrock that has been weathered by dissolution in water, forming features like sinkholes, caves, and cliffs.

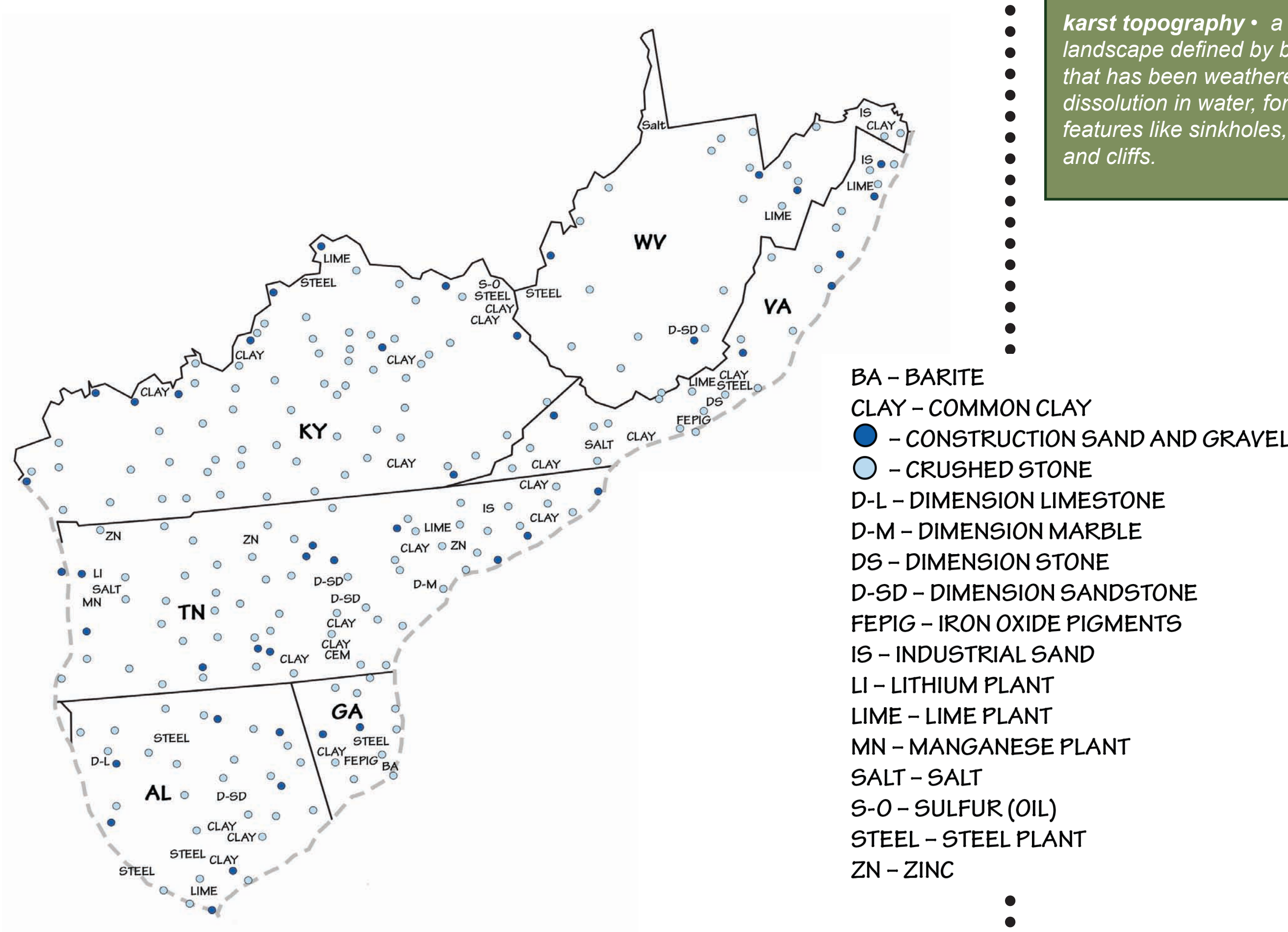
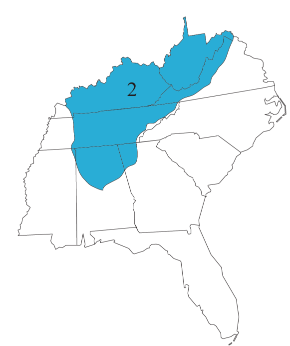


Figure 5.12: Principal mineral resources of the Inland Basin region.

Metallic Resources

Extensive deposits of lead, zinc, fluorite, and barite minerals occur in Cambrian and Ordovician dolostones along the eastern margin of the Valley and Ridge from south of Bethlehem, Pennsylvania, through western Virginia and eastern Tennessee, and into northern Georgia. These deposits generally developed as a result of hydrothermal fluids migrating through zones of higher permeability, **karst**, fractures, and faults. Important mining districts include the Mascot-Jefferson District in Tennessee and the Austinville-Ivanhoe District in Virginia (*Figure 5.13*). The lead and zinc works in southern Wythe County, Virginia, played a vital role in two early chapters in United States history. The Wythe County lead mines were opened in 1756 by Colonel John Chiswell, a British officer who discovered the lead deposits while hiding in a cave near the New



Pennsylvanian *• a subperiod of the Carboniferous, spanning from 323 to 299 million years ago.*

River to escape pursuing Indians. The mines were an important source of lead shot ammunition for the Colonial Army during the American Revolution, and the workings were expanded from 1775 to 1781 to meet the growing demand of the Continental Army. The Wythe County mines were also a critical resource for the Confederacy during the Civil War—reports suggest that about 1.6 million kilograms (3.5 million pounds) of lead for bullet-making were produced at the mines during the Civil War, accounting for one-third of the estimated 4.5 million kilograms (10 million pounds) of lead consumed by the entire Confederacy in the manufacture of 150 million cartridges. Production ended on December 31, 1981, when the New Jersey Zinc Company permanently closed the mine, ending its 225-year run.

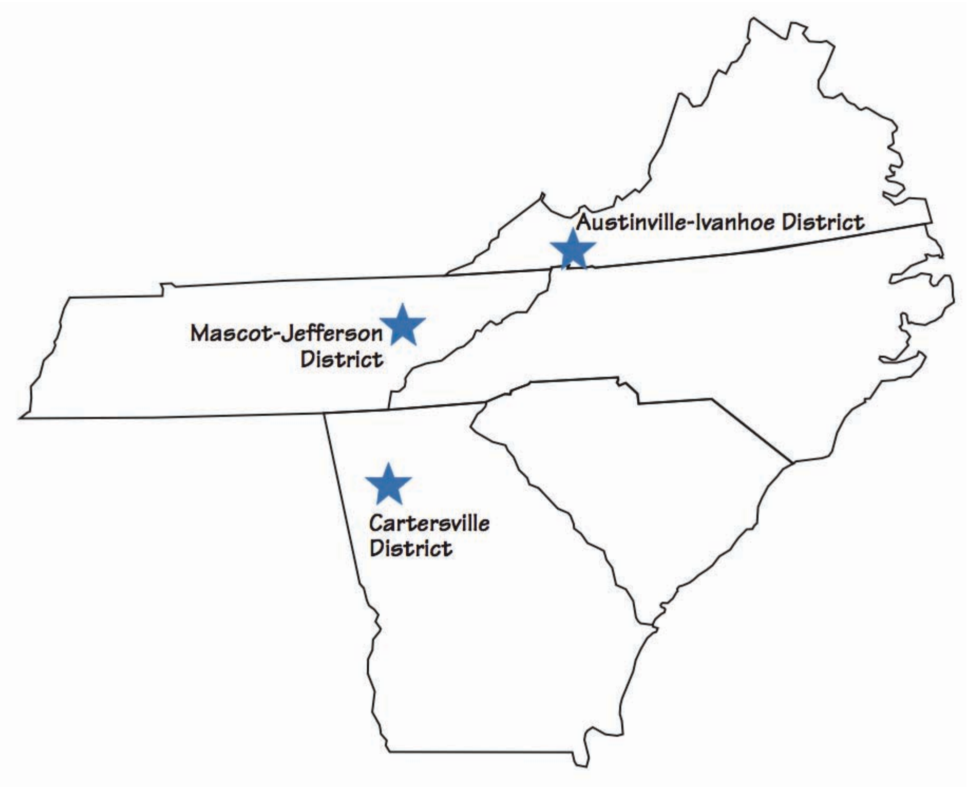
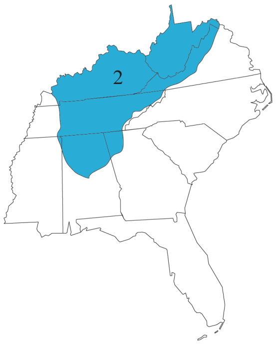


Figure 5.13: Significant lead, zinc, fluorite, and barite deposits are found in Virginia, Tennessee, and Georgia.

The last of Virginia's lead and zinc mines closed in 1984, but mining continues in eastern Tennessee, and barite is still extracted from lower grade lead-zinc deposits of the Cartersville District in northern Georgia (*see Figure 5.13*). These deposits vary widely in their relative proportions of lead and zinc sulfides, pyrite and chalcopyrite, and fluorite and barite.

Widespread deposits of sedimentary iron in the Inland Basin range in age from Cambrian to **Pennsylvanian**. The most extensive iron ore deposits in the Southeast are the middle Silurian Clinton Formation deposits (and their



Mining

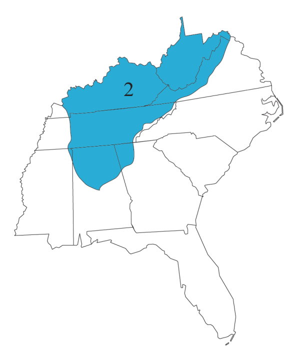
Mining is a profit-focused undertaking. The profitability of mining minerals or rocks depends on a number of factors, including the concentrations of recoverable elements or material contained in the deposit, the anticipated amount of the deposit that can be mined, its accessibility using current mining methods and technologies, its marketability, and lastly the cost of returning the site to its original state once the extraction phase of mining has ended (reclamation). All these factors determine the choice of mining method. Types of mining include underground (tunnel or shaft), surface (open pit or quarry), hydraulic operations (placer), solution using hot water, and seawater evaporation ponds. Once a mineral resource has been removed from the ground, the next step is to process it in order to recover its useful elements or to transform it so that it can be used in manufacturing or other industrial processes.

Modern mining is accomplished in three phases: exploration, extraction, and reclamation. Exploration is performed to determine the extent of the mineral resource and usually involves extensive use of drilling and geophysical techniques to determine the shape, size, and quality of the resource. Extraction involves removing the mineral resource from the ground. Reclamation is undertaken when mining ceases and is designed to restore the land to a condition where it can be used for other purposes. This last phase usually involves removing sources of contamination, which can be considerable depending on the scope of the mining activity.

shale • *a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.*

equivalents) that extend along the eastern side of the Appalachian Basin from New York to Alabama (*Figure 5.14*). Iron weathered from the eroding Taconic Mountains was deposited in various forms along the edge of the ancient seaway to the west, and occurs as oxides, carbonates, and silicates in sandstones, **shales**, and limestones. Weathering increases the grade of the ores and makes them more easily mined. The Clinton iron ores are especially rich and

See Chapter 6: Energy to learn where coal is found in the Inland Basin, and how it formed.



5 Mineral Resources

Region 2

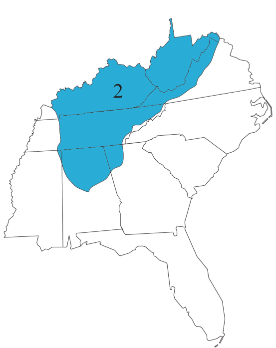
coal • *a combustible, compact black or dark-brown carbonaceous rock formed by the compaction of layers of partially decomposed vegetation.*

flux • *a mineral added to the metals in a furnace to promote fusing or to prevent the formation of oxides.*

commodity • *a good for which there is demand, but which is treated as equivalent across all markets, no matter who produces it.*

lime • *an inorganic white or grayish-white compound made by roasting limestone (calcium carbonate, $CaCO_3$) until all the carbon dioxide (CO_2) is driven off.*

soil • *the collection of natural materials that collect on Earth's surface, above the bedrock.*



thick near Birmingham, Alabama, where the dominant iron mineral is hematite. These iron deposits made Birmingham a major center of steel production (*Figure 5.15*), and about 375 million tons of hematite ore were mined there between 1840 and 1975. The success of the iron and steel industry around Birmingham was due to the thick, high-grade nature of the Clinton iron ore deposits, the close proximity of deposits of Pennsylvanian **coal** to fuel the blast furnaces, and the use of Cambrian and Ordovician limestone and dolostone as **flux** for smelting.

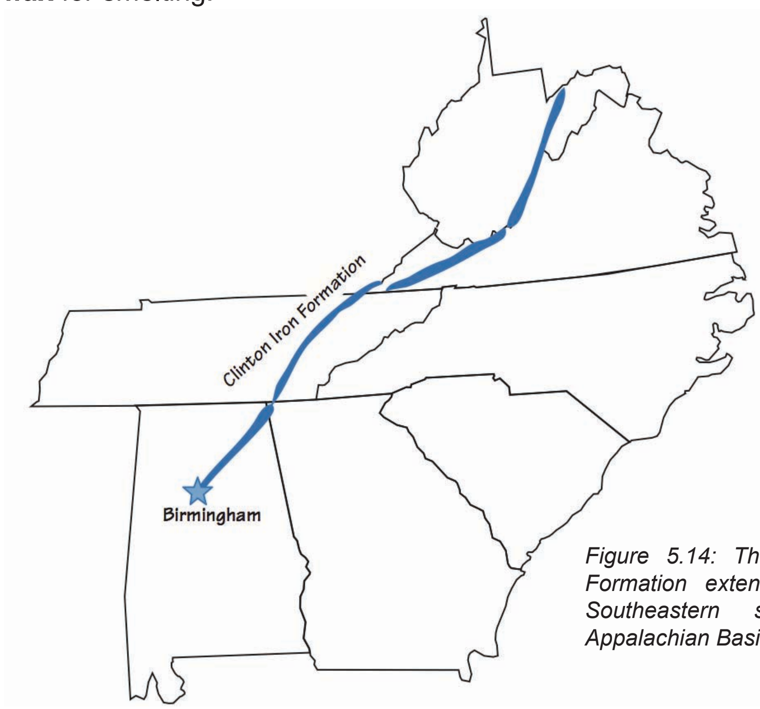


Figure 5.14: The Clinton Iron Ore Formation extends through several Southeastern states along the Appalachian Basin.

Figure 5.15: The furnace track at Sloss Furnaces National Historic Site in Birmingham, Alabama. The site was constructed in 1881, and by the end of its first year of operation it had sold 24,000 tons of iron. Most of the buildings and structures remaining on the site today date from 1900–1914. Sloss is the only 20th-century blast furnace preserved in the US as a historic industrial site.

Numerous small secondary iron deposits occur throughout the Inland Basin. Most are the products of weathering, formed when iron oxide was concentrated as residuum from carbonate rocks that were chemically weathered and eroded away. Some iron deposits are gossans, residual iron oxide deposits formed by the weathering of sulfide deposits at the surface. Small deposits of both types were mined in every state in the Southeast during the 1700s and 1800s to supply local forges that turned out small quantities of iron and steel for local markets. The first iron furnaces in the Southeast were built around 1765 in Virginia. Small furnaces appear in North Carolina in 1780, Tennessee, and West Virginia in 1790, Kentucky in 1791, and Alabama in 1815.

Non-Metallic Resources

The Inland Basin's industrial minerals are some of its most valuable non-metallic resources (*see Figure 5.12*). Sand and gravel is used for aggregate, and common clay is collected for use in brick making. Paleozoic limestone and dolomite (dolostone), which form the bedrock across much of the Inland Basin, are quarried for crushed stone throughout the region. The Reed Quarry in Kentucky is one of the largest producers of crushed stone in the United States, and crushed stone has been Tennessee's leading mineral **commodity** (by value) for over 25 years. Most of this crushed stone is used for construction aggregate and for the production of **lime** and cement. Once considered a waste byproduct of crushed stone, lime has important uses in agriculture, where it is regularly applied to make the **soil** "sweeter" (less acidic). Lime is also used in steel making, water purification, sulfur removal from smoke stacks, sewage treatment, and paper manufacturing. Alabama and Kentucky are two of the top lime-producing states in the nation.

Local dimension sandstone and industrial sandstones are quarried in the eastern part of the region, within the Valley and Ridge. The quartz-rich Tuscarora and Oriskany sandstones are commonly mined and crushed for use as industrial sand because they are 98% silica, and therefore useful for glass manufacturing. These stones, abundant in West Virginia, have made the state one of the nation's leading glass manufacturers. Some **Mississippian** and Pennsylvanian sandstones also contain natural **bitumen**, or tar. These tar sands historically have been quarried for the natural **asphalt** they contain.

Extensive evaporite deposits formed during the late Silurian in a shallow tropical sea at the northern end of the Appalachian Basin, and are present below the surface in northern West Virginia. Natural brines present as ancient seawater trapped in **porous** sedimentary rocks (**aquifers**) are found throughout the Inland Basin and contain in excess of 15% dissolved salts within 610 meters (2000 feet) of the surface throughout eastern Ohio, western West Virginia, and northeastern Kentucky. Mississippian-aged halite deposits occur below the surface around Saltville, Virginia, where salt was first discovered in 1840 in a mineshaft at a depth of 66 meters (215 feet).

Halite is mined in two ways. When deposited in thick beds, this salt can be excavated by mechanically carving and blasting it out. This method, called "room and pillar" mining, usually requires that pillars of salt be left at regular intervals to prevent the mine from collapsing (*Figure 5.16*). Another method,

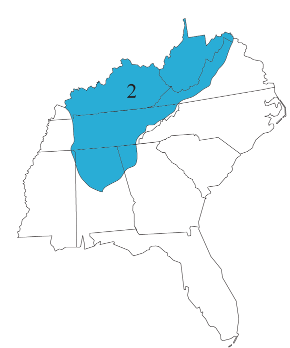
Mississippian • *a subperiod of the Carboniferous, spanning from 359 to 323 million years ago.*

bitumen • *any of the various flammable mixtures of hydrocarbons and other substances.*

asphalt • *a black, sticky, semi-solid and viscous form of petroleum.*

porosity • *the percentage of openings in a body of rock such as pores, joints, channels, and other cavities, in which gases or liquids may be trapped or migrate through.*

aquifer • *a water-bearing formation of gravel, permeable rock, or sand that is capable of providing water, in usable quantities, to springs or wells.*



solution mining • *the extraction of soluble minerals from subsurface strata by the injection of fluids.*

salt lick • *a naturally occurring salt deposit that animals regularly lick.*

petroleum • *a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface.*

called **solution mining**, involves drilling a well into a layer of salt. In some cases, the salt exists as part of a brine that can then be pumped to the surface, where the water is then removed, leaving the salt behind. In others, fresh water is pumped down to dissolve the salt, and the solution is brought back to the surface where the salt is removed (*Figure 5.17*). In the Saltville area of western Virginia, rock salt is extracted by solution mining.

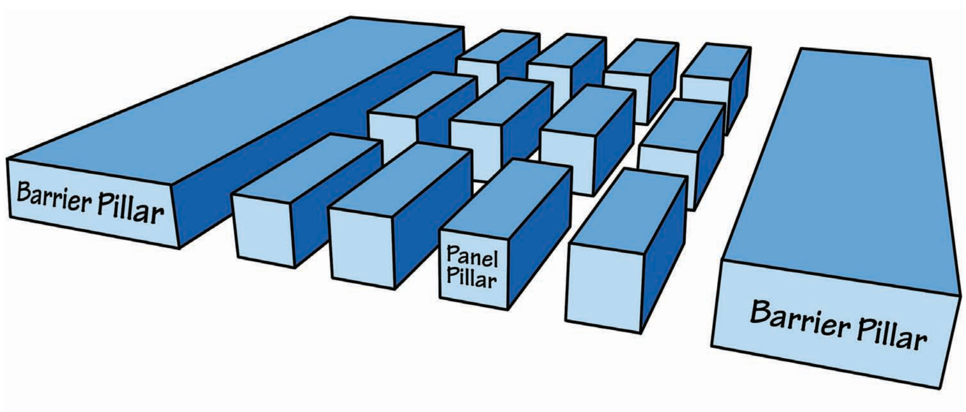
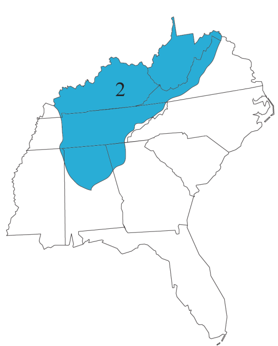


Figure 5.16: In pillar and room mining, the mine is divided up into smaller areas called "panels." Groups of panels are separated from one another by extra-large (barrier) pillars that are designed to prevent total mine collapse in the event of the failure of one or more regular-sized (panel) pillars.

Natural brine springs in the Kanawha Valley, near Charleston, West Virginia, formed **salt licks** that were extensively utilized by animals and later exploited by Native Americans, who boiled the brine to obtain salt. The Kanawha Licks near the town of Malden, West Virginia, became the center of a major colonial salt industry in the early 19th century (*Figure 5.18*). Salt, a powerful antibacterial, was a critical commodity for curing butter and meats in the absence of refrigeration.

Although it represents only a small fraction of total US salt production, the proximity of salt, coal, and **petroleum** resources with good railroad and river access has resulted in the growth of an extensive chemical industry in West Virginia along the Ohio River and in the Kanawha Valley, between Wheeling and Huntington. The Kanawha Valley salt industry reached a peak production of 113,638 cubic meters (3,224,786 bushels) in 1846, and was one of the largest salt manufacturing centers in the US. This brine industry declined in importance after 1861, but it was revitalized thanks to demand for chemical products during World War I, with the 1914 opening of the Warner-Klipstein Chemical Company plant in South Charleston to produce chlorine and caustic acid. West Virginia hosts three principal salt-producing companies: two in Marshall County and one in Tyler County. Most of the area's salt is now used by a

See Chapter 6: Energy for more about petroleum resources in the Inland Basin.



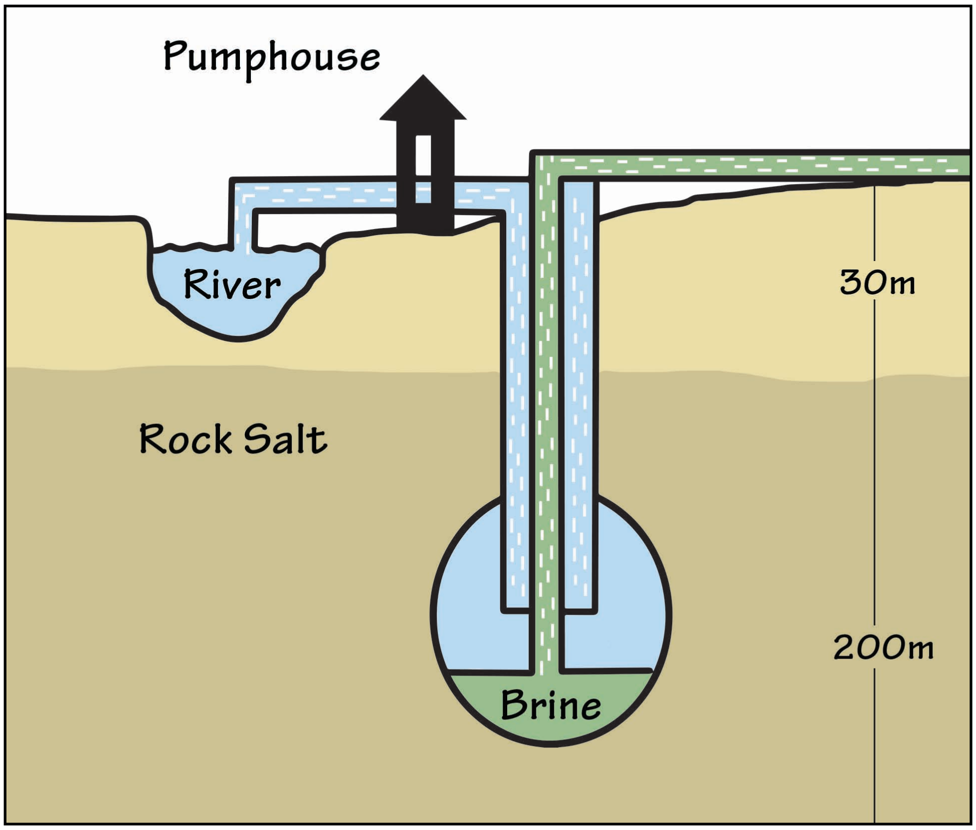


Figure 5.17: An example of solution mining that involves the pumping of fresh water through a borehole drilled into a subterranean salt deposit.

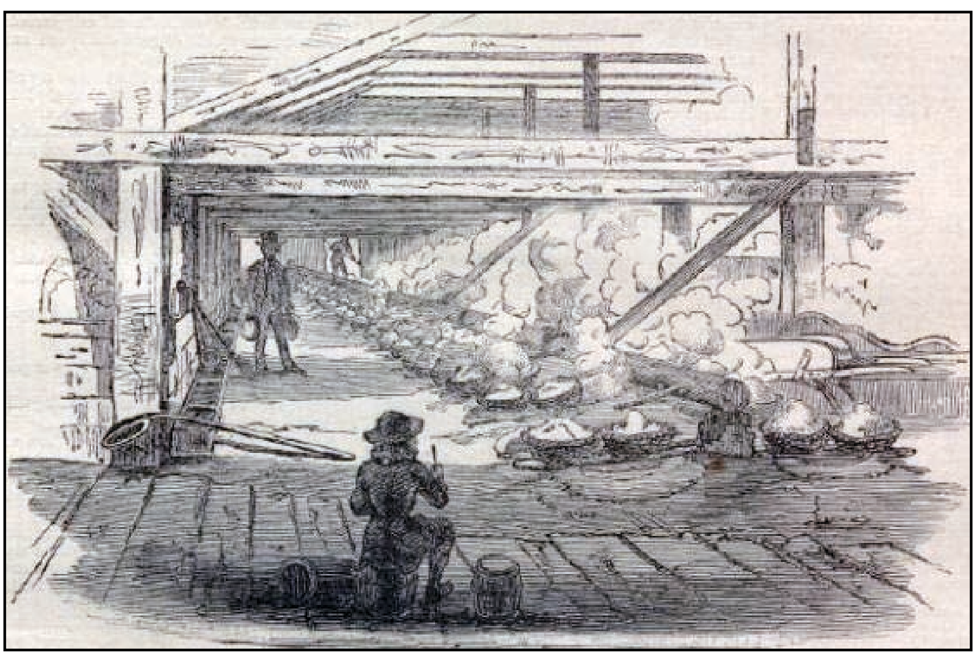
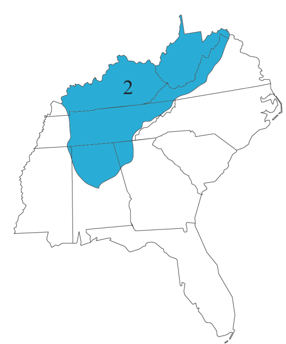


Figure 5.18: This 19th-century illustration depicts the boiling of brine-filled kettles to make salt during the Civil War.



Regions 2–3

Cretaceous • *a geologic time period spanning from 144 to 66 million years ago.*

Paleogene • *the geologic time period extending from 66 to 23 million years ago.*

Neogene • *the geologic time period extending from 23 to 2.6 million years ago.*

Quaternary • *a geologic time period that extends from 2.6 million years ago to the present.*

variety of chemical companies that have developed along the Kanawha River since that time. Today, the Westvaco Chlorine Products Corporation is the largest chlorine producer in the world.

Douglas Lake in Jefferson County, Tennessee, is known for distinctive quartz crystals called "Douglas Diamonds." During periods of water fluctuation, when expanses of the lake bottom are exposed, these crystals can be found scattered across the dry surface. The quartz precipitated from silica-rich hydrothermal solutions that flowed through fractures in the region's limestone and calcite bedrock; later weathering eroded the surrounding rock to expose these more resistant crystals (*Figure 5.19*).

Figure 5.19: Quartz crystals from Douglas Lake, Tennessee, also known as "Douglas Diamonds," on a 22-centimeter (8.5-inch) paper plate.

Mineral Resources of the Coastal Plain
Region 3

The Southeast has been largely tectonically inactive for about 150 million years; weathering and erosion are the dominant geologic processes that have operated during this time. Most of the Coastal Plain has eroded to a gently tilted plain, where erosion and deposition around rivers and coastlines has formed numerous placer concentrations of heavy minerals. Fluctuating sea levels during the **Cretaceous**, **Paleogene**, **Neogene**, and **Quaternary** left thick, extensive sedimentary deposits throughout the region (*Figure 5.20*).

See Chapter 4: Topography to find out how erosion has influenced the Southeastern landscape.

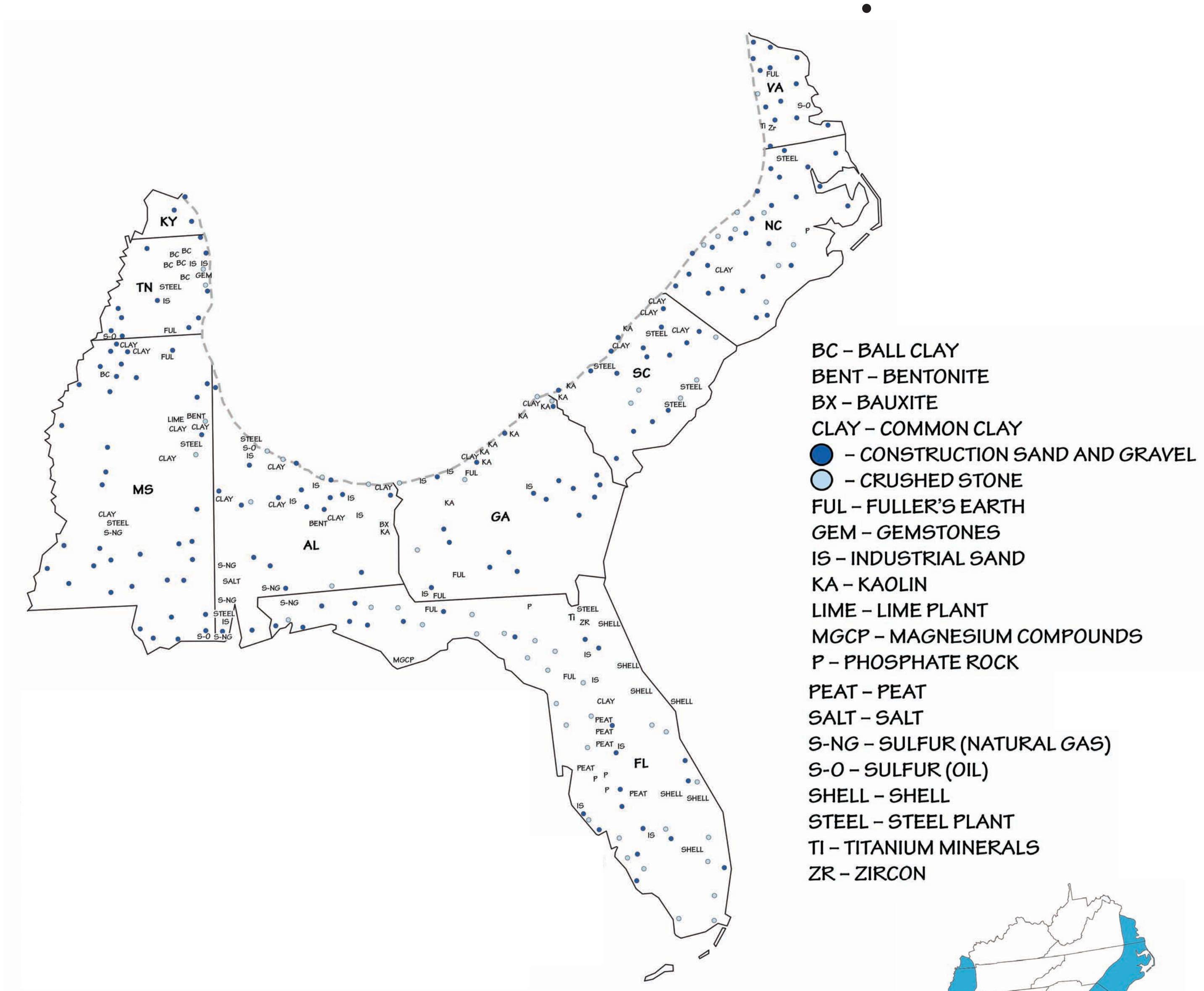


Figure 5.20: Principal mineral resources of the Coastal Plain region.

Mineral Resources

Metallic Resources

Although not mined commercially, numerous concentrations of heavy mineral sands have been identified in ancient river and beach deposits along the western margin of the Coastal Plain and offshore on the continental shelf. Deposits of rutile, ilmenite, monazite, zircon, and gold have been investigated in North and South Carolina. Although minor production has occurred in the past, these deposits are currently not economically viable to mine; some of them occur in environmentally sensitive or urban areas.

Bauxite is a residual product of weathering in the Coastal Plain's Cretaceous carbonate rocks, and bauxite deposits can be found in Georgia, Alabama, Tennessee, and Virginia. This clay-like mixture of several minerals is mined primarily as an ore of aluminum; most bauxite ore contains 45–55% aluminum oxide (*Figure 5.21*). The Southeast's bauxite deposits are generally small and of limited potential. Small-scale production has continued in Alabama to the present.

Figure 5.21: Bauxite is a rich aluminum ore, and the world's main source of aluminum. Specimen is 4.1 centimeters (1.6 inches) wide.

From the 17th to 19th centuries, iron foundries and steel mills in the Coastal Plain were fueled by "bog" iron ore mined from coastal swamps and Triassic basin coal. Steel mills of the late 19th and 20th centuries were more dependent on imported iron and coal, and tended to be near the ocean on navigable rivers, as their operation was heavily reliant on a considerable supply of fresh water.

Non-Metallic Resources

The Coastal Plain is blanketed by sand and gravel that were eroded from the Appalachian Mountains and redistributed by rivers and the ocean. These materials (along with clay) are the dominant natural resource mined on the Southeast Coastal Plain because they are abundant along the coast, in rivers, and along river terraces. Sand and gravel are primarily used in construction, concrete, and road fill; the region also produces industrial sand. Sedimentary rock is not commonly exposed at the surface, but sedimentary bedrock is mined in many quarries where sediment and soil cover are thin. Limestone is quarried as a building stone, to make crushed stone used as construction aggregate, and in the manufacture of cement and lime. In some areas, Cretaceous and **Cenozoic** sediments at the surface have been sufficiently hardened for use as a dimension stone. For example, Alabama's Marianna Limestone, though soft enough to be cut with a saw, hardens upon exposure and was commonly used as a dimension stone. Because much of Florida was deposited as a carbonate platform, there are extensive carbonate (limestone and dolomite) resources near the surface. Florida is one of the top producers of crushed stone in the US, and annually leads the nation in the manufacture of masonry cement. Shell limestone (**coquina**) can also be easily cut into dimension stone, and was used as a building material in many of the historic buildings in St. Augustine, Florida, including the Castillo de San Marcos—the first permanent European settlement in the United States.

__Cenozoic__ • the geologic time period spanning from 66 million years ago to the present.

__coquina__ • a porous, sometimes crumbly limestone, composed of fragments of shells and coral, and used as a building material.

See Chapter 2: Rocks to learn more about coquina and its historic use in construction.

Six of the top ten clay producers in the US occur in the Southeast's Coastal Plain, with Georgia and South Carolina in the lead. Several types of clay are found in the region, each used for different purposes. Common clay is used in the manufacture of bricks, lightweight aggregate, cement, and other structural clay products—North Carolina is annually the US leader in brick production because of its common clay resources. Ball clay is a plastic clay, so named because it was rolled into balls during the days of hand mining. Ball clay is used as a bonding agent in the manufacture of ceramics and is common in the upper Mississippi River Embayment.

At one time, sheep's wool was cleaned through a process called "fulling" before it was spun. The wool was cleaned using an absorbent type of clay that became known as "fuller's earth." Dusting this clay through the sheep's wool absorbed dirt and grease, making the wool easier to spin.

Kaolinite is an earthy white clay, also known as "china clay," which is used in the manufacture of ceramics (including fine porcelain), as a paper coating, in refractories, and as an additive in rubber products, fertilizers, cosmetics, and detergents. Before the Revolutionary War, kaolinite from South Carolina was exported to England for the production of Wedgwood pottery and china. Deposits of kaolin clay occur along the western margin of the Coastal Plain

along a 480-kilometer-long (300-mile-long) trend from Aiken, South Carolina, through Macon, Georgia, to Eufaula, Alabama (*Figure 5.22*). These clays are formed from the weathering of the Piedmont's crystalline rocks, and occur as lenses in late Cretaceous- to Neogene-aged sediments. Mining of these deposits accounts for around 90% of total United States kaolinite production and 40% of global production. Fuller's earth is another type of earthy clay with a higher moisture content than other clays. Because it naturally absorbs water, it is used in the manufacture of kitty litter, as an adsorbent in refining oils, and as an additive to various types of pastes and putties.

Figure 5.22: Tailings from an old open-pit kaolin mine in Hitchcock Woods near Aiken, South Carolina.

Bentonite is currently mined in Mississippi and Alabama; it is altered **volcanic ash** that originated from Cretaceous volcanoes in the central and western US and was subsequently blown into the Southeastern US by prevailing **winds**. Bentonite is used in drilling muds and can be used as a sealant in instances where it is important to provide a barrier for water flow through rock or sediment.

Phosphate is present in Coastal Plain sediment along the Atlantic coast from the Chesapeake Bay to Florida**.** These deposits developed in deep ocean waters during the Neogene, where current and wave action concentrated phosphate-rich sediment that eventually hardened to become phosphate rock. Phosphates are used primarily to make fertilizers, but are also used in the manufacture of phosphoric acid, detergents, food additives, pesticides, soft drinks, and other products. The highest grade and most extensive deposits occur in the **Miocene** formations of North Carolina and Florida, which together account for about 95% of domestic production of phosphate and about half of global production. The

bentonite *• a clay, formed from decomposed volcanic ash, with a high content of the mineral montmorillonite.*

volcanic ash *• fine, unconsolidated pyroclastic grains under 2 millimeters (0.08 inches) in diameter.*

wind *• the movement of air from areas of high pressure to areas of low pressure.*

Miocene *• a geological time unit extending from 23 to 5 million years ago.*

potash *• a name used for a variety of salts containing potassium.*

Region 3

Aurora phosphate operation at Lee Creek in Beaufort County, North Carolina is the largest integrated phosphate mining and chemical plant in the world. In fact, it is the world's largest **potash** producer and is capable of producing over six million tons of phosphate ore per year. Florida, however, contains the largest known deposits of phosphates in the US; the state provides two-thirds of the country's phosphate needs and nearly one quarter of the world's phosphates. Fertilizer is one of Florida's leading exports, with an annual value of over $2 billion (*Figure 5.23*).

Figure 5.23: A phosphate fertilizer processing plant in Nichols, Florida.

Some of the largest swamps in the US are found in the Coastal Plain, including the Everglades of Florida, the Okefenokee Swamp of Georgia, and the Great Dismal Swamp of Virginia and North Carolina. Swamps, bogs, and marshes support abundant vegetation, thick piles of which accumulate as the plants naturally die and are buried by successive layers of dead plants. This creates a low-oxygen environment in which the plant material is not being decomposed. As the layers are buried deeper, they are **compressed** into **peat** (with further compression and much longer spans of time, the organic material becomes **lignite** and then coal). Peats produced in these swampy environments are a valuable resource, and Florida is the top peat producer in the country. Peats are used in potting soil, as a soil conditioner, as insulation for packing fruits and vegetables, and as a protein additive in cattle food.

Thick salt sequences, related to the early rifting of Pangaea and the formation of the Gulf of Mexico during the Triassic and Jurassic periods, underlie much of the Gulf Coast. However, salt is currently only mined in Alabama. Sulfur is produced from sources associated with **salt domes** along the Gulf Coastal Plain, and as a byproduct from the processing of oil and gas.

compression • *flattening or squeezing as a result of forces acting on an object from all or most directions.*

peat • *an accumulation of partially decayed plant matter.*

lignite • *a soft, brownish-black coal in which the alteration of plant matter has proceeded farther than in peat but not as far as in bituminous coal.*

salt dome • *a largely subsurface geologic structure, consisting of a vertical cylinder of salt embedded in horizontal or inclined sedimentary strata.*

Resources

Resources

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Chapter 6: Energy in the Southeastern US

Everything we do depends upon **energy**—without it there would be no civilization, no sunlight, no food, and no life. Energy moves people and goods, produces electricity, heats our homes and businesses, and is used in manufacturing and other industrial processes. But what *is* energy? Energy is the **power** derived from the utilization of physical or chemical resources. In this chapter, we are especially interested in the energy used to provide light and **heat**, or to power machines.

For most of human history, the way we captured and used energy changed little. With very few exceptions*, materials were moved by human or animal power, and heat was produced largely through the burning of wood. Nearly all the energy to power human society was, in other words, **biomass**. But the transition from brute force and wood burning to the various industrial sources of energy— and the accompanying adoption of energy-intensive lifestyles—has occurred remarkably quickly, in the course of just the last several generations. This has caused changes in virtually every aspect of human life, from economics to war to architecture. Much of the rural US was without access to electricity until the 1930s, and cars have been around for only slightly longer. Our energy **system** (how we get energy and what we use it for) has changed and is changing remarkably quickly, though some aspects of the energy system are also remarkably resistant to change.

The use of **wind** to generate electricity, for example, grew very quickly in the late 2000s and early 2010s. In 2002, wind produced less than 11 million megawatt hours (MWh) of electricity in the US. In 2011, it produced more than 120 million MWh—more than 1000% growth in ten years! That aspect of change stands in contrast to our long-lasting reliance on **fossil fuels**, such as **coal**, oil, and **natural gas**. Our reliance on fossil fuels is driven by a number of factors:

***Exceptions include the use of sails on boats by a very small percentage of the world's population to move people and goods, and the Chinese use of natural gas to boil brine in the production of salt beginning roughly 2000 years ago.**

Electricity is a good example of an *energy carrier*: a source of energy that has been subject to human-induced energy transfers or transformations.

Wind power, on the other hand, is a *primary energy source*: a source of energy found in nature that has not been subject to any human manipulation.

energy • *the power derived from the use of physical or chemical resources.*

power • *the rate at which energy is transferred, usually measured in watts or, less frequently, horsepower.*

heat • *a form of energy transferred from one body to another as a result of a difference in temperature or a change in phase.*

biomass • *organic material from one or more organisms.*

system • *a set of connected things or parts forming a complex whole.*

wind • *the movement of air from areas of high pressure to areas of low pressure.*

CHAPTER AUTHORS

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the low upfront cost, very high energy densities, and the cost and durability of the infrastructure built to use fossil fuels.

Energy production and use not only changes across time, but also with geography, as we will see by looking at energy production and use across different regions of the US.

What do different units of energy mean?

Heat is energy, and heat is at the root of all the ways that we move materials or generate light, so measurements of heat can be thought of as the most basic way to measure energy. The **British thermal unit** (abbreviated Btu or BTU) is the most commonly used unit for heat energy and is approximately the amount of heat required to raise one pound of water by one degree Fahrenheit. A Btu is also roughly 1055 **joules**, or the amount of energy released by burning a single wooden match. A joule is the energy expended (or work done) to apply a force of one newton over a distance of one meter. Since a typical apple weighs about one newton, lifting an apple one meter requires about a joule of energy. That means that one Btu—the energy contained in a wooden match—is equivalent to the total amount of energy required to lift an apple 1000 meters, or one kilometer.

This comparison of the energy of heat to the energy of motion (**kinetic energy**) might be a little confusing, but energy is transformed from one type to another all the time in our energy system. This is perhaps most obvious with electricity, where electrical energy is transformed into light, heat, or motion at the flip of a switch. Those processes can also be reversed—light, heat, and motion can all be transformed into electricity. The machines that make those transitions in either direction are always imperfect, so energy always **degrades** into heat when it is transformed from one form to another.

The principle of *Conservation of Energy* tells us that energy is neither created nor destroyed, but can be altered from one form to another.

Another measure of energy, the kilowatt-hour (kWh), represents the amount of energy required to light ten 100-**watt** light bulbs for one hour. *Figure 6.1* compares different ways to make and use one kWh.

How do we look at energy in the Earth system?

The concepts used to understand energy in the Earth system are fundamental to all disciplines of science; energy is an interdisciplinary topic. One cannot study physics or understand biomes, photosynthesis, fire, evolution, seismology, **chemical reactions**, or genetics without considering energy. In the US, every successive generation has enjoyed the luxury of more advanced technology (e.g., the ability to travel more frequently, more quickly, and over greater distances). Especially as the global population grows and standards of living increase in some parts of the world, so too does global energy demand continue to grow.

Review

British Thermal Unit (BTu or BTU) *• the most commonly used unit for heat energy. One Btu is approximately the amount of heat required to raise one pound of water by one degree Fahrenheit.*

joule *• the energy expended (or work done) to apply a force of one newton over a distance of one meter.*

kinetic energy *• the energy of a body in motion.*

degrade (energy) *• the transformation of energy into a form in which it is less available for doing work, such as heat.*

watt *• a unit of power measuring the rate of energy conversion or transfer designated by the International System of Units as one joule per second.*

chemical reaction *• a process that involves changes in the structure and energy content of atoms, molecules, or ions but not their nuclei.*

Review

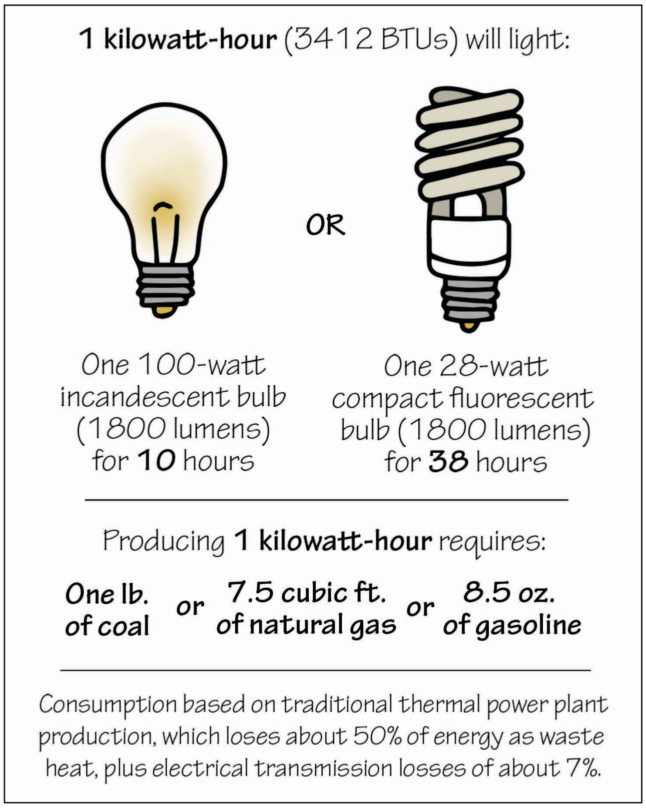


Figure 6.1: Examples of uses and sources of one kilowatt-hour.

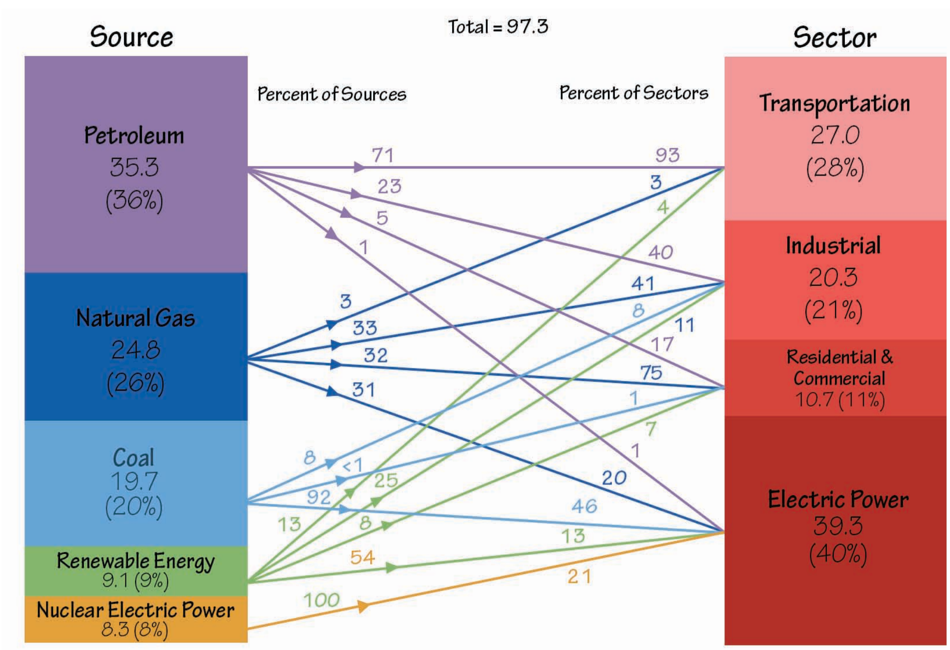


Figure 6.2: US energy production sources and use sectors for 2011. Petroleum provides more energy than any other source, and most of it is used for transportation. More energy is used to generate electricity than for any other use, and electricity is generated by all five energy sources. Nuclear is unique among sources in that all of the energy it generates goes to a single sector: electric power.

6 Energy

Review

petroleum • *a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface.*

renewable energy • *energy obtained from sources that are virtually inexhaustible (defined in terms of comparison to the lifetime of the Sun) and replenish naturally over small time scales relative to human life spans.*

nuclear • *pertaining to a reaction, as in fission, fusion, or radioactive decay, that alters the energy, composition, or structure of an atomic nucleus.*

Figure 6.2 shows the sources and uses of energy in the US, by sector. The Energy Information Administration (EIA) categorizes energy as coming from one of five sources (**petroleum**, natural gas, coal, **renewable energy**, and **nuclear** electric power) and being used in one of four energy sectors (transportation, industrial, residential & commercial, and electric power). All of the energy that powers our society comes from one of these five sources and is used in one of these four sectors.

The more we come to understand the Earth system, the more we realize that there is a finite amount of consumable energy, and that harvesting certain resources for use in energy consumption may have wide ranging and permanent effects on the planet's life. Understanding energy within the Earth system is the first step to making informed decisions about energy transitions.

Becoming "Energy Literate"

Energy is neither lost nor gained within the universe, but rather is constantly flowing through the Earth system. In order to fully understand energy in our daily lives—and make informed decisions—we need to understand energy in the context of that system. Becoming energy literate gives us the tools to apply this understanding to solving problems and answering questions. The Seven Principles of Energy, as detailed in *Energy Literacy: Energy Principles and Fundamental Concepts for Energy Education* are as follows:

Energy Literacy: Energy Principles and Fundamental Concepts for Energy Education **is a publication of the US Department of Energy. It can be accessed for free online; see Resources for more information.**

1	**Energy is a physical quantity that follows precise natural laws.**
2	**Physical processes on Earth are the result of energy flow through the Earth system.**
3	**Biological processes depend on energy flow through the Earth system.**
4	**Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination.**
5	**Energy decisions are influenced by economic, political, environmental, and social factors.**
6	**The amount of energy used by human society depends on many factors.**
7	**The quality of life of individuals and societies is affected by energy choices.**

Each principle is defined by a set of fundamental concepts that can help clarify ties to curricula. Keeping these energy principles in mind when we teach others about energy can help us contextualize and make relevant our own energy consumption and its effect on the Earth system.

Energy in the Southeastern Regions

The Southeast produces fossil fuels (coal, oil, and natural gas) in modest to large quantities, and production of fossil fuels has been a major part of the area's economic and historical development for over a century (*Figures 6.3 and 6.4*). Most fossil fuel discoveries in the Southeast come from two distinct geologic provinces: the Inland Basin (including the **Appalachian**, **Illinois**, and Black Warrior basins) and the Gulf Coastal Plain.

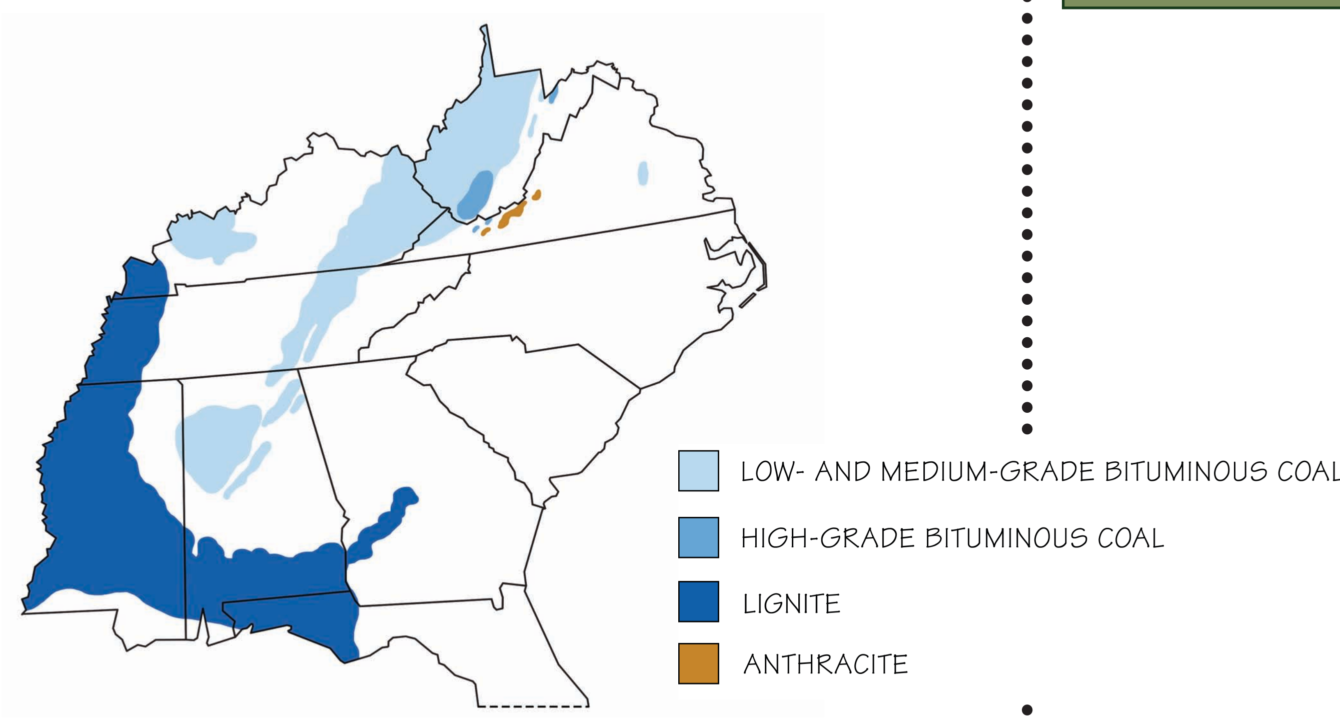


Figure 6.3: Coal-producing regions of the Southeastern US. The Inland Basin is a particularly significant coal-producing area. (See TFG website for full-color version.)

The Southeast also produces a substantial proportion of its electricity using nuclear energy, and the Southeastern states collectively produce about 35% of the nuclear energy consumed in the US (*Figure 6.5*). Nuclear energy growth in the Southeast has been enabled not because uranium (the raw material used for fission in nuclear power plants) is locally abundant, but rather that the Southeast has substantial water resources necessary for steam production and cooling in the power plants.

Regions

Appalachian Basin • *an inland basin, formed by the Taconic and Acadian mountain-building events.*

Illinois Basin • *an inland basin centered in the state of Illinois, which formed when Baltica approached North America in the Ordovician.*

6

Energy

Regions

biofuel *• carbon-based fuel produced from renewable sources of biomass like plants and garbage.*

climate *• a description of the average temperature, range of temperature, humidity, precipitation, and other atmospheric/hydrospheric conditions a region experiences over a period of many years (usually more than 30).*

topography *• the landscape of an area, including the presence or absence of hills and the slopes between high and low areas.*

active plate margin *• the boundary between two plates of the Earth's crust that are colliding, pulling apart, or moving past each other.*

hot spot *• a volcanic region thought to be fed by underlying mantle that is anomalously hot compared with the mantle elsewhere.*

igneous rocks *• rocks derived from the cooling of magma underground or molten lava on the Earth's surface.*

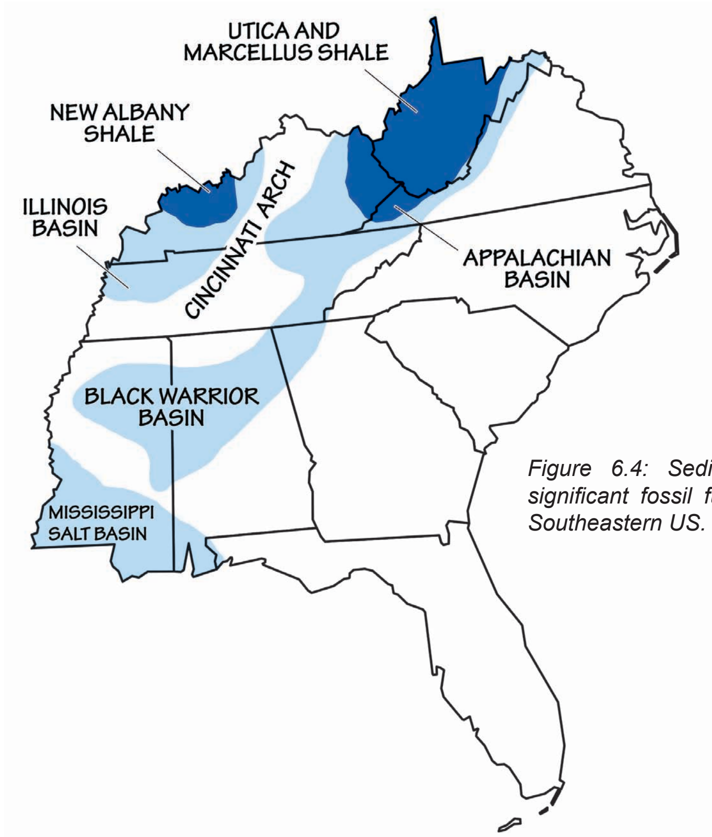


Figure 6.4: Sedimentary basins contain significant fossil fuel accumulations in the Southeastern US.

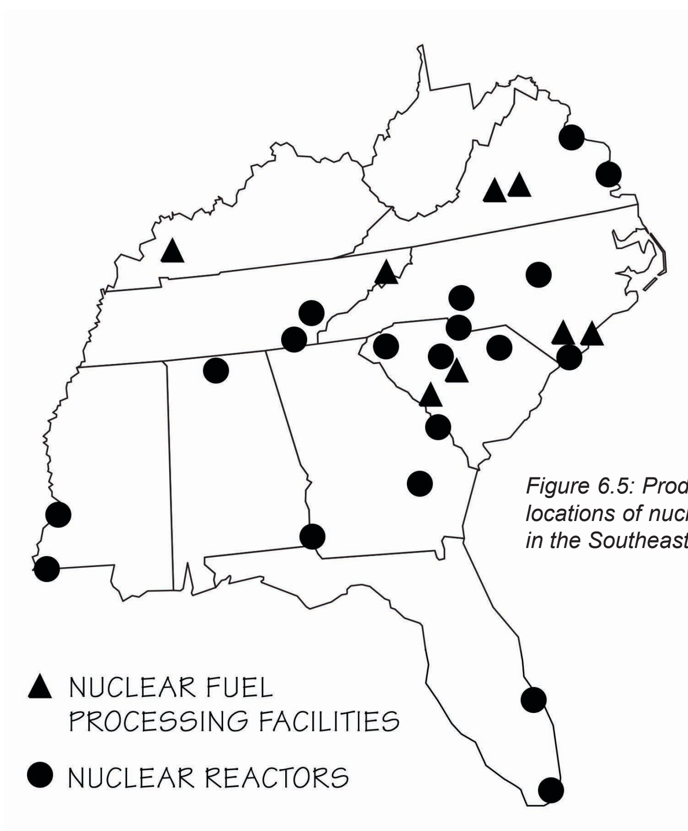


Figure 6.5: Production of nuclear power and locations of nuclear fuel processing facilities in the Southeastern states.

Energy 6

Region 1

The Southeast has a relatively high capacity for generating solar energy and **biofuels**, given its **climate** and agricultural potential. Though these sources are increasing rapidly, they remain a relatively small part of energy production in the Southeastern US. The area has low wind energy potential by comparison to the rest of the US (with the exception of West Virginia) due to generally low wind speed associated with climate and **topography**, and relatively low potential for deep geothermal energy due to its distance from **active plate boundaries** and **hot spots**.

Energy in the Blue Ridge and Piedmont
Region 1

The Blue Ridge and Piedmont is not known for its energy production by comparison with the other regions of the Southeast. Fossil fuel resources here are minimal, hydroelectric power generation occurs mostly along the region's eastern periphery, and solar and wind production remain minor compared to total energy demand. Nuclear power is a major local source of energy production.

Fossil Fuels

Oil and gas are not produced in the Blue Ridge and Piedmont region. The area is underlain primarily by **igneous** and **metamorphic rocks**, which do not form under the conditions necessary to produce petroleum. **Bituminous coals** occur in small, isolated **Triassic**-**Jurassic rift basins** in the North Carolina and Virginia Piedmont (*Figure 6.6*). These **rifts** formed as the supercontinent **Pangaea** broke apart during the **Mesozoic**, creating numerous cracks in the **crust** along the margins of North America, Africa, and

See Chapter 1: Geologic History to learn more about the rifting of Pangaea in the Mesozoic.

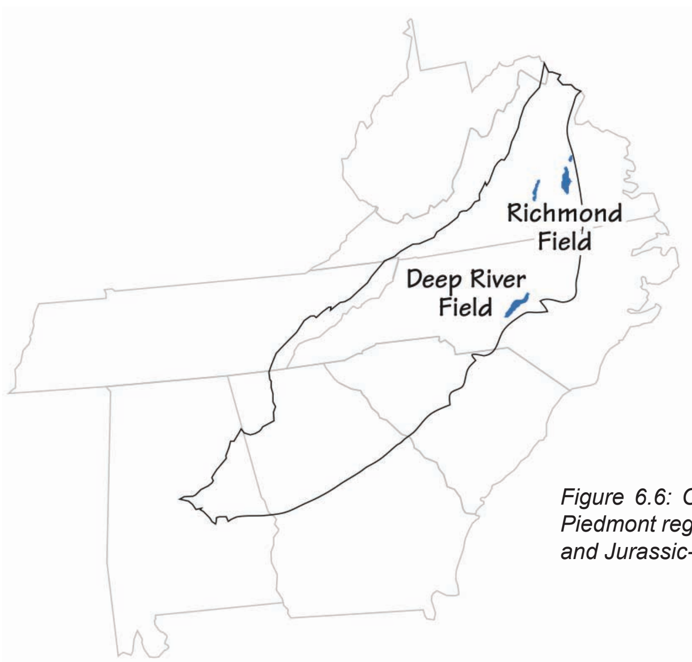


Figure 6.6: Coal in the Blue Ridge and Piedmont region is found only in Triassic- and Jurassic-aged rift basins.

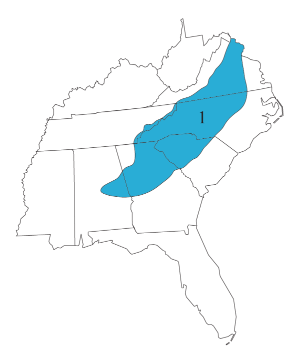
metamorphic rocks • *rocks formed by the recrystallization and realignment of minerals in pre-existing sedimentary, igneous, and metamorphic rocks when exposed to high enough temperature and/or pressure.*

bituminous coal • *a relatively soft coal containing a tarlike substance called bitumen, which is usually formed as a result of high pressure on lignite.*

coal • *a combustible, compact black or dark-brown carbonaceous rock formed by the compaction of layers of partially decomposed vegetation.*

Triassic • *a geologic time period that spans from 252 to 201 million years ago.*

Jurassic • *the geologic time period lasting from 201 to 145 million years ago.*



peat • an accumulation of partially decayed plant matter.

tree • any woody perennial plant with a central trunk.

fault • a fracture in the Earth's crust in which the rock on one side of the fracture moves measurably in relation to the rock on the other side.

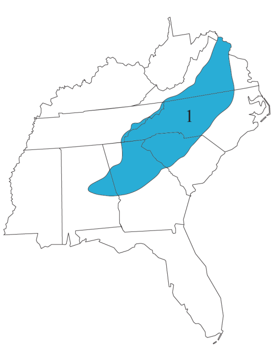
England. The rift basins filled with sediment, sometimes becoming swampy lowlands. **Peats** accumulated in these swamps and were altered to coal after they were buried.

None of the coal deposited in the Triassic-Jurassic rift basins is currently mined, although there has been some historic production. The Richmond Basin of Virginia was the nation's first major coal field, discovered in 1699 and mined primarily in the early 1800s. The only other notable coal deposits in the Southeast's Mesozoic rift basins are those of the Triassic Deep River rift basin in North Carolina. Bituminous coal beds there, occupying a zone about 56 kilometers (35 miles) long and 8 to 16 kilometers (5 to 10 miles) wide, were mined for about a century between the 1850s and 1950s. Production during 1949 was around 14,000 tons, but the coal seam is deeply buried and badly broken by numerous dissecting **faults**, and mining ceased in 1953. It is estimated that 110 million tons of coal remain in the area.

Fossil Fuels

Fossil fuels—oil, natural gas, and coal—are made of the preserved organic remains of ancient organisms. Coal and lignite result from the burial, compaction, and heating of preserved plant matter, whereas petroleum and natural gas originate deep underground through a slow process involving the low-grade heating of sedimentary source rocks that contain an abundance of organic matter. In either case, organic matter is only preserved when the rate of accumulation is higher than the rate of decay. This happens most often when the oxygen supply is sufficiently low that oxygen-loving bacteria cannot thrive, greatly slowing the breakdown of organic matter. In this way, organic matter can be incorporated into the buried sediment. The organics are compacted and heated with the rest of the rock, eventually transforming into fossil fuels.

The history of surface environments, evolution of life, and geologic processes beneath the surface have all influenced where fossil fuel deposits formed and accumulated. The largest oil and gas reserves were at one time nutrient-rich seas with abundant surface phytoplankton and organic-rich bottom sediments; the largest coal beds were swampy environments where fallen forest *trees* and leaves were buried in stagnant muds.



Alternative Energy

Nuclear power is a major source of energy production in the Blue Ridge and Piedmont, especially in North and South Carolina (*see Figure 6.5*). Throughout the Piedmont, abundant rivers and lakes provide the means to facilitate the production of nuclear energy. Currently, Virginia and the Carolinas are planning expansions of their existing plants, or bringing new plants on board. North Carolina has also been at the forefront of expanding its solar power production, taking advantage of several federal government incentives to increase the state's solar energy production by over 1100% since 2007 (*see Figure 6.21*). The North Carolina Solar Center at North Carolina State University works to promote and educate the public about solar, wind, biofuel, and other renewable energy options throughout the state. A few solar plants are also scattered through Georgia's Piedmont.

Precipitation and the relatively high topographic area associated with the Blue Ridge and Piedmont provide the region with great potential for hydroelectric power (*Figure 6.7*), which uses the gravitational force of falling or rushing water to rotate turbines that convert the water's force into energy. There are also several pumped storage facilities within the region, where water is pumped uphill into reservoirs in times of excess production, essentially acting as batteries. Hydroelectric plants are scattered throughout the Blue Ridge and Piedmont; many are located along the topographic drop associated with the Fall Line, where the harder rocks of the Piedmont meet the sediments of the Atlantic Coastal Plain

See Chapter 4: Topography to learn about the Fall Line, which divides the Piedmont from the Coastal Plain.

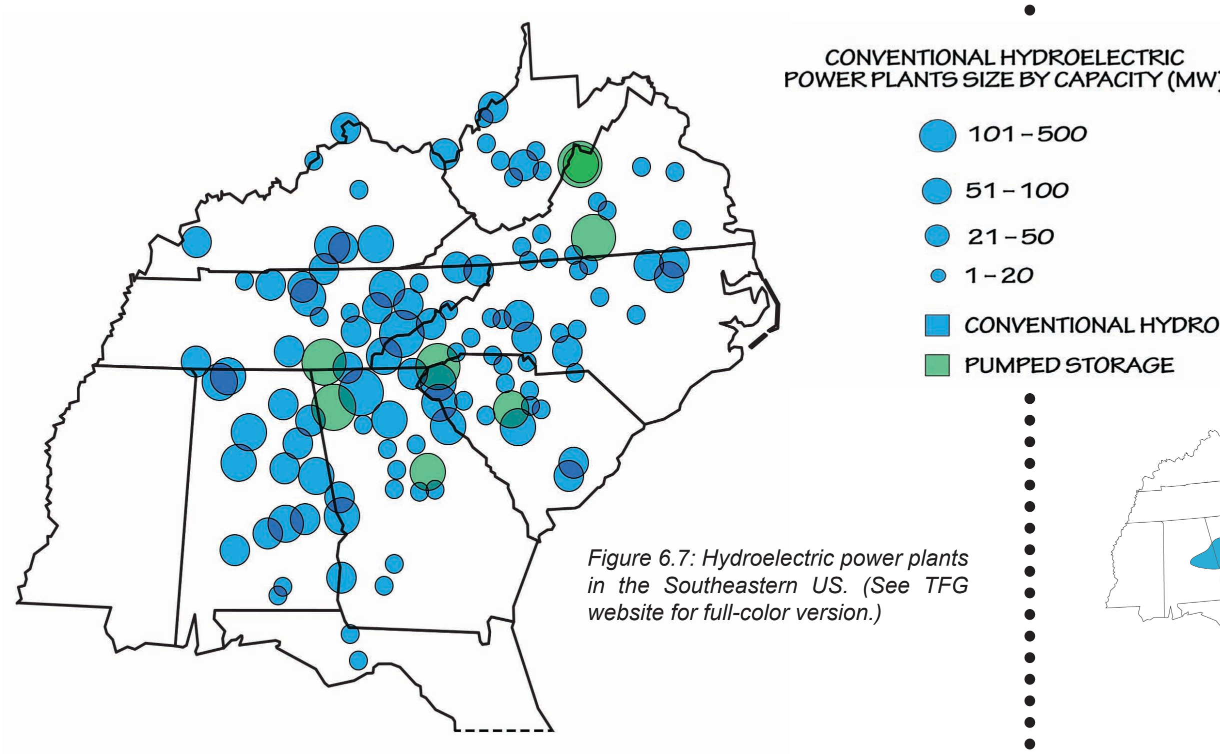
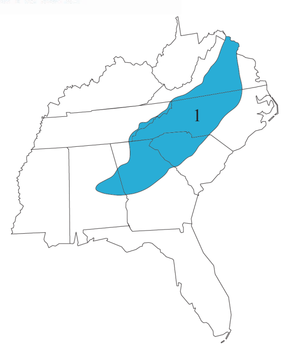


Figure 6.7: Hydroelectric power plants in the Southeastern US. (See TFG website for full-color version.)



__relief__ • the change in elevation over a distance.

__Paleozoic__ • a geologic time interval that extends from 541 to 252 million years ago.

__Taconic Orogeny__ • a late Ordovician mountain-building event involving the collision and accretion of a volcanic island arc along the eastern coast of North America.

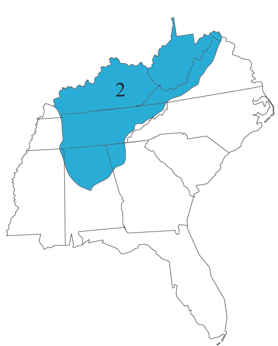
__Acadian Orogeny__ • a Devonian mountain-building event involving the collision of the eastern coast of North America and the accreted terrane of Avalon.

(*Figure 6.8*). The steep **relief** and waterfalls of the Appalachian Mountains, especially in western North Carolina and northern Georgia, also provide ample opportunities for hydroelectricity production. North Carolina ranks 9th in the US for hydropower generation, with over 70 hydroelectric dams, though this only accounts for about 3% of the state's electric demand.

Figure 6.8: The J. Strom Thurmond Dam (also known as Clarks Hill Dam) is located on the Savannah River at the border of Georgia and South Carolina. The 334-meter-wide (1096-foot-wide) dam houses a 380 MW hydroelectric plant.

Energy in the Inland Basin
Region 2

The Inland Basin is a renowned source of fossil fuels: its ancient environments and geological history were ideal for the formation and preservation of widespread deposits of coal, oil, and natural gas (*see Figures 6.3 and 6.4*). Appalachian Basin coal, along with oil and natural gas, fueled the industrial growth of the Eastern Seaboard and westward expansion. The coal-bearing region of the Appalachian Basin extends 1300 kilometers (800 miles) from northern Pennsylvania to Alabama, and covers an area of 186,000 square kilometers (72,000 square miles) in parts of nine states. The Inland Basin also has modest hydroelectric power generated by a wet climate and topographic relief. Solar energy and biofuel production are growing industries, but remain small.



Oil and Gas

The Appalachian Basin, a sedimentary basin formed in the **Paleozoic** during the **Taconic** and **Acadian orogenies**, was the site of much early oil exploration. During the formation of the ancestral Appalachian Mountains, the crust was buckled and **downwarped** repeatedly to form the basin, which is deepest beneath the Appalachian Plateau. The **sedimentary rocks** of the Appalachian Plateau are not tightly folded like the Valley and Ridge (an adjoining **physiographic** region), but have broad, gentle folds, as well as faults, which provide the opportunity to trap oil and gas (*Figure 6.9*). These energy resources have been extracted from rock layers of **Ordovician** through **Pennsylvanian** age. Famous rock units acting as reservoirs include the Oriskany Sandstone, which extends from New York into Virginia, and the Greenbrier Limestone (the "Big Lime") and its equivalents, which extend throughout West Virginia, eastern Kentucky (*Figure 6.10*) and Tennessee, and parts of Alabama, Georgia, and Virginia. Not all reservoirs are extensive—more isolated reservoirs are found in the **Mississippian**-aged Fort Payne Formation in eastern Tennessee. These reservoirs occur in **permeable carbonate** mounds (called **bioherms**) that were formed in shallow seas. The mounds were buried by mud, which formed a **shale caprock** that acts as a **stratigraphic** trap for oil that migrated into the mounds.

Thomas Jefferson visited springs venting natural gas on a stream called Burning Springs, a tributary of the Little Kanawha River in West Virginia, as early as 1781. He wrote an article describing the brilliant flame that could be produced by thrusting a lighted candle into the escaping gas.

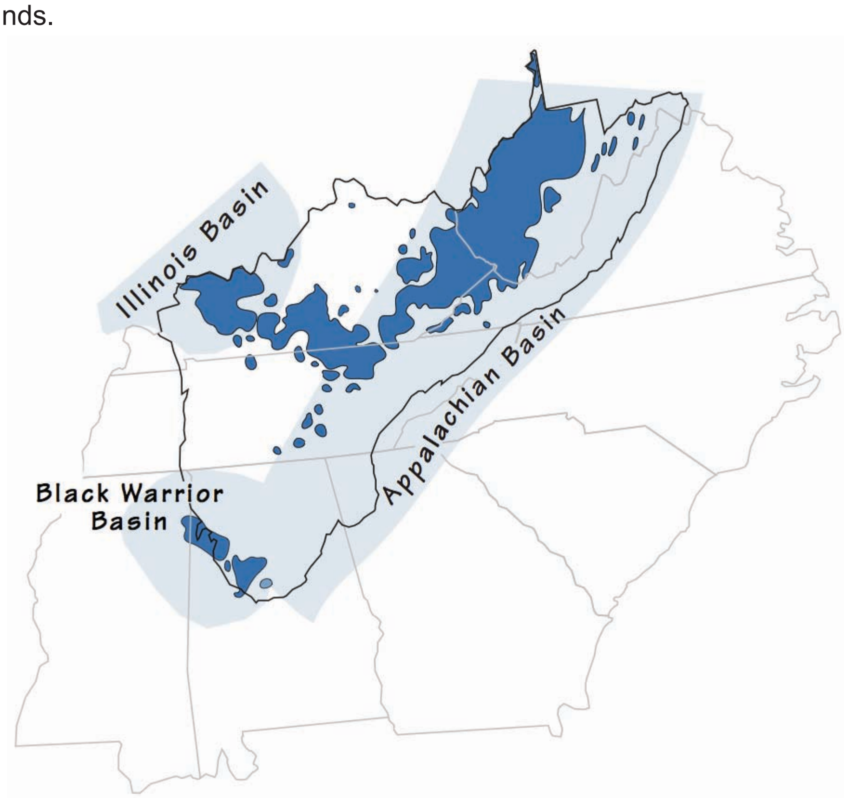


Figure 6.9: Clusters of oil and gas fields in the Inland Basin.

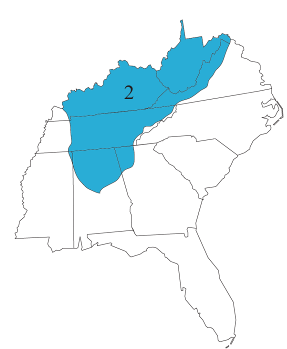
downwarp • *a segment of the Earth's crust that is broadly bent downward.*

sedimentary rock • *rock formed through the accumulation and consolidation of grains of broken rock, crystals, skeletal fragments, and organic matter.*

physiography • *a subfield of geography that studies the Earth's physical processes and patterns.*

Ordovician • *a geologic time period spanning from 485 to 443 million years ago.*

Pennsylvanian • *a subperiod of the Carboniferous, spanning from 323 to 299 million years ago.*



Energy

Region 2

salt • a mineral composed primarily of sodium chloride ($NaCl$).

Devonian • a geologic time period spanning from 419 to 359 million years ago.

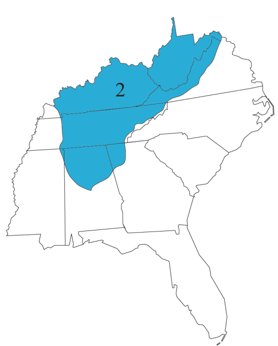
inland sea • a shallow sea covering the central area of a continent during periods of high sea level.

fracture • a physical property of minerals, formed when a mineral crystal breaks.

Figure 6.10: An oil pumpjack in Magoffin County, Kentucky. Between 1980 and 2005, the county produced 3.4 million barrels of oil and 450 million cubic meters (15.8 billion cubic feet) of natural gas.

In the early and mid-1800s, drillers searching for **salt** in the Appalachians sometimes struck oil by accident. In 1819, Martin Beatty of Abingdon, Virginia encountered oil while drilling for salt on the South Fork of the Cumberland River in Kentucky, near the Tennessee state line. Another salt prospect well near Burkesville, Kentucky struck pressurized oil in March 1829. Called the "Great American Oil Well," the gusher flowed into the nearby Cumberland River and the oil was carried over 64 kilometers (40 miles) downstream. The floating oil ignited and burned for three weeks, halting riverboat traffic. Overall, the well is estimated to have produced 50,000 barrels of oil, most of which was sold as lamp oil or medicine. In 1859, the Rathbone brothers struck oil in a well drilled along Burning Springs in West Virginia; based on this discovery, they drilled another well the following year, producing 1200 barrels of oil a day. Petroleum production spread rapidly throughout the Appalachian Basin in the 1860s, reaching its peak by 1900, the culmination of the first major US oil boom.

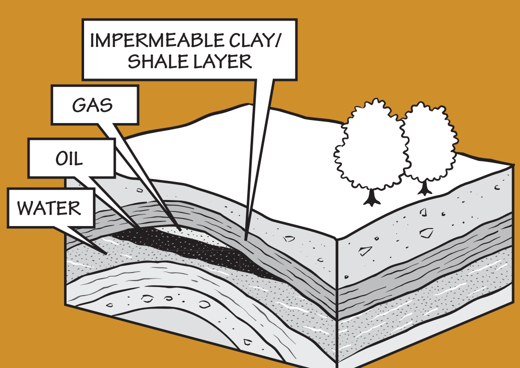
Large amounts of gas have also been produced from thick **Devonian**-aged black shales, deposited in oxygen-poor **inland seas** where organic material was preserved at the sea bed. With time, pressure, and heat, organic material in the shale was changed into petroleum and gas. Devonian-aged shales are the major source rock for most of the Inland Basin's younger petroleum reservoirs, and they are also a major gas reservoir. Because the shales are not permeable, gas production occurs where the rocks are naturally **fractured**, or where it is induced by hydraulic fracturing. This method fractures rocks beneath the surface, releasing gas and oil trapped in source rocks that have very low permeability (also known as "tight" layers). Hydraulic fracturing uses high volumes of water introduced at high pressure through horizontal wells along the source rock layer, to create thousands of tiny fractures (*Figure 6.11*). Most

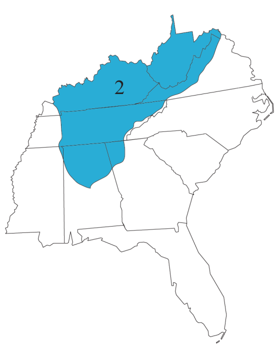


Oil and Gas

Oil and gas form from organic matter in the pores of sediments subjected to heat and pressure. The organic matter is primarily composed of photosynthetic plankton that die and sink to the bottom of large water bodies in vast numbers. Shale in particular is often organic rich, because organic matter settles and accumulates in the same places that mud (clay and silt particles) settles out of the water. In most environments, organic matter is recycled by bacteria before it can be buried, but the quiet waters where mud accumulates are often relatively stagnant and low in oxygen. In these places, the bacterial decay rate is low relative to the rate of organic matter sinking and to the rate that the organic matter becomes buried in muddy sediments. Under such conditions, organic matter may accumulate enough to make up several percent or more of the deposited sediment.

Because oil and gas are under pressure, they will move gradually upward to areas of lower pressure through tiny connections between pore spaces and natural fractures in the rocks. Reservoir rocks typically have a considerable amount of pore space, and to be viable there must be a way of trapping the oil and gas, such as through a geologic structure or a change in rock type that will prevent the resource from escaping. Often, natural gas and oil are trapped below the surface under impermeable layers that do not have sufficient spaces for liquids and gases to travel through. Folds or "arches" in impermeable layers, or faults in rock layers, are common ways of trapping oil and gas below the surface.





Energy

Region 2

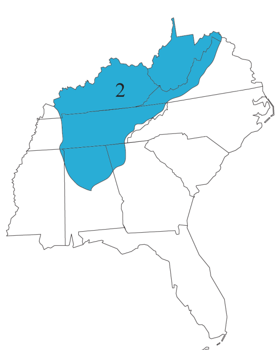
sand • *rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

sandstone • *sedimentary rock formed by cementing together grains of sand.*

fluvial • *see outwash plain: large sandy flats created by sediment-laden water deposited when a glacier melts.*

porosity • *the percentage of openings in a body of rock such as pores, joints, channels, and other cavities, in which gases or liquids may be trapped or migrate through.*

limestone • *a sedimentary rock composed of calcium carbonate ($CaCO_3$).*



Gushers, an icon of oil exploration during the late 19th and early 20th centuries, occurred when highly pressurized reservoirs were breached by simple drilling techniques. Oil or gas would travel up the borehole at a tremendous speed, pushing the drill bit out and spewing out into the air. Although iconic, gushers were extremely dangerous and wasteful; as well as spewing thousands of barrels of oil onto the landscape, they were responsible for the destruction of life and equipment. The advent of specialized blowout prevention valves in the 1920s enabled workers to prevent gushers and to regain control of blown wells. Today, this equipment is standard in both on- and offshore oil mining.

horizontal wells are drilled where the source rock is about 100–150 meters (330–490 feet) thick. The fractures are held open by small grains of **sand** carried by gel in the water, increasing its viscosity. A number of chemicals are added to the water to increase the recovery of fossil fuels, including a chemical to reduce friction as the mixture is introduced (thus the term "slickwater"). "Slickwater, high-volume hydraulic fracturing"—often shortened to "hydraulic fracturing" or simply "fracking"—has greatly increased the accessibility of available fossil fuel resources and the production rate of oil and gas. It has also been controversial, in large part because of associated environmental impacts. The middle Devonian Marcellus shale, which underlies part of West Virginia, is the most famous Southeastern unit that has been subjected to fracking. Most of the Marcellus shale, however, underlies Pennsylvania, where natural gas extraction has increased dramatically since 2008.

The Illinois Basin, deepest in south-central Illinois, continues into western Kentucky and extreme north-central Tennessee. Similarly to the Appalachian Basin, oil and gas have been produced from Ordovician through Pennsylvanian-aged strata. The reservoirs are primarily structural and stratigraphic traps in Mississippian and Pennsylvanian **sandstones** that formed in a wide range of **fluvial**, coastal, and shallow marine environments. Some of these shallow-sea sandstones are very **porous**, making them effective reservoir rocks. Many of the Illinois Basin's Mississippian **limestones**, which were deposited in shallow tropical seas, are also reservoirs. Some of these limestone layers are made of spherical grains called **oolites** that form along coastlines as concentric precipitated layers of **calcium carbonate**. These oolitic limestones are extensive and similar in age to the "Big Lime" of the Appalachian Basin.

The Black Warrior basin occupies northwestern Alabama and northeastern Mississippi. The first petroleum discovery in the region was made in 1909, when natural gas was struck in the Pennsylvanian-aged rocks of northwestern Alabama. Most traps in this basin are formed by folds and faults, and contain both oil and natural gas. Less oil is produced in this basin than in parts of the Appalachian Basin or the Illinois Basin to the north.

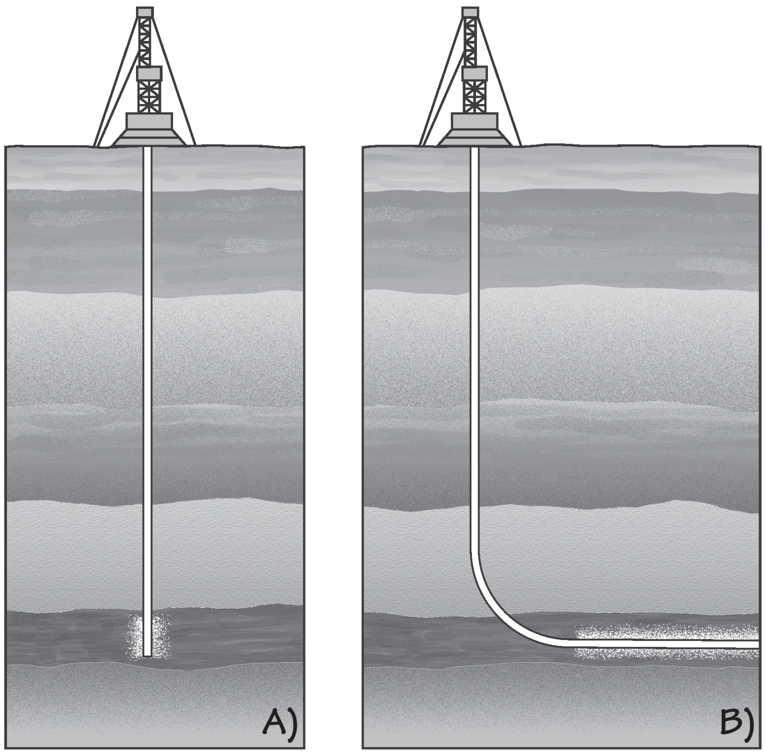


Figure 6.11: Oil wells (not to scale). A) A conventional vertical well. B) An unconventional horizontal well. Hydraulic fracturing may be carried out along horizontal wells running for 1.6 kilometers (1 mile) or more along layers with oil or gas trapped in pore spaces.

Oil and gas are also produced in the "Cumberland Saddle," a sag along the **Cincinnati Arch** separating the Illinois and Appalachian Basins. In the Saddle, **Cambrian** and Ordovician rock units—tens of thousands of meters (yards) deep within the basins—are exposed at the surface. Substantial petroleum has been produced from limestones and **dolomites** of the Cambrian-Ordovician Knox Group in Tennessee and south-central Kentucky. Much of the petroleum from the Knox reservoirs was trapped in ancient sinkholes and caves along an **unconformity**, which marks a surface of **erosion** and **weathering** where the carbonates were exposed during a drop in sea level before being buried by the next marine **transgression**.

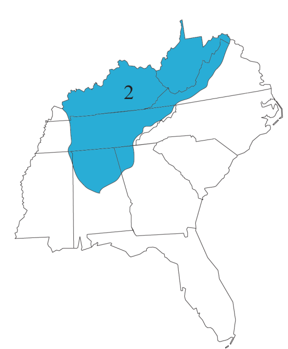
Natural **asphalt** or **bitumen** is present in rocks throughout the Inland Basin. These deposits represent oil reservoirs that have lost most of their lighter hydrocarbons, so they have become viscous, like tar. Oil that trickles out at the Earth's surface is known as a "seep." Natural seeps of crude oil and natural gas were known to Native Americans and used in medicines before European colonization. Early European settlers used surface petroleum for medical purposes, greasing wagon wheels, softening leather, and caulking log cabins. Small local distilleries produced kerosene for lamps by the 1850s. In the Southeast, the most extensive deposits are found in Kentucky and Alabama (*Figure 6.12*); natural asphalt was first "discovered" in Lawrence County, Alabama in 1840. Alabama reserves contain at least 700 million tons of material, including around 100 million tons of petroleum, with limited production from 1927 to the present. Kentucky reserves contain at least 500 million tons.

oolite *• a sedimentary rock consisting of tiny (<2 mm) spherical grains made of concentric layers of calcium carbonate.*

calcium carbonate *• a chemical compound with the formula $CaCO_3$, commonly found in rocks in the mineral forms calcite and aragonite, as well as the shells and skeletons of marine organisms.*

Cincinnati Arch *• an uplifted region that existed between the Illinois Basin, the Michigan Basin, and the Appalachian Basin during the late Ordovician and Devonian.*

Cambrian *• a geologic time period lasting from 541 to 485 million years ago.*



Energy

derrick • *a lifting device in the form of a framework steel tower that is built over a deep drill hole, typically an oil well.*

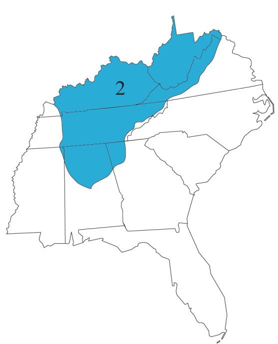
delta • *a typically wedge-shaped deposit formed as sediment is eroded from mountains and transported by streams across lower elevations.*

Carboniferous • *a geologic time period that extends from 359 to 299 million years ago.*

How does oil drilling work?

Once an oil trap or reservoir rock has been detected on land, oil crews excavate a broad flat pit for equipment and supplies around the area where the well will be drilled. Once the initial hole is prepared, an apparatus called a drilling rig is set up. The rig is a complex piece of machinery designed to drill through rock to a predetermined depth. A typical drilling rig usually contains generators to power the system, motors and hoists to lift the rotary drill, and circulation systems to remove rock from the borehole and lubricate the drill bit with mud. It also contains high-pressure blowout prevention equipment to prevent pressurized oil or gas from rising uncontrollably to the surface after being tapped. The support structure used to hold the drilling apparatus is called a *derrick*. In the early days of oil exploration, drilling rigs were semi-permanent structures and derricks were left onsite after the wells were completed. Today, however, most rigs are mobile and can be moved from well to well. Once the well has been drilled to a depth just above the oil reservoir, a cement casing is poured into the well to structurally reinforce it. Once the casing is set and sealed, oil is then allowed to flow into the well, the rig is removed, and production equipment can be put in place to extract the oil.

Offshore drilling follows much the same process as on-shore drilling, but utilizes a mobile offshore drilling unit (MODU) to dig the well. There are several different types of MODUs, including submersible units that sit on the sea floor, drilling ships, and specialized rigs that operate from atop floating barges.



Coal

Erosion of sediment from the Appalachian Mountains, which were formed by the assembly of Pangaea in the late Paleozoic, created vast coastlines and **deltas** in the Inland Basin. Widespread deposits of coal are associated with these areas. The main period of coal formation is known as the **Carboniferous** because of the abundant carbon (coal) found in rocks of this age. In the United States, the interval of time represented by the Carboniferous is divided into the Mississippian (major limestone and minor coal deposits) and Pennsylvanian (major coal deposits) periods. Globally, Carboniferous-aged rocks contain a substantial amount of the world's coal resources. Coal is a major source of

Figure 6.12: Asphalt seeps from the walls of Tumbling Rock Cave near Scottsboro, Alabama.

power in the Southeastern US, with power plants mostly using coal mined within the area. Kentucky and West Virginia are major centers for coal production and processing in the US. The Lamberts Point coal export facility in Norfolk, Virginia is the largest and fastest coal transload facility (that is, transferring from one form of transportation to another) in the Northern Hemisphere, servicing approximately one-third to one-half of US coal exports since 2000. West Virginia provides coal to most of the Northeastern US, producing well over 100 million tons of coal per year.

Coal is plentiful in the Inland Basin thanks to local environmental conditions during the Mississippian and Pennsylvanian (*Figure 6.13*). Tropical climate, fluctuating sea levels, and basin **subsidence** resulted in the cyclic growth and burial of vast peat swamps, some of which may have been among the largest tropical peat swamps of all time. The sea advanced and retreated hundreds of times, shifting the shoreline back and forth across the region, and leaving hundreds of coal beds preserved when and where conditions were right for burial of peat. Time, deep burial, and metamorphism transformed the peat layers into high grade **anthracite** and bituminous coal beds. Anthracite coals from Mississippian-aged peat swamps are preserved in the Valley Coalfields of Virginia, but none are presently mined. Coals deposited during the Pennsylvanian period occur in repeated successions of sedimentary rock layers known as **cyclothems** (*Figure 6.14*), which resulted from repetitive sea level changes caused by the formation and melting of continental **glaciers** on the supercontinent **Gondwana** from about 330 to 260 million years ago. Coal beds were preserved on the eastern margin of the elongate Appalachian Basin (including the Black Warrior Basin of Alabama), and in the Illinois Basin, which extends southward into western Kentucky. Vast, Pennsylvanian-aged coal

See Chapter 8: Climate to learn more about glacial cycles throughout geologic time.

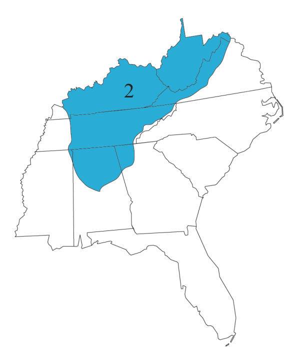
subsidence • *the sinking of an area of the land surface.*

anthracite • *a dense, shiny coal that has a high carbon content and little volatile matter.*

cyclothem • *alternating sequences of marine and non-marine sedimentary rocks, usually including coal, characterized by their light and dark colors.*

glacier • *a body of dense ice on land that does not melt away annually and has sufficient mass to move under its own weight.*

Gondwana • *the super-continent of the Southern Hemisphere, composed of Africa, Australia, India, and South America.*



Energy

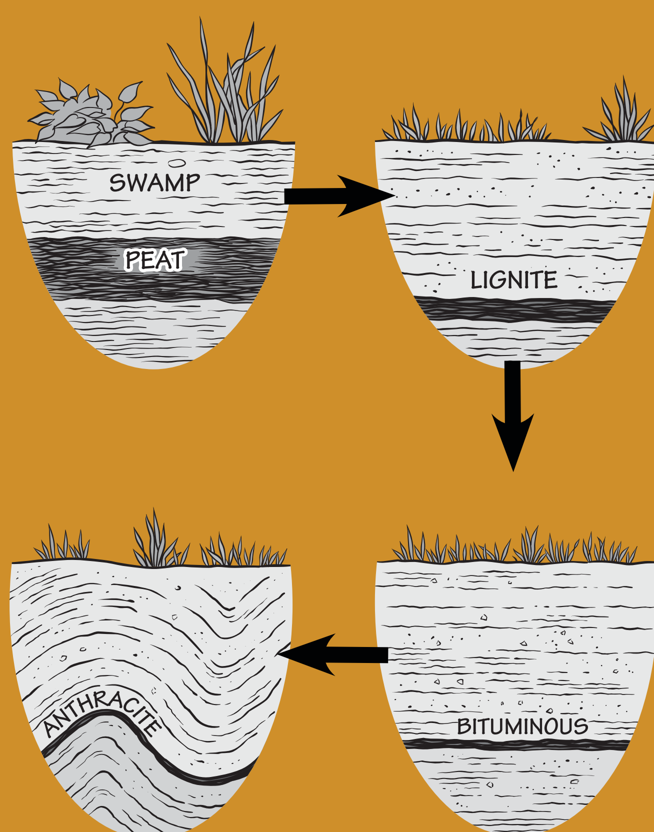
Region 2

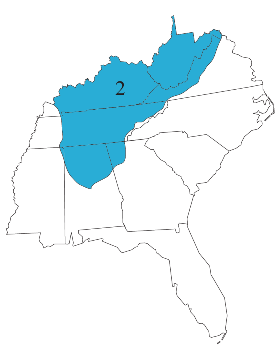
compression • *flattening or squeezing as a result of forces acting on an object from all or most directions.*

Coal

As leaves and wood are buried more and more deeply, pressure on them builds from overlying sediments, squeezing and *compressing* them into coal. The coal becomes gradually more enriched in carbon as water and other components are squeezed out: peat becomes lignite, bituminous, and eventually anthracite coal, which contains up to 95% carbon. Anthracite has the fewest pollutants of the four types of coal, because it has the highest amount of pure carbon. By the time a peat bed has been turned into a layer of anthracite, the layer is one-tenth its original thickness.

The Carboniferous period takes its name from the carbon in coal. Globally, a remarkable amount of today's coal formed from the plants of the Carboniferous, which included thick forests of trees with woody vascular tissues.





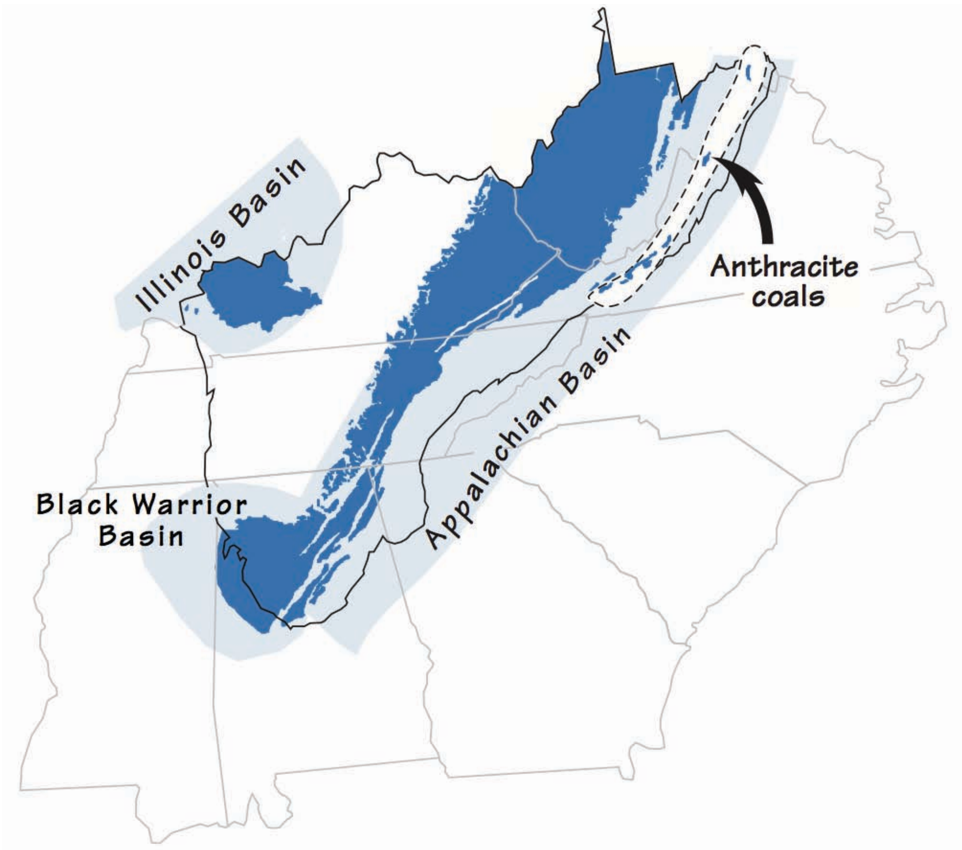


Figure 6.13: Bituminous and anthracite coal deposits of the Inland Basin region. Anthracite coals are found within the dashed circle in Virginia and West Virginia.

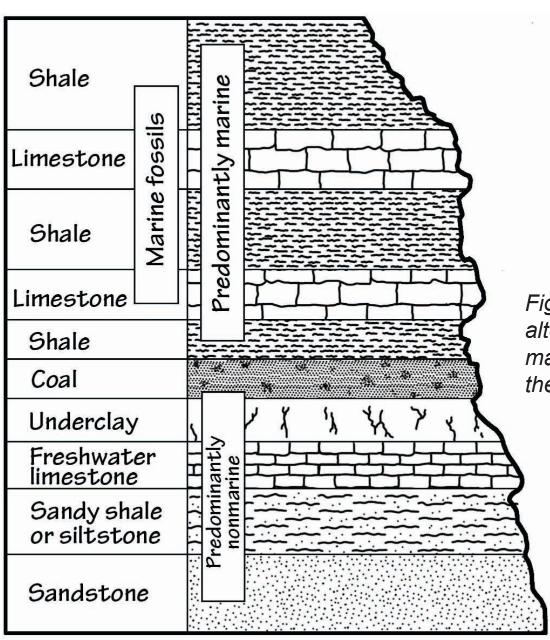
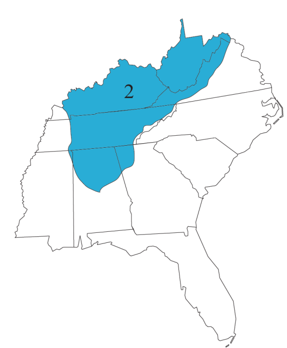


Figure 6.14: An example of a cyclothem: alternating sequences of marine and non-marine sedimentary rocks, characterized by their light and dark colors.



Permian • *the geologic time period lasting from 299 to 252 million years ago.*

Silurian • *a geologic time period spanning from 443 to 419 million years ago.*

atmosphere • *a layer of gases surrounding a planet.*

fuel • *a material substance possessing internal potential energy that can be transferred to the surroundings for specific uses.*

deposits are present from West Virginia and western Virginia, across eastern Kentucky and Tennessee, and into northern Alabama. Lesser amounts of coal occur in **Permian**-aged strata in West Virginia.

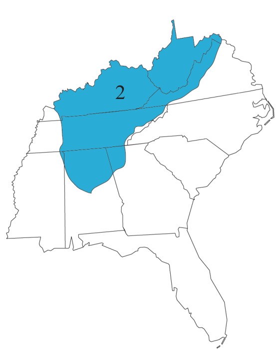
Extensive coal is not associated with the coastal deposits and deltas that formed during the earlier Taconic and Acadian orogenies, even though geologic and climatic conditions were similar, because the plants that make up the coastal swamp forests (which produced sufficient biomass for accumulation of large peat deposits) had not yet evolved. Plants had only just begun to spread on to land and evolve roots and vascular tissue during the **Silurian** period. Diversification and evolution of plants during the Devonian was rapid, leading to a proliferation of swamp-loving land plants during the Carboniferous. As forests evolved and increased in size in the late Devonian and Carboniferous, significant quantities of organic matter were produced via photosynthesis on land for the first time. Organisms that would later cause fast rates of decay had yet to evolve, and a relatively high percentage of organic matter in swampy habitats accumulated as peat, which eventually was buried and became coal. The burial of huge quantities of terrestrial organic matter took carbon dioxide out of the **atmosphere**, and CO_2 concentrations decreased to the point that global cooling led to the growth of continental glaciers. Today we are enacting the same process in reverse—in only a few hundred years, releasing carbon dioxide into the atmosphere that took millions of years to be buried.

See Chapter 3: Fossils for more about the plants that lived in the Southeast's Carboniferous swamps.

Coal in the Inland Basin was first reported along a tributary of the Kanawha River, West Virginia in 1742. Initially, only small amounts of coal were used for heating by local blacksmiths or by settlers living near coal outcrops. In 1810, people in Wheeling, West Virginia, began using locally mined coal to heat their cabins. The first steamboat on the Ohio River in 1811 burned coal from West Virginia, and coal began to replace charcoal as a **fuel** for the Kanawha River salt furnaces by 1817. In 1820, the first commercial mine opened in Kentucky. West Virginia produced about 300,000 tons of coal in 1840, of which two-thirds was used in the Kanawha salt furnaces. Factories and homes in Wheeling consumed most of the remainder. Production continued to expand until the outbreak of the Civil War, when coal production became a matter of military strategy. After the war, the Appalachian Basin coal industry began a rapid and sustained growth that paralleled the industrialization of the United States.

See Chapter 5: Mineral Resources to learn about the colonial salt industry along the Kanawha River.

The mining of Pennsylvanian coal is a major industry in Kentucky, Tennessee, Virginia, and West Virginia. More than 60 sites have been or are currently being mined in the southeast part of the Appalachian Basin and southern part of the Illinois Basin in western Kentucky. In 2013, West Virginia and Kentucky



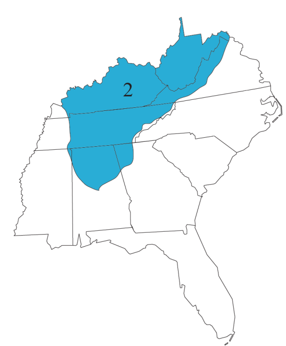
produced the second and third most coal in the country, accounting for 12% and 8% respectively of the national production. Well over half of the coal produced in the US in the last 180 years has come from deposits in the Appalachian Basin. Since the 1960s, coal in the Appalachians has been extracted using mountaintop removal mining, a method that involves blasting away the summit of a mountain to expose underlying coal seams (*Figure 6.15*). West Virginia and Kentucky each use approximately 1100 tons of explosives per day to facilitate this mining method.

Figure 6.15: Mountaintop removal mining for coal on Kayford Mountain, West Virginia. In 2006, mountaintop removal mining provided 30% of West Virginia's coal.

coalification *• the process by which coal is formed from plant materials through compression and heating over long periods of time.*

aquifer *• a water-bearing formation of gravel, permeable rock, or sand that is capable of providing water, in usable quantities, to springs or wells.*

Since about 1980, large reserves of natural gas have been exploited in tandem with coal seams. This gas, called coalbed methane, is a byproduct of the process of **coalification**, and it accounts for over 5% of US methane production. Coal seams have long been vented, in part because of the potential build-up of methane (CH_4, the primary gas in "natural gas") released from fissures around the coal. While long considered primarily a safety hazard to be mitigated in subsurface mines, methods have been developed to trap the methane as an additional energy source. In some subsurface coal seams, water saturates fractures (or cleats) in the seam, making the seam an **aquifer** (which in some places may be clean enough to be part of the local water supply). If there is sufficient water pressure, methane present within the coal fractures may be trapped in the coal. To extract this methane, water can be removed via wells, thereby reducing pressure and allowing methane to escape toward lower pressures along the well bore (*Figure 6.16*). Methane is then separated from the water. After water removal it may take some years for the aquifer to be recharged, that is, refilled with water from rain at the surface that infiltrates below the surface to the aquifer. Production rates for coalbed methane climbed steeply beginning in the early 1990s, and peaked in about 2008, when about



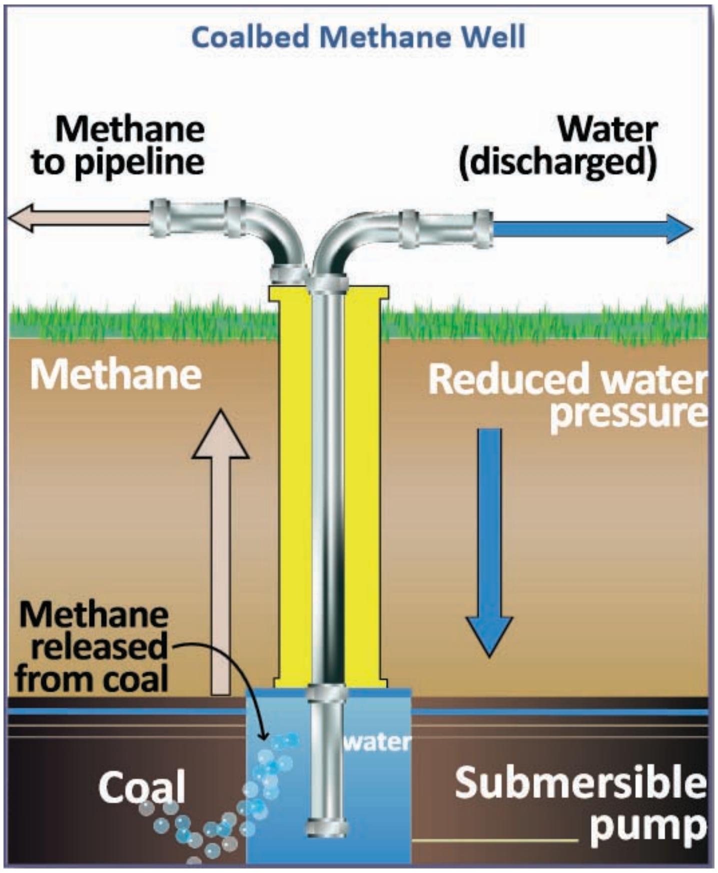
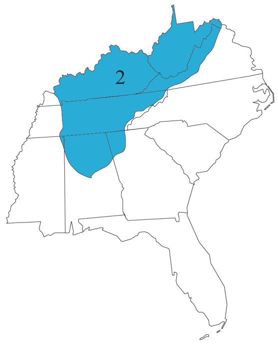


Figure 6.16: Coalbed methane production involves using water or other fluids to reduce pressure on the coal seam by creating a crack through which the methane can escape into a well.

a tenth of the country's yearly natural gas production came from coalbed methane. In recent years, it has declined as shale gas methane production has increased. In Alabama, the gas is sometimes extracted in advance of underground coal mining. The Black Warrior Basin in northern Alabama and the Southwest Virginia Coalfield have hundreds of coalbed methane wells currently in operation, and Virginia is the fifth leading state in coalbed methane production.

Alternative Energy

The Appalachian Mountains to the east of the Inland Basin, combined with the Cumberland Plateau running through the region, facilitate hydroelectric power. Major hydropower plants dot rivers and lakes from the James River in West Virginia along the Cumberland River running through Kentucky and Tennessee to the Coosa River in Alabama. A substantial fraction of hydroelectric power in the Inland Basin comes from dams built by the Tennessee Valley Authority. Alabama ranks fifth in the nation for renewable electricity generation, and is also one of the largest hydroelectric producers east of the Rocky Mountains. Southern Company, the largest electricity producer in the US, operates 34 hydropower facilities in Alabama and Georgia with a total of 2730 MW produced.



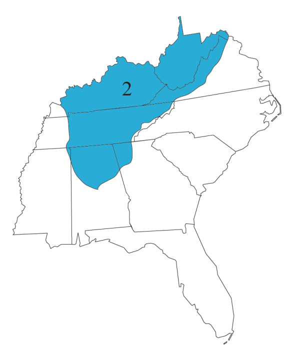
Tennessee Valley Authority

The Tennessee Valley Authority (TVA) was founded in 1933 by the US government to provide a wide range of services to promote economic development, including electricity generation, in the Tennessee Valley, which was hit especially hard by the Great Depression. The area covered the southern part of the Inland Basin—Tennessee and parts of states immediately north, south, and east. Numerous dams were built for hydroelectric plants, in the 1930s for economic development, and in the 1940s for Word War II. Today, TVA remains a large public power utility, with 1/3 of its power from coal, 1/3 from nuclear, 1/10 from hydroelectric, and 1/10 from natural gas. It is beginning to add other sources of renewable energy, such as solar arrays and biofuels.

The Southeast has one of the lowest wind resource potentials in the US, and has not been extensively developed for wind power. The primary exception is the spine of the Appalachians, which is oriented perpendicular to the prevailing winds and thus receives much higher average wind speeds; however, building large wind farms in tightly confined mountainous areas is logistically challenging. West Virginia is the only state in the Southeast with significant existing wind energy production—in 2015, the state ranked about 25th in the US, with five plants producing a total of 615.3 MW of power (*Figure 6.17*). Tennessee has a single 2.1 MW wind farm.

Figure 6.17: Turbines at the Mountaineer Wind Energy Center in Tucker County, West Virginia.

Three nuclear power plants are located in the Inland Basin, two in Tennessee and one in Alabama. All three—the Watts Bar Nuclear Plant (1123 MW, Tennessee), the Sequoyah plant (2277 MW, Tennessee), and the Browns Ferry Nuclear Plant (3310 MW, Alabama)—are located along the Tennessee River.



Region 3

watershed • *an area of land from which all water under or on it drains to the same location.*

Cretaceous • *a geologic time period spanning from 144 to 66 million years ago.*

gypsum • *a soft sulfate mineral that is widely mined for its use as fertilizer and as a constituent of plaster.*

salt dome • *a largely subsurface geologic structure, consisting of a vertical cylinder of salt embedded in horizontal or inclined sedimentary strata.*

solution mining • *the extraction of soluble minerals from subsurface strata by the injection of fluids.*

Energy in the Coastal Plain
Region 3

The Southeastern Coastal Plain is best known for its oil and gas deposits in and offshore of Mississippi and Alabama, though the deposits are not as extensive as adjoining geologically equivalent formations in Louisiana and Texas. While the Gulf Coast in the Southeast has not been nearly as productive as the Gulf Coast of Louisiana and Texas to the west, it shows some similar characteristics as a petroleum producer. Natural gas also drives the Coastal Plain; harvest of natural gas and the infrastructure to move this energy resource throughout the region are extensive, allowing for natural gas to be one of the most consumed energies. The Coastal Plain also supports a variety of alternative energy sources, including solar, biomass, and nuclear power generation.

Conventional Oil and Gas

As Pangaea broke apart during the Jurassic, the Gulf of Mexico opened and began to take shape. In its early stages, the Gulf experienced periods of restricted marine circulation, during which salt was deposited through evaporation in flat layers now known as the Louann Salt Formation (*Figure 6.18*). Since the late Jurassic, the Gulf of Mexico has been accumulating thick deposits of marine sediments, which have been supplemented since that time by sediments eroded from the Mississippi River **watershed** in central North America. The Coastal Plain along southern Mississippi and southwest Alabama was submerged under high sea levels for much of the late **Cretaceous** and Paleogene periods, and it is now the site of thick layers of limestones, shales, and sandstones. Many late Cretaceous and early Paleogene shales became source rocks for oil, significant quantities of which have migrated stratigraphically into the sandstone and porous limestone, ultimately pooling in reservoirs trapped under a variety of impermeable sedimentary deposits such as **gypsum**, anhydrite, limestone, and dolomite. The underlying Jurassic salt structures that occur in abundance along the Gulf of Mexico explain the geographic distribution of many oil and gas reservoirs from eastern Texas to western Alabama. Locally thick occurrences of this salt are found in the Mississippi Interior Salt Basin, which extends from central Louisiana through central Mississippi and southwestern Alabama *(see Figure 6.4)*. Impermeable rocks pushed up by **salt domes** became caprock where oil could be trapped—this is the case in the South Carlton field in southwestern Alabama, the Norphlet Formation in central and southern Mississippi and Alabama, and dozens of fields in central Mississippi, with oil and gas production mostly occurring in Cretaceous sandstones (*Figure 6.19*).

See Chapter 2: Rocks to learn how the Coastal Plain's sedimentary rocks were deposited.

Salt domes in the Coastal Plain are also used to store large quantities of oil and gas. Storage caverns are created by injecting the salt with water to dissolve a cavity within the salt structure—a process called **solution mining** (*Figure 6.20*). Sempra US Gas & Power's Mississippi Hub Storage is one such storage operation, currently holding up to 850 million cubic meters (30 billion cubic

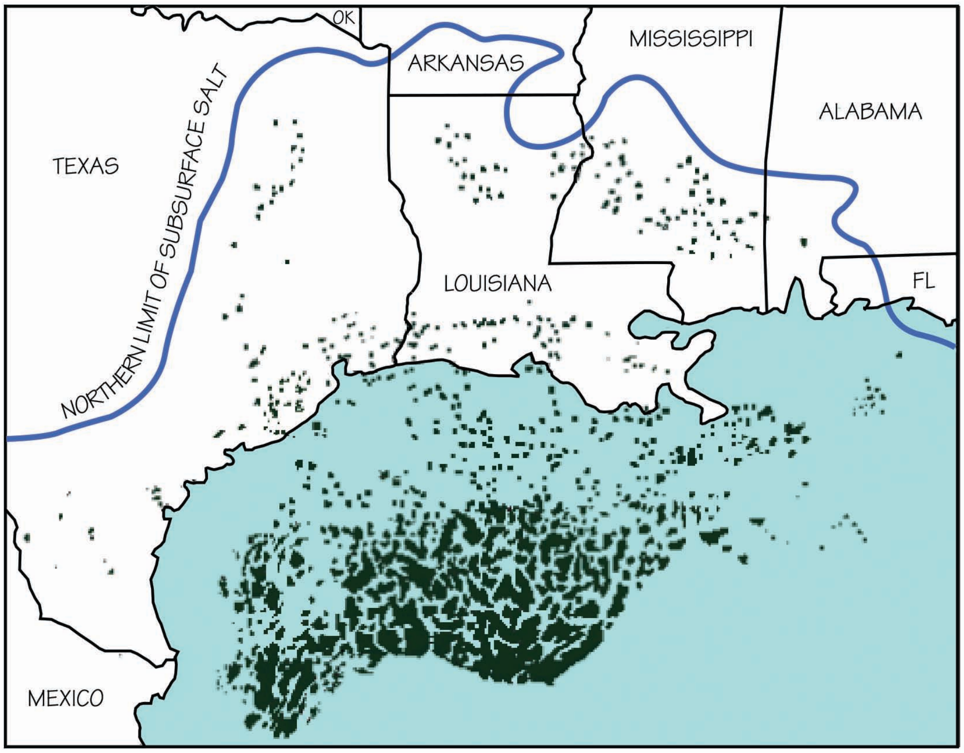


Figure 6.18: The Louann Salt Formation extends under the surface of the Coastal Plain to the blue line. The "blobs" are known salt structures where the salt layer has been deformed.

Figure 6.19: Clusters of known oil and gas fields in the Coastal Plain region.

mineral • *a naturally occurring solid with a specific chemical composition and crystalline structure.*

density • *a physical property of minerals, describing the mineral's mass per volume.*

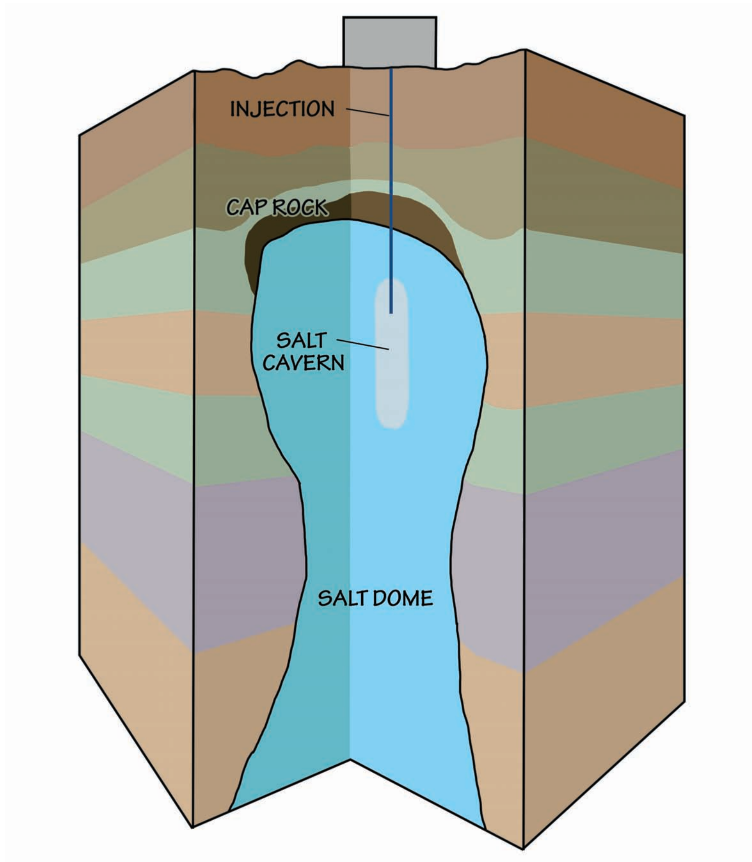


Figure 6.20: Solution mining is used to create a storage cavern inside a salt dome.

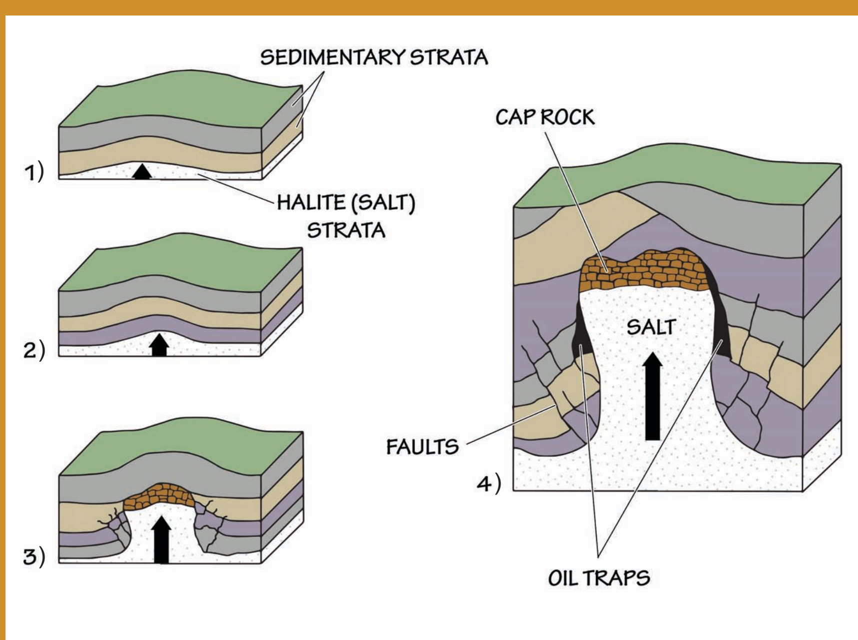
Salt Domes

Rock salt (the *mineral* halite) is solid and impermeable, but when it is under very high pressure it can flow like a thick liquid. When a layer of salt is buried under thousands of feet of overlying sediment, it will start to deform. Because it is less *dense* than the rocks above it, it flows upward toward areas of lower pressure, forming geological structures named for their shapes (e.g., domes, canopies, tables, and lenses). Salt domes are extremely common geologic features along the Gulf Coast, and their origin lies in the Jurassic, when salt was deposited through evaporation in flat layers now known as the Louann Salt Formation. Today, this salt layer is covered by over 6000

Salt Domes (continued)

meters (20,000 feet) of sedimentary rock, through which the salt has moved upward with time, forming hundreds of salt domes.

As salt structures grow, they in turn influence the topography of the surrounding landscape, creating zones of *uplift* surrounding areas of subsidence, fractures, and faults. When salt flows upward, it deforms the surrounding strata, creating gaps in which oil and gas may pool and be trapped. Oil and gas also accumulate under and along the salt structures. Salt domes have led to some of the most prolific oil reservoirs in the Gulf Coast, both on- and offshore. In addition, due to their inherent impermeability, the salt domes themselves are often solution-mined (by pumping water underground to dissolve the salt) to create caverns that have been used to store petroleum, gas, and even chemical waste.



FORMATION OF A SALT DOME

uplift • *upward movement of the crust due to compression, subduction, or mountain building.*

Paleocene *• a geologic time interval spanning from about 66 to 56 million years ago.*

Oligocene *• a geologic time interval spanning from about 34 to 23 million years ago.*

Miocene *• a geological time unit extending from 23 to 5 million years ago.*

Eocene *• a geologic time period extending from 56 to 33 million years ago.*

weather *• the measure of short-term conditions of the atmosphere such as temperature, wind speed, and humidity.*

feet) of natural gas in four storage caverns below Simpson County, Mississippi. Other salt dome storage facilities include the Bond Salt Dome Storage Field in Jackson County, Mississippi, and the McIntosh storage cavern in Alabama.

The Florida peninsula has produced small quantities of oil since the mid-1900s from deep (3000–4000 meter [9800–13,100 feet]) Cretaceous-aged rocks. Though the thick sequence of carbonate rocks in Florida is permeable and acts as a reservoir, there are very few source rocks, and therefore, little oil or gas with which to supply the potential reservoirs. Small amounts of oil are still being produced today in a belt of porous Cretaceous limestones from west of Miami to near Fort Myers.

Offshore Oil and Gas

Today, oil and gas production associated with Coastal Plain sediments has moved mostly offshore, into the Gulf of Mexico. Much of this oil and gas formed and was trapped in similar ways to that onshore, with salt structures leading to offshore traps (*see Figure 6.18*). Substantial amounts of sediment were eroded from the midcontinent into the Gulf of Mexico through the ancestral Red, Mississippi, and Sabine river systems. Offshore reservoirs now exist where sandy sediments accumulated, not just on the continental shelf, but also along deeper submarine fans along the continental slope and even abyssal plain. Many of the reservoirs offshore are thick **Paleocene** to **Oligocene** and especially **Miocene** deposits, with Cretaceous and **Eocene**-aged source rocks. The largest Gulf of Mexico oil field to date was found in 1999, 250 kilometers (155 miles) due south of the Mississippi coastline. Drilling in the deepest parts of the Gulf is extremely challenging due in part to **weather**, harsh environments, and water pressure at depth. This became publicly apparent during the Deepwater Horizon oil spill event in 2010, when a seafloor gusher discharged 4.9 million barrels of oil over a period of 87 days before it was capped.

Coal

During the last 100 million years, the seas have advanced and retreated several times, shifting the position of the Coastal Plain's shoreline back and forth. At different times, peat swamps accumulated along the old coastlines and far up the Mississippi River Valley. The largest deposits of resulting coal are Eocene-aged deposits, which are present from Texas east across northern Louisiana and eastern Arkansas, into Mississippi and Alabama, and also north into the **Mississippi Embayment** (*see Figure 6.3*). These thinly bedded coals are formed from plants that lived in marshy environments, brackish lagoons, and between streams near the Eocene coastline.

See Chapter 1: Geologic History to learn about sea level changes through geologic times.

In contrast to the Carboniferous peats of the Inland Basin, which became anthracite and higher grade bituminous coal, the Coastal Plain's peats were not as deeply buried, and therefore were not exposed to the same pressures and temperatures. Therefore, in the Gulf Coastal Plain only **lignite** and "high volatile" (lower grade) bituminous coals exist. Along the Atlantic Coastal Plain there are some large deposits of peat that have not yet been compacted, including

Holocene deposits in coastal North Carolina. Here, the peat ranges from 0.3–4.6 meters (1–15 feet) thick and averages 1.4 meters (4.5 feet) thick. The largest deposits are found in the Albemarle-Pamlico penin-sula and the Great Dismal Swamp.

See Chapter 5: Mineral Resour-ces to learn more about peat and its uses.

Solar Energy

Between August of 2014 and August of 2015, North Carolina's production of electricity from solar power increased 127%—more than in any other state in the country during that time period. The state's solar electric power production in 2015 accounted for more than twice the total production for all the other states in the Southeast combined (*Figure 6.21*). While production of solar electric power has grown exponentially in North Carolina and in the US as a whole, more than half of the country's solar electric production is found in California. The total US output of solar power is also still dwarfed by other sources. For example, in August 2015, five times more electric power was produced in Florida from burning natural gas than the entire country produced from solar power that month, and in North Carolina, the explosive growth of solar production brought electric production from non-hydro renewables to just 3.4% of the state's total.

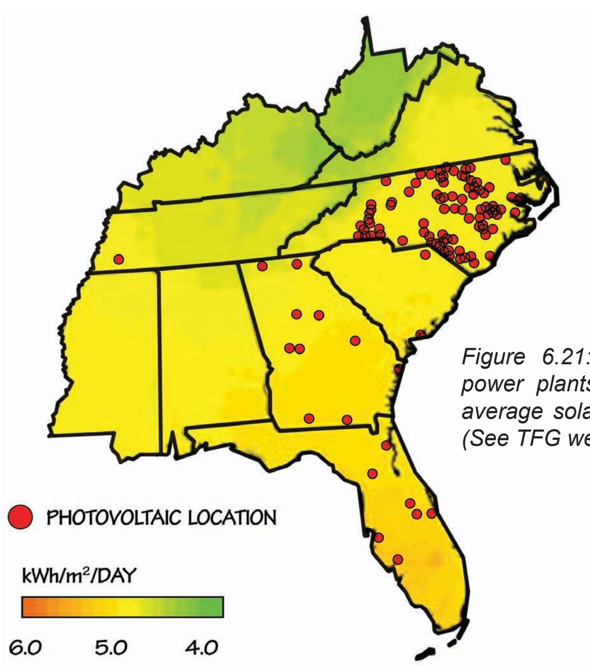


Figure 6.21: Locations of existing photovoltaic power plants overlaid on a map of the annual average solar resource for the Southeastern US. (See TFG website for full-color version.)

Bioethanol and Biomass Plants

The Coastal Plain is rich in biomass resources—organic materials burned to generate energy. Many areas generate hundreds of thousands of tons of biomass materials—including oil (soybeans and canola), sugar (sugarcane, beets, and sorghum), starch (rice, corn, and grains), and cellulose (wood, crop waste, and municipal waste)—every year from forestry, urban waste, and agriculture.

Mississippi Embayment • *a topographically low-lying basin in the south-central United States, stretching from Illinois to Louisiana.*

lignite • *a soft, brownish-black coal in which the alteration of plant matter has proceeded farther than in peat but not as far as in bituminous coal.*

Holocene • *the most recent portion of the Quaternary, beginning about 11,700 years ago and continuing to the present.*

Energy

Across the Southeastern states, biomass accounts for 6.3% of energy use. States within the Coastal Plain have a slightly higher percentage of their energy coming from biomass. Alabama has the largest share—10.1% in 2013—of the states in the region. Of the 737 public and private-access biodiesel fueling stations nationwide, more than 18% are in North Carolina. A bioethanol and electric power plant that produces energy from wood, vegetable, and municipal wastes was recently built in Vero Beach, Florida. The new fermentation and gasification process uses municipal and other non-food biomass waste, thus avoiding issues associated with using farm crops for biofuel production. The power plant produces commercial-level amounts of biofuel (300 million liters [80 million gallons] of ethanol), as well as electricity to run the plant and to provide from six to eight MW of energy for area homes and businesses. Many people see this type of plant as one possible solution to reducing municipal waste and the use of fossil fuels.

Nuclear Power

Every Southeastern state in the Coastal Plain supports at least one nuclear power plant. Of the 18 plants in the Southeastern US, 9 of these are located in the Coastal Plain region, producing a combined total of 17,029 MW of power. The largest nuclear facility is the Turkey Point Nuclear Generating Station near Miami, Florida, which has a capacity of 3552 MW (*Figure 6.22*). There are also several nuclear reactor fuel processing facilities in the Coastal Plain, notably in North and South Carolina.

Figure 6.22: Turkey Point is the largest nuclear generating station in Florida and the sixth largest power plant in the US. It currently operates five power-generating units, and an expansion of two additional nuclear reactors is scheduled to begin in 2017.

Energy Facts by State

Due to local laws and guidelines, energy production and use is highly regulated by each state government. Below is a state-by-state assessment of energy production and use in the Southeastern US (from http://www.eia.gov/state/).

Alabama

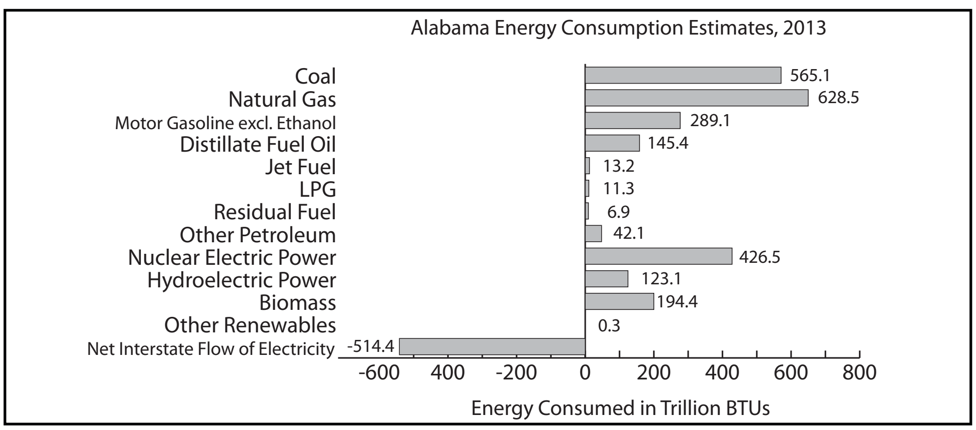
- The three reactors at the Browns Ferry Nuclear Plant in Limestone County, Alabama have a combined generating capacity of 3310 MW, second in capacity only to Arizona's Palo Verde plant.

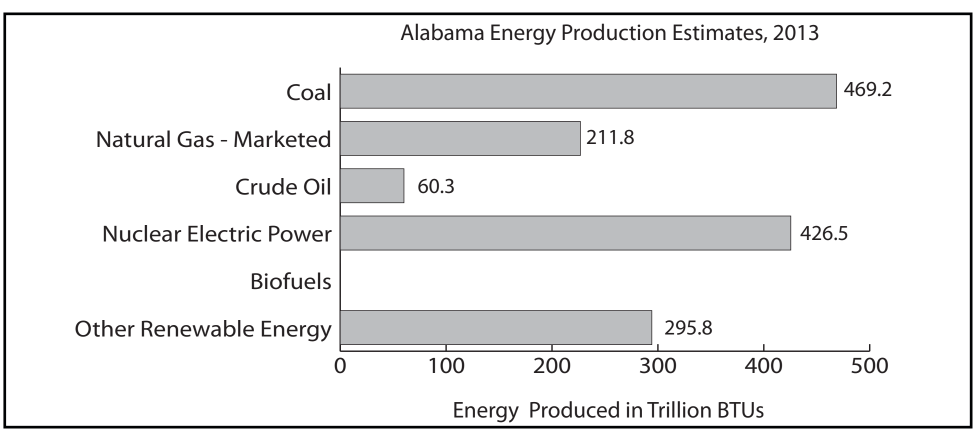
- In 2013, Alabama ranked 17th in the nation for the number of producing natural gas wells.

- Mobile, Alabama was the fourth-largest seaport for exporting US coal in 2013. Coking coal used in the steelmaking process accounted for 82% of total exported coal.

- Alabama ranked ninth in 2014 in net electricity generation from renewable energy resources. Conventional hydroelectric power supplied 75% of Alabama's generation from renewable resources.

- Alabama ranked sixth in the US in net electricity generation from wood waste, landfill gas, and other biomass in 2014; nearly all of that electricity was generated by nonutility power producers, primarily in the industrial sector.





6 Energy

Region 3

Florida

- Geologists believe there may be large oil and natural gas deposits in the Federal Outer Continental Shelf off of Florida's western coast.

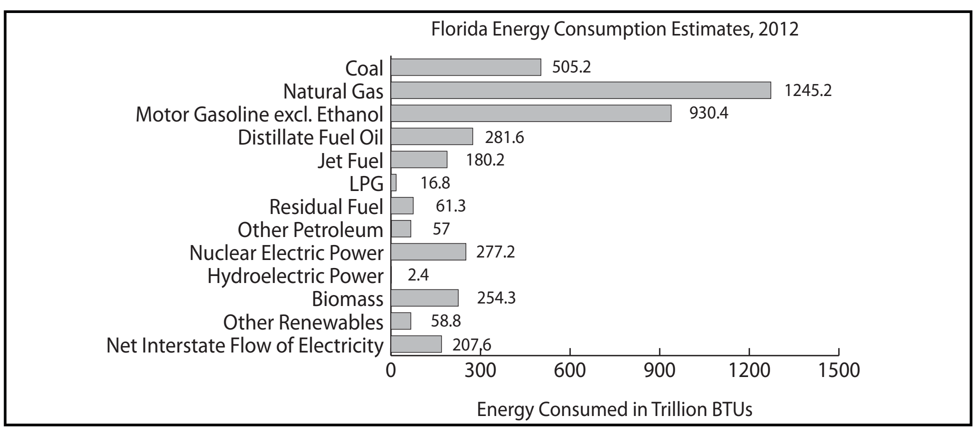
- Electricity accounts for 90% of the site energy consumed by Florida households, and the annual electricity expenditures of $1900 are 40% higher than the US average, according to EIA's Residential Energy Consumption Survey.

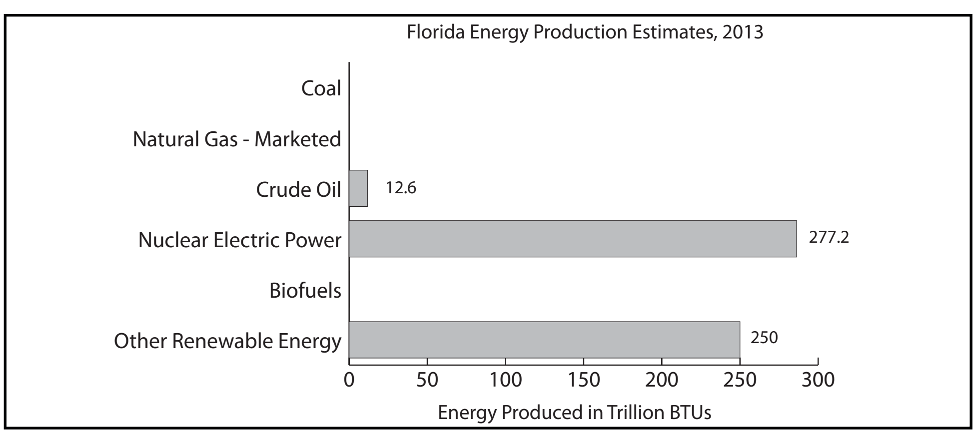
- A Florida facility using a gas fermentation process to produce an estimated 30 million liters (8 million gallons) of cellulosic ethanol from citrus fruit, vegetable, and yard wastes began commercial-scale production in 2013.

- Florida was second only to Texas in 2014 in net electricity generation from natural gas, which accounted for 61% of Florida's net generation; coal accounted for almost 23%, the state's nuclear power plants accounted for 12%, and other resources, including renewable energy, supplied the remaining electricity generation.

- Renewable energy accounted for 2.3% of Florida's total net electricity generation in 2014, and the state ranked 10th in the nation in net generation from utility-scale solar energy.

- In part because of high air conditioning use during the hot summer months and the widespread use of electricity for home heating during the winter months, Florida's retail electricity sales to the residential sector were second in the nation after Texas in 2014.





Georgia

- The Elba Island, Georgia, liquefied natural gas receiving terminal has a peak capacity of 51 million cubic meters (1.8 billion cubic feet) of gas per day, a storage capacity of 330 million cubic meters (11.5 billion cubic feet) of gas, and is pursuing the addition of export facilities.

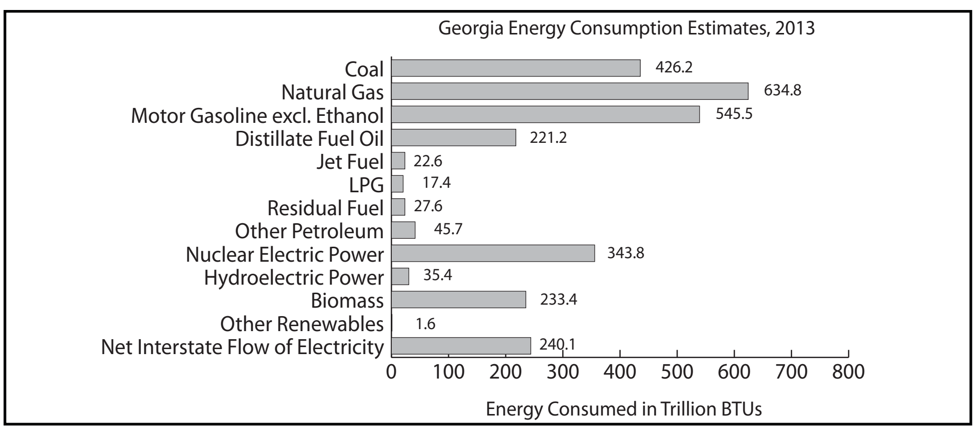
- Georgia is one of the few states where at least 30% of household energy consumption is used for space heating and at least 10% of the energy consumed in homes is used for air conditioning (compared to the national average of 41% for heating and 6% for air conditioning), according to EIA's Residential Energy Consumption Survey.

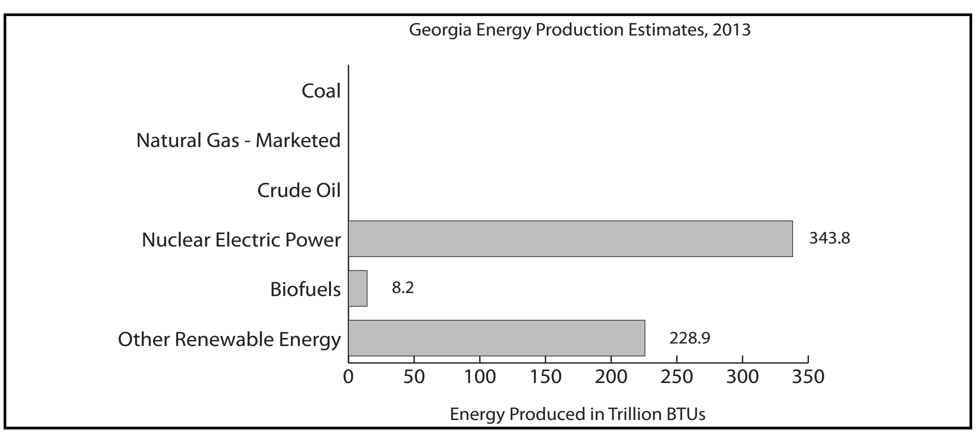
- In February 2012, the Nuclear Regulatory Commission approved the construction of two new nuclear reactors at the Vogtle nuclear power plant in Burke County, Georgia. The anticipated startup dates for the two reactors are in 2019 and 2020.

- Georgia's four existing nuclear reactor units accounted for 26% of the state's net electricity generation in 2014, coal accounted for 36%, natural gas accounted for 32%, and renewable energy, including hydroelectric power, contributed 6%.

- Georgia is heavily forested and has been a leading state in the production of lumber and pulpwood, which contribute feedstock for biomass electricity generation. In 2014, Georgia ranked third in the nation in net electricity generation from biomass.

- In 2014, Georgia ranked 10th in the nation in net electricity generation and 8th in retail sales of electricity.





6 Energy

State Facts

Kentucky

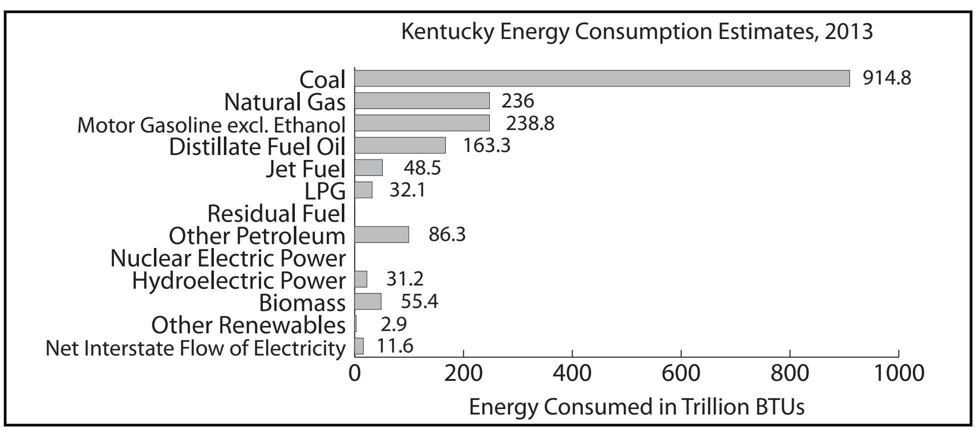
- Most of Kentucky's natural gas comes from the Big Sandy field located in the eastern part of the state. Big Sandy is the largest natural gas field in the Appalachian Basin.

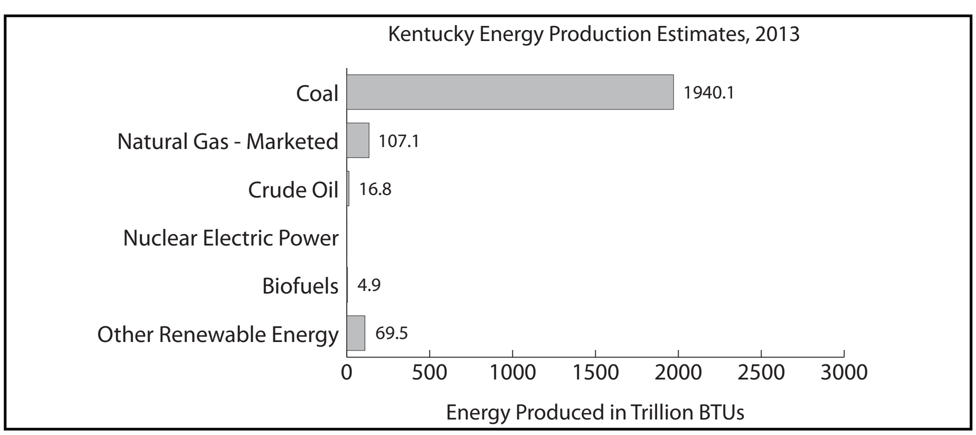
- Three of Kentucky's electric power plants—Paradise, Trimble County, and Ghent—are included on the 2012 list of the 100 largest US power plants by net summer capacity.

- Kentucky was the third largest coal-producing state in 2013. Kentucky's output of 80 million tons of coal accounted for 8.2% of total US coal production.

- Coal fueled 92% of Kentucky's net electricity generation in 2014.

- In 2014, Kentucky had two oil refineries with a combined operating capacity of about 247,500 barrels per calendar day.





Mississippi

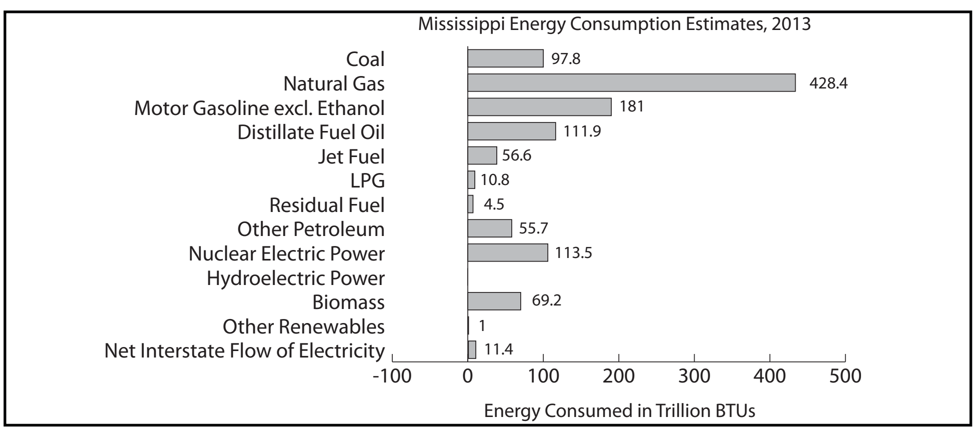
- Mississippi's one ethanol plant can produce 204 million liters (54 million gallons) of biofuel annually, equal to nearly 0.4% of total US ethanol production capacity.

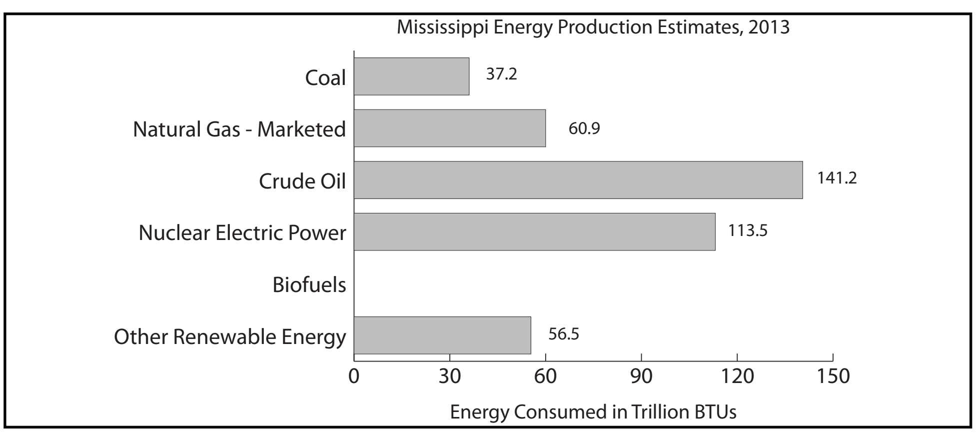
- The Gulf Liquefied Natural Gas terminal at Pascagoula, Mississippi was designed to send imported natural gas by pipeline to users throughout the South. Plans to add liquefaction and export capabilities are being pursued.

- As of January 2014, the Pascagoula oil refinery and a Texas refinery were tied for the 10th-largest refinery by capacity in the United States. The Pascagoula refinery is able to process 330,000 barrels of crude oil per calendar day.

- The 1251 MW Grand Gulf nuclear power plant, near Port Gibson along the Mississippi River, generated nearly 19% of Mississippi's electricity in 2014.

- Mississippi generated 2.7% of its electricity from renewable energy resources during 2014, with wood and wood waste accounting for almost all of the state’s renewable electricity generation.



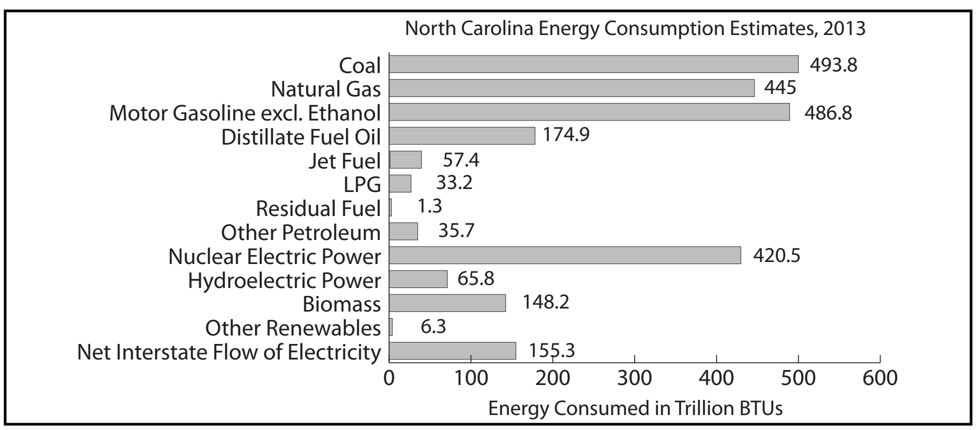


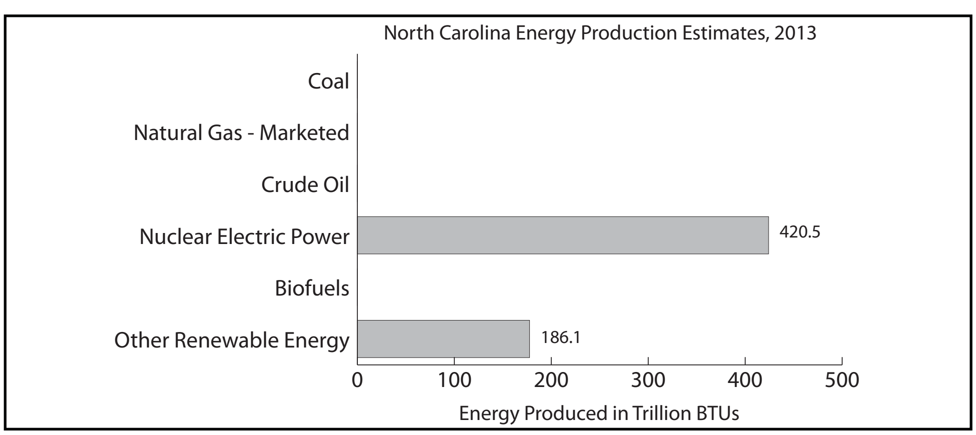
6 Energy

State Facts

North Carolina

- The Dixie Pipeline transports propane from Texas, Louisiana, and Mississippi to customers throughout the Southeast and terminates in Apex, North Carolina.
- Of the 737 public and private-access biodiesel fueling stations nationwide, more than 18% are in North Carolina.
- North Carolina ranked sixth in the nation in net electricity generation from nuclear power in 2014, producing 5.1% of the nation's total.
- More than a third of North Carolina's net electricity generation—38.7% in 2014—comes from coal shipped by rail and truck, primarily from West Virginia, Kentucky, and Pennsylvania.
- In 2014, 6.6% of North Carolina's utility-scale net electricity generation came from renewable energy resources, all of which came from conventional hydroelectric power, biomass, and solar energy.





South Carolina

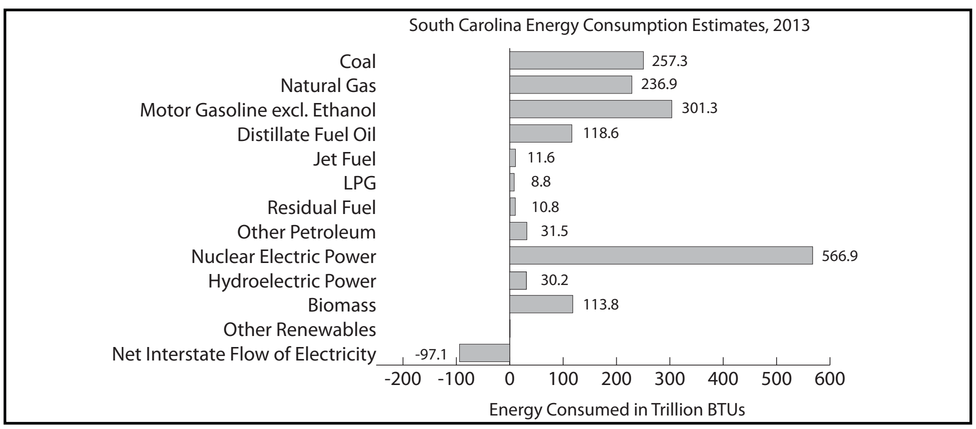
- South Carolina's electric power sector received 34% of its domestic coal deliveries from Kentucky and 29% from Pennsylvania in 2013.

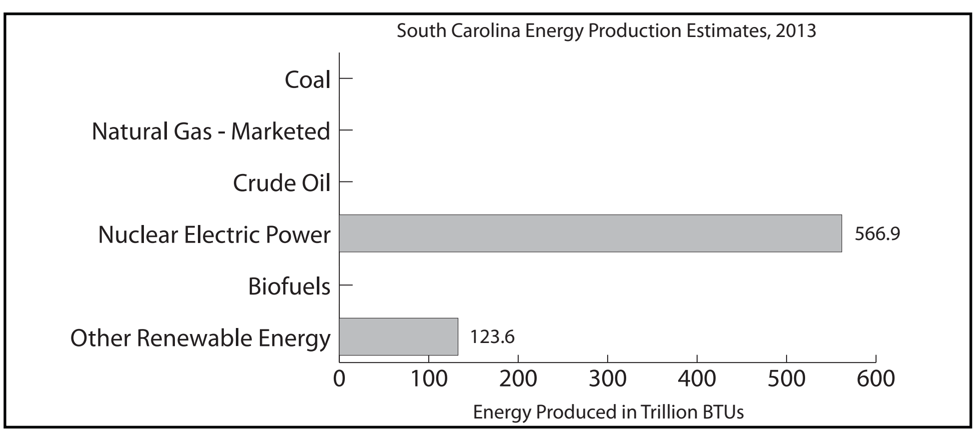
- In 2013, renewable energy resources accounted for 5% of South Carolina's net electricity generation; almost 59% of that generation came from conventional hydroelectric power.

- In 2014, South Carolina was eighth in the nation in per capita retail electricity sales, in part because of high air conditioning demand during the hot summer months and the widespread use of electricity for home heating in winter.

- South Carolina's four existing nuclear power plants supplied 54% of the state's net electricity generation in 2014. Two new reactors are under construction at the V.C. Summer Nuclear Station site in Fairfield County.

- South Carolina enacted a renewable portfolio standard in 2014 authorizing the creation of distributed energy resource programs to encourage the development of in-state renewable energy generation capacity.





6 Energy

State Facts

Tennessee

- Average site electricity consumption for Tennessee households is 33% higher than the national average and is among the highest in the nation. Spending for electricity is closer to the US average because of relatively low electricity prices, according to EIA's Residential Energy Consumption Survey.

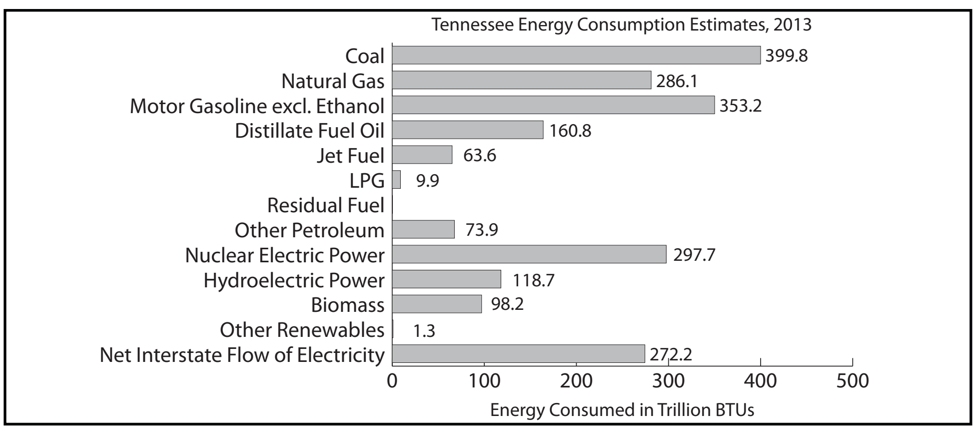
- The newest nuclear reactor in the United States, the single unit at the Watts Bar 1 nuclear power plant, began operating in 1996. Watts Bar 2 is scheduled to be the next US reactor to come online in late 2015.

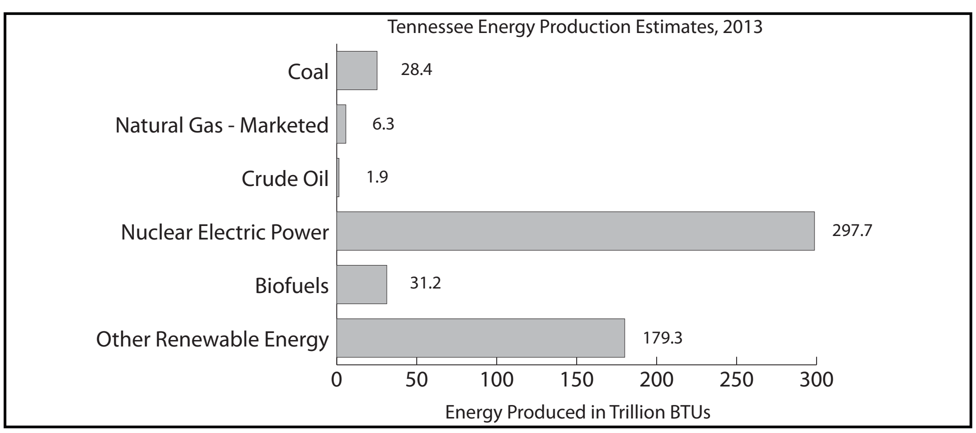
- The Southeast's first major wind farm, located on Tennessee's Buffalo Mountain near Oliver Springs, began operating as a 2 MW facility in 2000. The wind farm's generating capacity has been expanded to 29 MW.

- In 2013, Tennessee ranked among the lowest ten producing states for both crude oil and marketed natural gas production, while coal production ranked fourth from the bottom among the 25 coal-producing states. Exploration for additional oil and natural gas resources is occurring in the Chattanooga shale in the eastern part of the state.

- At 9.6 million MWh in 2014, Tennessee's net electricity generation from hydroelectric power was the third highest of states east of the Mississippi River.

- The largest single solar installation at a US automotive manufacturing facility, and the largest solar installation in Tennessee at 9.5 MW, began operations in Chattanooga, Tennessee in 2013.





Energy

6

State Facts

Virginia

- For Virginia households, average site electricity consumption (14 MWh per year) and costs ($1584 per year) are higher than the national average but similar to those in neighboring states, where electricity is the most common heating fuel, according to EIA's Residential Energy Consumption Survey.

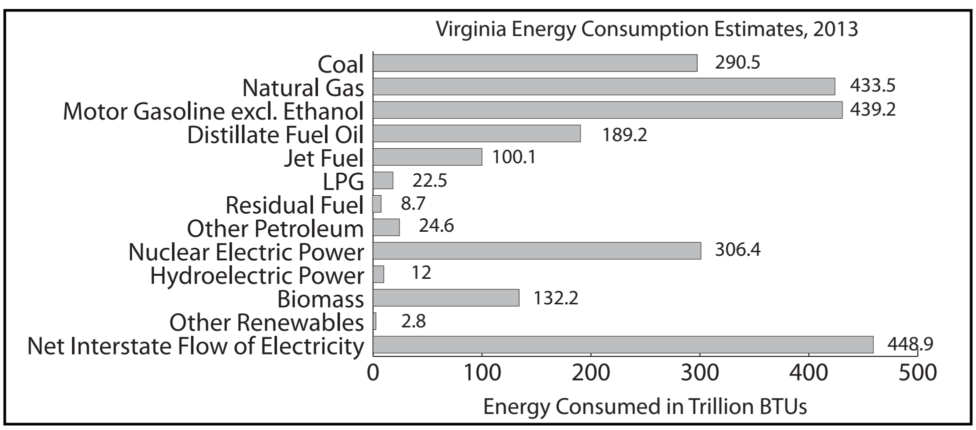
- Based on proved reserves, two of Virginia's natural gas fields were ranked among the top 100 natural gas fields in the US at the end of 2013. Virginia also ranked fourth among the states in coalbed methane proved reserves at the end of 2013.

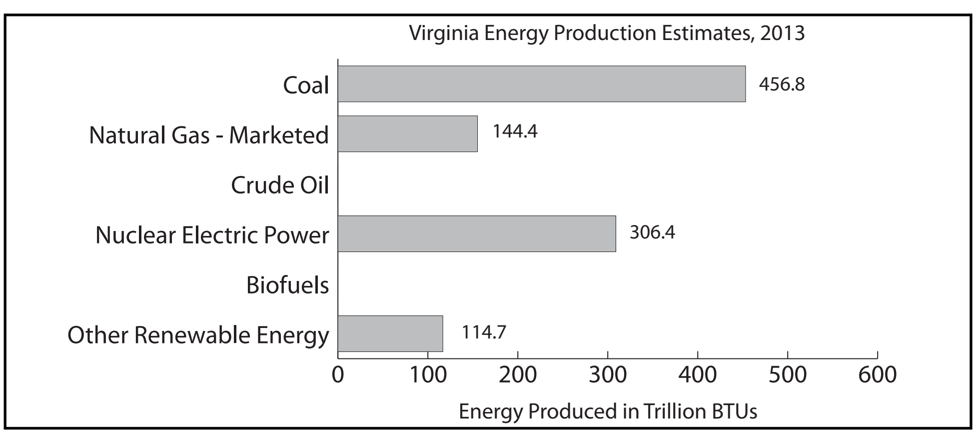
- Virginia accounted for 4.1% of US coal production east of the Mississippi River in 2013. The ports in the Norfolk Customs District—America's largest coal export center—processed more than 42% of US coal exports in 2014.

- Virginia established a voluntary renewable portfolio standard to encourage investor-owned utilities to procure a portion of the electricity sold in Virginia from renewable energy resources. In 2014, 6.5% of the state's net electricity generation came from renewable energy, three-fourths of which was biomass.

- Virginia's two nuclear power plants provided 39% of the state's net electricity generation in 2014.

- In 2015, the Virginia Department of Mines, Minerals, and Energy received the first federal offshore wind energy research lease issued by the US Bureau of Ocean Energy Management.





6 Energy

State Facts

West Virginia

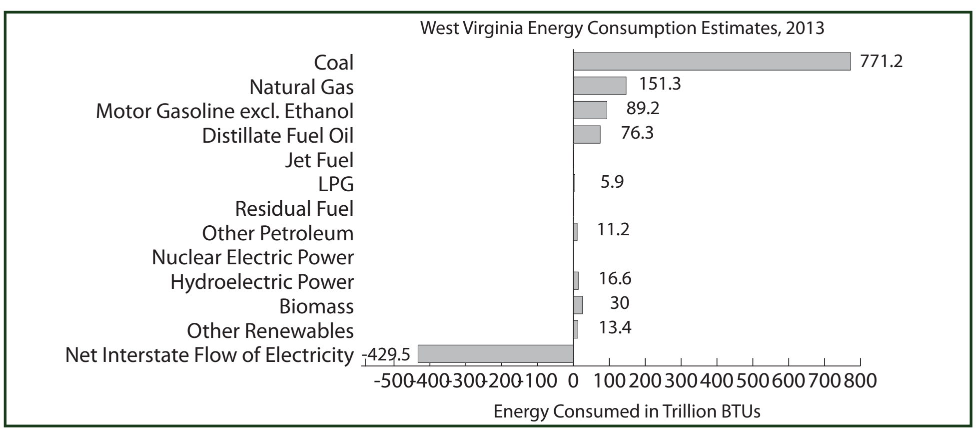
- West Virginia typically generates more electricity than it consumes.

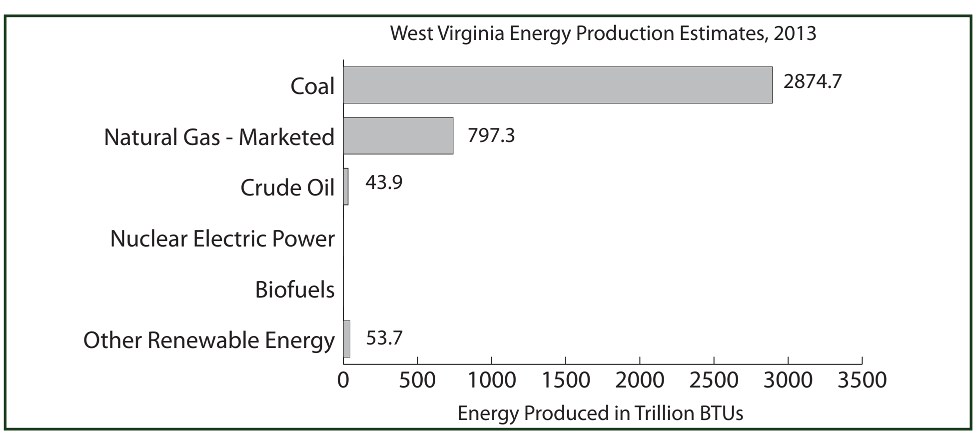
- West Virginia ranked fifth in the nation in total energy production in 2012, producing 4.7% of the nation's total.

- In 2012, West Virginia was the largest coal producer east of the Mississippi River and the second largest in the nation after Wyoming; the state accounted for 12% of the US total coal production that year.

- In 2013, 44% (51 million tons) of the coal that was mined in West Virginia was shipped to other states, and 33% (38 million tons) was exported to foreign countries.

- Coal-fired electric power plants accounted for 95.5% of West Virginia's net electricity generation in 2014, and renewable energy resources—primarily hydroelectric power and wind energy—contributed 3.5%.





Energy and Climate Change
The Future of Energy in the US

Americans have come to rely on a diverse and abundant energy system, one that provides a continuous supply of energy with few interruptions. However, **climate change** is projected to play a big part in altering our supply, production, and demand for energy. Increases in temperatures will be accompanied by an increase in energy for cooling, while projected increases in the occurrence of **hurricanes**, floods, **tornados**, and other extreme weather events will continue to have a significant effect on the infrastructure of power grids and energy delivery systems. Drought and water shortages are already affecting energy production and supply. For example, in the Northeast, mild winter temperatures prior to the winter of 2013–2014 had decreased energy demands for heat, but they did not fully offset increased demands for cooling, and the regionally harsher winter of 2013–2014 saw increased demands for heating fuels. These types of disruptions affect us both locally and nationally, are diverse in nature, and will require equally diverse solutions.

See Chapter 8: Climate for more information about climate change and its effects on the Southeast.

Energy is a **commodity**, and supply and demand around the world will also affect the US energy system. As the global population grows, and industrialization of the world continues, demand for energy will increase even further as resources are depleted. These factors can significantly affect US energy costs through competition for imported and exported energy products. Mediation of our energy production could have a huge positive impact on climate change. Unfortunately, there is no energy production system or source currently available that is truly **sustainable**. All forms of energy have negative impacts on the environment, as do many of the ways in which we use them.

Until we have a sustainable means of producing and delivering energy, we need to consider which means of energy production and transport make the least impact; we are faced with a sort of "energy triage." The answer to this problem will be multifaceted, depending in large part on which energy resources and delivery methods are available in each part of the US. The sources of energy that provide the least impact for the best price for people living in the Southeast are probably not the same as for those in other areas, such as the Southwest or Northeast.

Adaptation—changing our habits of energy use and delivery—can also make it easier for our existing energy infrastructure to adjust to the needs brought on by climate change. Investing in adaptation can pay off in the short term by reducing risks and vulnerabilities, thus minimizing future risks. Increasing sustainable energy practices (including harvesting and production) and improving infrastructure and delivery methods can go a long way toward not only decreasing the effects of climate change, but also our energy security.

climate change • *See global warming: the current increase in the average temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere.*

hurricane • *a rapidly rotating storm system with heavy winds, a low-pressure center, and a spiral arrangement of thunderstorms.*

tornado • *a vertical funnel-shaped storm with a visible horizontal rotation.*

commodity • *a good for which there is demand, but which is treated as equivalent across all markets, no matter who produces it.*

sustainable • *able to be maintained at a steady level without exhausting natural resources or causing severe ecological damage, as in a behavior or practice.*

efficiency • *the use of a relatively small amount of energy for a given task, purpose, or service; achieving a specific output with less energy input.*

Some of these changes are grounded in the development of new technologies for energy production and energy **efficiency**, while others may be related to changes in behavior. These changes in technology and behavior may go hand in hand; roughly 2% of electricity production now goes to data centers, for example—a use that did not exist in 1985. Additionally, the Internet is rapidly changing other ways we use energy, allowing us to telecommute and changing the way we shop.

In closing, some key points to keep in mind regarding the future of energy are:

1. Extreme weather events are affecting energy production and delivery facilities, causing supply disruptions of varying lengths and magnitudes and affecting other infrastructure that depends on energy supply. The frequency and intensity of extreme weather events are expected to increase.

See Chapter 9: Earth Hazards to learn more about extreme weather events.

2. Higher summer temperatures are likely to increase electricity use, causing higher summer peak loads, while warmer winters are likely to decrease energy demands for heating. Net energy use is projected to increase as rising demands for cooling outpace declining heating energy demands.

3. Both episodic and long-lasting changes in water availability will constrain different forms of energy production.

4. In the longer term, sea level rise will affect the coastal facilities and infrastructure on which many energy systems, markets, and consumers depend.

5. As we invest in new energy technologies, future energy systems will differ from those of the present in uncertain ways. Depending on the way in which our energy system changes, climate change will introduce both new risks and new opportunities.

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Chapter 7:
Soils of the Southeastern US

It's sometimes easy to take the soil beneath our feet for granted. Yet soil has always been with us—it is the foundation of our houses and roads, and from the soil comes our food, fiber, and paper. Soil is the interface between living earth and solid rock, between biology and geology. The engineer, the scientist, and the gardener may all look at the soil beneath them in different ways, but perhaps no one has a more integral relationship with soil than a farmer. The economic success of producing crops is intimately tied to the quality of the soil upon which those crops grow, and the most successful farmers are well versed in the science of their soil. Soils store and purify water, and they exchange gases with the **atmosphere**. They support agriculture and natural ecosystems and provide a grassy surface for our parks and fodder for our gardens. Everyone, everywhere, every day, depends upon the soil.

What is Soil?

Generally, **soil** refers to the top layer of earth—the loose surface of earth as distinguished from rock—where vegetation grows. The word is derived (through Old French) from the Latin *solum*, which means "floor" or "ground." Soil is one of the most important resources we have—the most basic resource upon which all terrestrial life depends. The Southeast has a wide variety of soils, and each type of soil has a story to tell of its origin.

Soils form from the top down, and typically reach a depth of about one meter (3.3 feet) at their more developed stages, although some can reach much deeper. Soils are composed of a mixture of two key ingredients. The first is plant litter, such as dead grasses, leaves, and fallen debris. Worms, bacteria, and fungi do the job of breaking these down into nutritious organic matter that helps soil to nourish future plant growth. The second important component of soil is sediment derived from the **weathering** of rock that is then transported by **wind**, water, or gravity. Both of these components influence the texture (*Figure 7.1*) and consistency of the soil, as well as the **minerals** available for consumption by plants.

All soils might seem alike, but there can be vast differences in soil properties even within small areas! A single acre may contain several different soil types, each with its own assets and drawbacks. Some types of soil are clayey or prone to flooding, while others are stable enough to be used as a foundation for buildings. The most identifiable physical properties of soils are texture, structure, and **color**, which provide the basis for distinguishing soil **horizons**. Texture refers to the percentage of sand, silt, and clay that makes up the soil. Soil textures have specific names, as indicated in *Figure 7.1*.

atmosphere • *a layer of gases surrounding a planet.*

soil • *the collection of natural materials that collect on Earth's surface, above the bedrock.*

weathering • *the breakdown of rocks by physical or chemical means.*

wind • *the movement of air from areas of high pressure to areas of low pressure.*

mineral • *a naturally occurring solid with a specific chemical composition and crystalline structure.*

horizon • *a layer in the soil, usually parallel to the surface, which has physical characteristcs (usually color and texture) that are different from the layers above and below it.*

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7 Soils

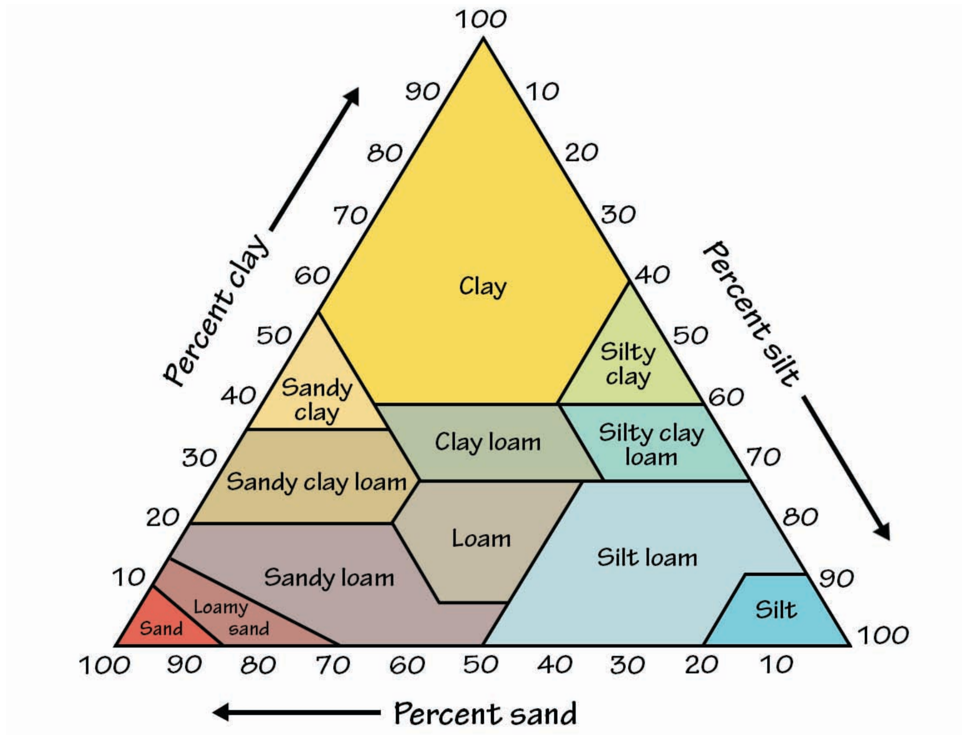


Figure 7.1: Soil texture triangle.

Generally, the best agricultural soils are those with about equal amounts of **clay**, **silt**, and **sand**. A soil of that type is called a **loam**. Soils that are mostly sand do not hold water very well and dry quickly, while soils with too much clay may never dry out. Soil structure refers to the way the soil forms clumps, known as **peds**. Peds are identified by the shape of the soil clods, which take the form of balls, blocks, columns, and plates. These structures are easiest to see in recently plowed fields, where the soil is often granular and loose or lumpy. Soil color is its most obvious physical property. The color is influenced by mineral content, the amount of organic material, and the amount of water it routinely holds. The colors are identified by a standard soil color chart called the Munsell chart.

Five main variables affect the characteristics of soil worldwide. In the Southeast, all soils are the products of subtle differences among these five factors:

1. *Parent material* is the original geologic material from which the soil formed. This can be bedrock, preexisting soils, or other materials such as **till**, **loess**, and rock fragments.

2. *Climate* strongly determines the temperature regime, amount of moisture, and type of **biota** that interact with the **parent material**. This affects the extent of chemical and physical weathering on the soil-forming material. For example, if a particular **climate** lacks precipitation, mechanical weathering from wind or ice fracturing will predominate.

Review

clay • *the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.*

silt • *fine granular sediment most commonly composed of quartz and feldspar crystals.*

sand • *rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

loam • *a soil containing equal amounts of clay, silt, and sand.*

till • *unconsolidated sediment that is eroded from the bedrock, then carried and eventually deposited by glaciers as they recede.*

loess • *very fine grained, wind-blown sediment, usually rock flour left behind by the grinding action of flowing glaciers.*

biota • *the organisms living in a given region, including plants, animals, fungi, protists, and bacteria.*

If, however, a climate has abundant precipitation, chemical **erosion** from water will be accelerated, resulting in substantial leaching.

3. *Topography*, or landscape, of the area is related to the relative position of the soil on the landscape. This includes the presence or absence of hills and the slopes between high and low areas. As the slope increases, water can carry larger sediment sizes, allowing for large sediment loads during major precipitation events. **Topography** also influences natural drainage. Gravity moves water down slopes to depressions or streams and pulls free water downward through the soil. Soils on hills tend to be dry, and soils in depressions and valleys are often wet or saturated. Areas with steep slopes that are susceptible to frequent erosion typically have very young soils, as they do not have long to develop before the ingredients are rearranged and the clock is reset. Flatter, more arid areas may have more time to develop, but they have significantly less plant life and will produce a very different soil than will a wetter environment. Slope also frequently determines the types of vegetation covering a soil—for example, different slopes on the same hill might receive varying amounts of sunlight during the growing season—which in turn can cause the characteristics of the soils to diverge if differing forms of vegetation dominate opposite slopes.

4. *Biota or living organisms* that live on or in the material affect soil development through their influence on the amount and distribution of organic matter in the soil. For example, plants contribute significantly to the formation of **humus**, and animals alter a soil's characteristics by leaving behind decayed remains and wastes. Decomposers like bacteria and fungi help to free up the nutrients locked away in these remains and wastes, and these freed nutrients are then recycled and used by new life forms within the same soil. In fact, more than 90% of the nutrients used by a forest in a given year are derived from the decomposition of old organic matter fallen to the forest floor. Animal burrows also create spaces in the soil horizons that allow for deeper penetration of air and water, which, in turn, aid plant development by helping to dissolve mineral nutrients into a form that plants can absorb and process. For its part, organic matter impacts the water-holding capacity of the soil, the soil's fertility, and root penetration.

5. *Time* is required for soils to develop while the four elements mentioned above interact. Older soils have deeper and thicker **subsoils** than do younger soils, but only if other soil forming factors remain constant. For example, it takes approximately 500 years to generate 2.5 centimeters (1 inch) of new **topsoil** beneath grass or forest—but it only takes a few years for erosion and weathering to destroy the same amount of unprotected topsoil.

Several types of **chemical reactions** are important for soil development; of these, acid-base reactions are some of the most important and complex. When carbon dioxide (CO_2) dissolves in water it forms weak carbonic acid. CO_2 found

Review

parent material • *the original geologic material from which soil formed.*

climate • *a description of the average temperature, range of temperature, humidity, precipitation, and other atmospheric/hydrospheric conditions a region experiences over a period of many years (usually more than 30).*

erosion • *the transport of weathered materials.*

humus • *a soil horizon containing organic matter.*

subsoil • *the layer of soil beneath the topsoil, composed of sand, silt and/or clay.*

topsoil • *the surface or upper layer of soil, as distinct from the subsoil, and usually containing organic matter.*

chemical reaction • *a process that involves changes in the structure and energy content of atoms, molecules, or ions but not their nuclei.*

in soil water can come from the atmosphere, where it dissolves in rainwater. Even more CO_2 usually comes from the soil itself, where it is produced by respiring organisms. The amount of CO_2 in soil gases can easily reach levels ten times higher than the amount found in the atmosphere (over 4000 ppm in soil vs. 400 ppm in the atmosphere), making soil water potentially more acidic than rainwater. As this acidic water slowly reacts with fresh minerals, it buffers the soil's pH and keeps it in a range (6–8) preferred by many organisms. Acid-driven weathering breaks down the soil's primary **igneous** minerals, typically transforming them to **silica**-rich clays. As the soil's primary minerals are depleted, it loses the ability to buffer acidity, and the pH of highly weathered soil can drop to around 4. These weathered soils tend to be rich in **aluminum**, **iron**, and **titanium**.

In highly weathered settings, soil loses most of its nutrients, and the store of nutrients that remains is mostly found in organic matter. In weathered soils, only the top 25 centimeters (10 inches) or so may be very biologically active, and rooting depths are very shallow. If this thin layer is lost to erosion, the underlying mineral soil may be infertile and incapable of rapid recovery.

Soil Orders

Just as rocks are classified into different types based on how they formed (igneous, **metamorphic**, or **sedimentary**), their mineral composition, and other characteristics, soils also have their own classification scheme. Soil develops in horizons, or layers, whose formation is dependent on the available ingredients, environmental conditions, and the time it takes to mature. Since the organic and chemical processes that form soils first impact the top of the soil column and then work their way downward, horizontal layers of soil with different characteristics are formed, resulting in divergent colors, textures, and compositions.

A vertical cross-section of all the horizons or layers of soil present in a given area is referred to as a soil profile. Some horizons are completely absent in certain profiles while others are common to most. Each horizon corresponds to a stage in the weathering of rock and decay of plant matter, and each is found at a specific position beneath the surface (*Figure 7.2*). The *O horizon* at the top of the profile contains partially decayed plant material and transitions down to the *A horizon*, which contains mineral matter with a mix of humus and is commonly referred to as topsoil. Below the A horizon lies the *B horizon* or subsoil, which contains mineral material that has leached from above. The *C horizon* at the base of the soil profile contains partially altered parent material.

Soils can also be categorized by their location (northern vs. southern soils), the type of vegetation growing on them (forest soils vs. desert soils), their topographic position (hilltop soils vs. valley soils), or other distinguishing features. The system used to classify soils based on their properties is called **soil taxonomy** *(Figure 7.3)*, and it was developed by the United States Department of Agriculture (USDA) with the help of soil scientists from across the country. It provides a convenient, uniform, and detailed classification of soils throughout the US (*Figure 7.4*), allowing for an easier understanding of how and why different regions have developed unique soils.

igneous rocks • *rocks derived from the cooling of magma underground or molten lava on the Earth's surface.*

silica • *a chemical compound also known as silicon dioxide (SiO_2).*

aluminum • *a metallic chemical element (Al), and the most abundant metal in the Earth's crust.*

iron • *a metallic chemical element (Fe).*

titanium • *a metallic chemical element (Ti) that is important because of its lightweight nature, strength and resistance to corrosion.*

metamorphic rocks • *rocks formed by the recrystallization and realignment of minerals in pre-existing sedimentary, igneous, and metamorphic rocks when exposed to high enough temperature and/or pressure.*

sedimentary rock • *rock formed through the accumulation and consolidation of grains of broken rock, crystals, skeletal fragments, and organic matter.*

Soil Orders

soil taxonomy • *the system used to classify soils based on their properties.*

soil orders • *the twelve major units of soil taxonomy, which are defined by diagnostic horizons, composition, soil structures, and other characteristics.*

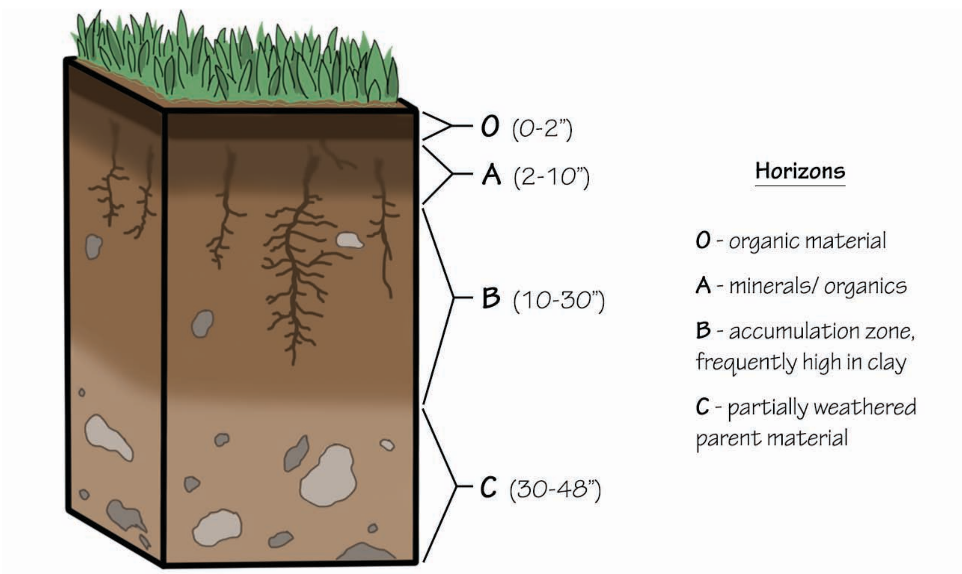


Figure 7.2: A typical soil profile shows the transition from the parent material (C horizon) to the highly developed or changed horizons (O through B). Not every soil profile will have all the horizons present.

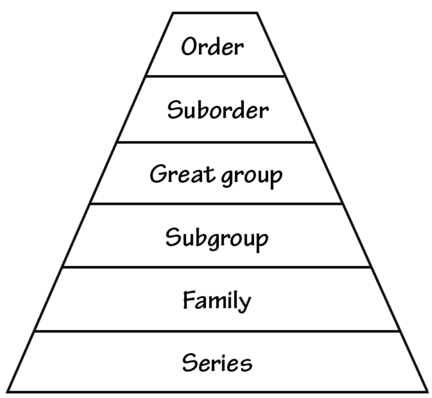


Figure 7.3: Soil taxonomy.

In soil taxonomy, all soils are arranged into one of 12 major units, or **soil orders**. These 12 orders are defined by diagnostic horizons, composition, soil structures, and other characteristics. Soil orders depend mainly on climate, parent material, and the organisms within the soil. These orders are further broken down into 64 suborders based on properties that influence soil development and plant growth, with the most important property being how wet the soil is throughout the year. The suborders are, in turn, separated into great groups (300+) and subgroups (2400+). Similar soils within a subgroup are grouped into even more selective families (7500+), and similar soils within families are grouped together into the most exclusive category of all: a series. There are more than 19,000 soil series described in the United States, with more being defined every year.

7 Soils

Soil Orders

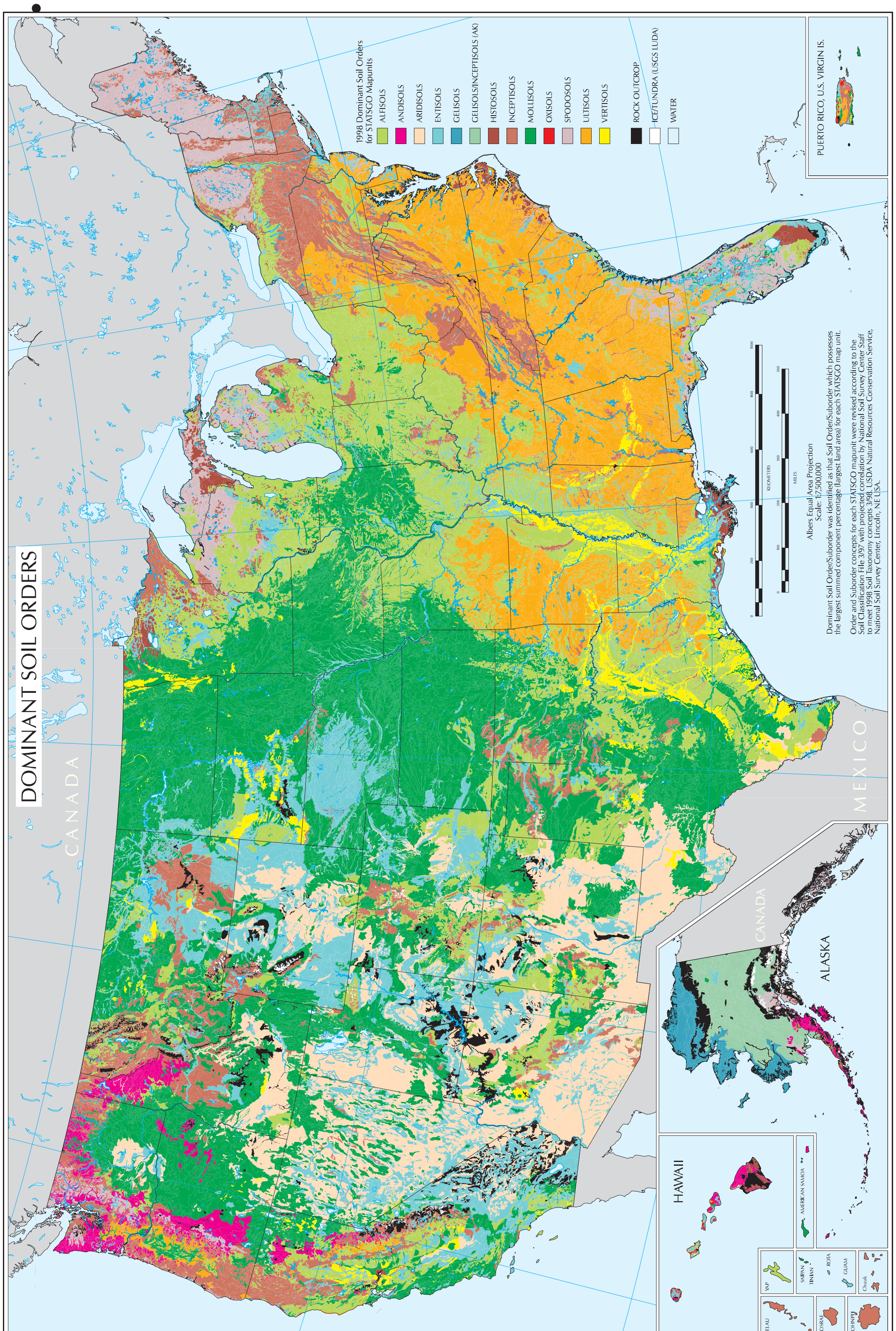


Figure 7.4: Dominant soil orders of the United States. (See TFG website for full-color version.)

The 12 soil orders

Name	Description	Controlling Factors	Percentage of global ice-free land surface	Percentage of US ice-free land surface
Alfisols	Highly fertile and productive agricultural soils in which clays often accumulate below the surface. Found in humid and subhumid climates.	climate and organisms	~10%	~14%
Andisols	Often formed in volcanic materials, these highly productive soils possess very high water- and nutrient-holding capabilities. Commonly found in cool areas with moderate to high levels of precipitation.	parent material	~1%	~2%
Aridisols	Soils formed in very dry (arid) climates. The lack of moisture restricts weathering and leaching, resulting in both the accumulation of salts and limited subsurface development. Commonly found in deserts.	climate	~12%	~8%

Soil Orders

Entisols	Soils of relatively recent origin with little or no horizon development. Commonly found in areas where erosion or deposition rates outpace rates of soil development, such as flood-plains, mountains, and badland areas.	time and topography	~16%	~12%
Gelisols	Weakly weathered soils formed in areas that contain permafrost within the soil profile.	climate	~9%	~9%
Histosols	Organic-rich soils found along lake coastal areas where poor drainage creates conditions of slow decomposition and peat (or muck) accumulates.	topography	~1%	~2%
Inceptisols	Soils that exhibit only moderate weathering and development. Often found on steep (relatively young) topography and overlying erosion-resistant bedrock.	time and climate	~17%	~10%
Mollisols	Agricultural soils made highly productive due to a very fertile, organic-rich surface layer.	climate and organisms	~7%	~22%

Oxisols	Very old, extremely leached and weathered soils with a subsurface accumulation of iron and aluminum oxides. Commonly found in humid, tropical environments.	climate and time	~8%	~.02%
Spodosols	Acidic soils in which aluminum and iron oxides accumulate below the surface. They typically form under pine vegetation and sandy parent material.	parent material, climate, and organisms	~4%	~4%
Ultisols	Soils with subsurface clay accumulations that possess low native fertility and are often red hued (due to the presence of iron oxides). Found in humid tropical and subtropical climates.	climate, time, and organisms	~8%	~9%
Vertisols	Clayey soils with high shrink/swell capacity. During dry periods, these soils shrink and develop wide cracks; during wet periods, they swell with moisture.	parent material	~2%	~2%

7 Soils

Soil Orders

floodplain • *the land around a river that is prone to flooding.*

peat • *an accumulation of partially decayed plant matter.*

conifer • *a woody plant bearing cones that contain its seeds.*

kaolinite • *a silicate clay mineral, also known as china clay.*

Dominant Soils of the Southeast

The Southeastern US contains a diverse variety of soils, and 8 of the 12 soil orders are present there.

Alfisols are partially leached soils with a high degree of fertility in which clays often accumulate below the surface. They tend to develop in cooler, more forested environments, and commonly form a band separating humid areas from more arid areas. Alfisols are found widely distributed throughout the Southeast, and they form a belt that extends along the Mississippi River and through Kentucky (*Figure 7.5*).

Entisols are soils of recent origin with poorly developed horizons, typically formed near **floodplains**. Entisols are common in the Coastal Plain region (where young, unconsolidated sediments dominate) as well as along streams and river valleys throughout the Southeast (*Figure 7.6*).

Inceptisols are soils with poorly developed horizons that are associated with steep slopes and erosion-resistant parent material. They are widely distributed in the Southeast, but are heavily concentrated in the Blue Ridge and Piedmont region where the landscape is typical for the development of this soil type. (*Figure 7.7*)

Histosols are carbon-rich soils, where half or more of the upper 80 centimeters (32 inches) is organic. They contain high concentrations of organic matter, due to their development in wetland environments with poor drainage and a slow rate of decomposition. They are saturated year round, and are often called bogs, moors, **peats**, or mucks. They are mainly associated with bogs and mucks in Florida and along the North Carolina coast (*Figure 7.8*).

Mollisols are the dominant soils of grasslands. The thick, black A horizon makes these soils extremely productive and valuable to agriculture. While these soils are extensive in the Great Plains of the Midwest, in the Southeast they are found only in Florida and a few other rare locations (*Figure 7.9*).

Spodosols are acidic soils with an accumulation of iron and aluminum in the humus. These soils support cool, moist **coniferous** stands of forest and are found primarily in Florida and along the Atlantic Coastal Plain (*Figure 7.10*).

Ultisols are weathered soils rich in the clay mineral **kaolinite.** They form in warm, humid climates with distinctive wet-dry seasons. Although they have low native fertility, they can become highly productive agricultural soils with the proper use of fertilizer. Ultisols are the most common soil in the Southeast and often support forest vegetation (*Figure 7.11*).

Vertisols are very dark soils, rich in swelling clays. Their distinguishing feature is that they form deeply cracked surfaces during dry periods, but swell again in the wet season, sealing all the cracks. As a result, they are very difficult soils to build roads or other structures on. These soils are most commonly associated with the Black Belt agricultural region in Alabama and Mississippi, and with the Mississippi River Valley (*Figure 7.12*).

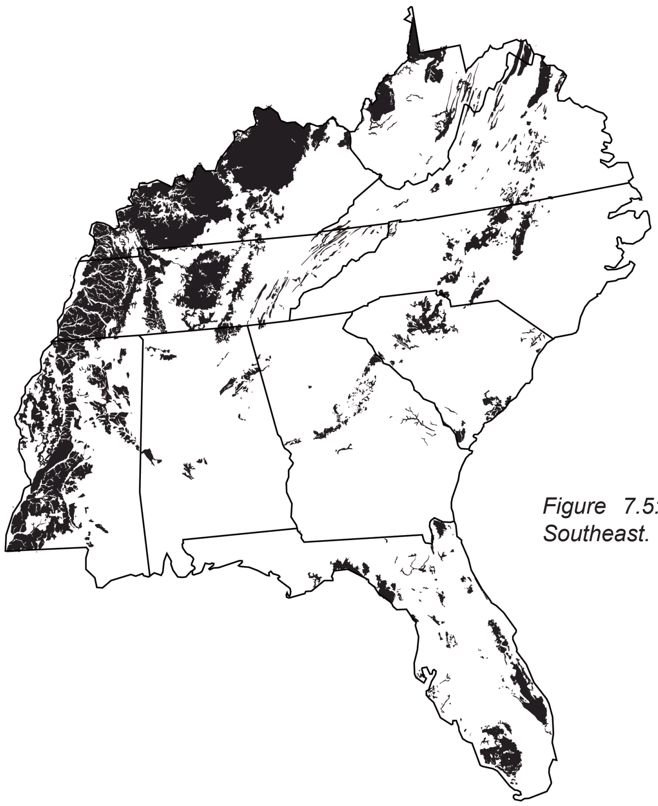


Figure 7.5: Alfisols of the Southeast.

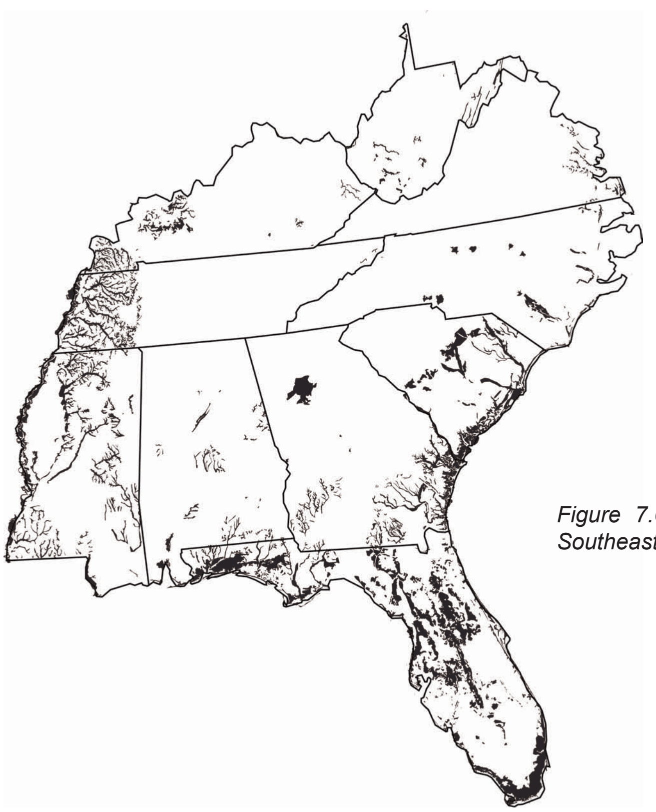


Figure 7.6: Entisols of the Southeast.

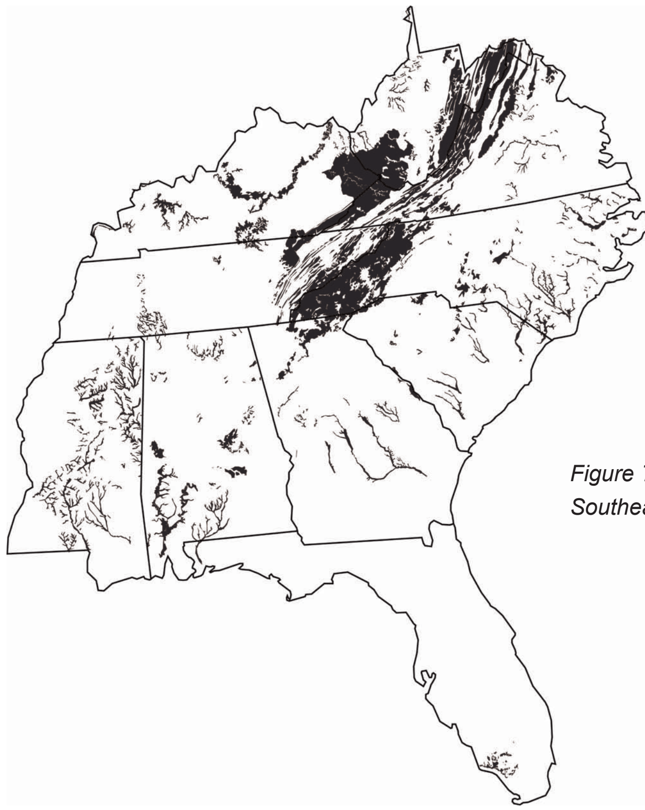


Figure 7.7: Inceptisols of the Southeast.

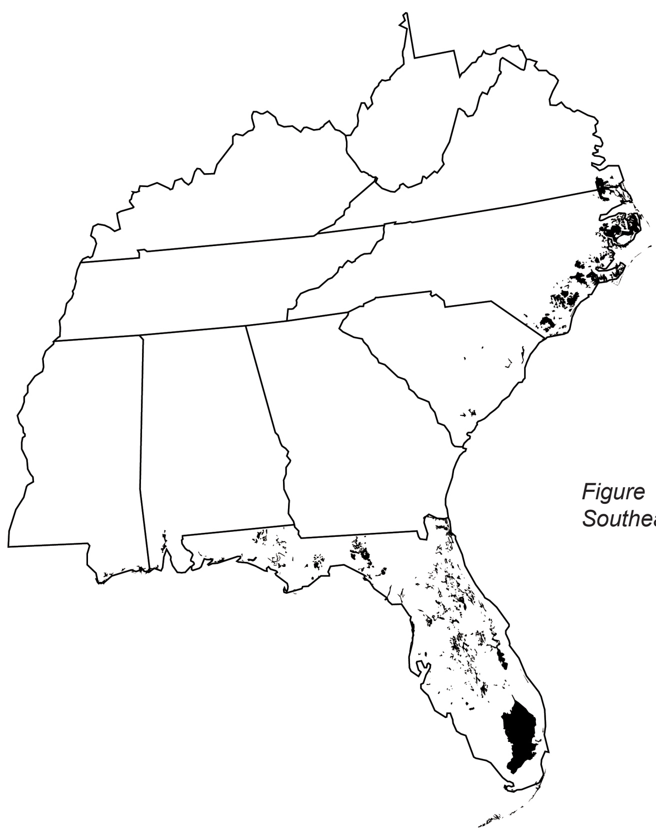


Figure 7.8: Histosols of the Southeast.

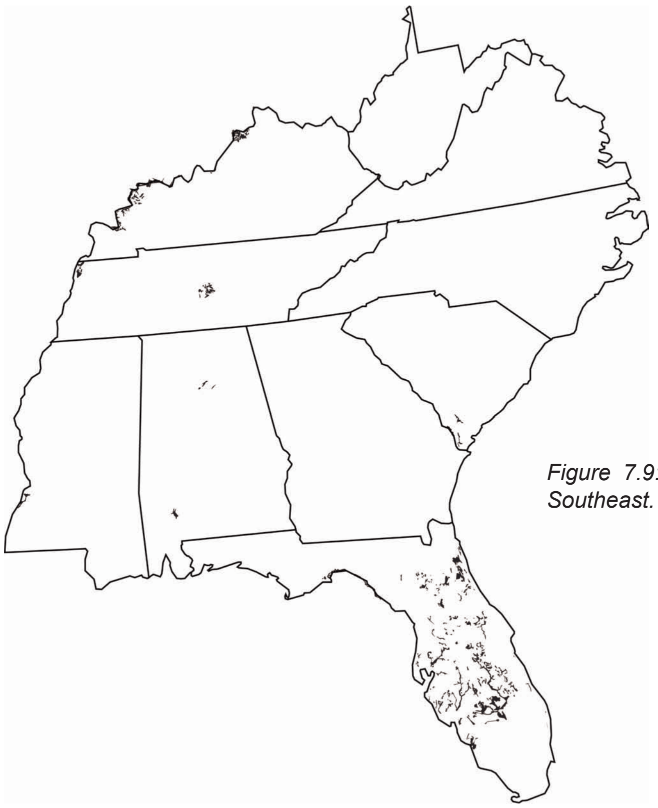


Figure 7.9: Mollisols of the Southeast.

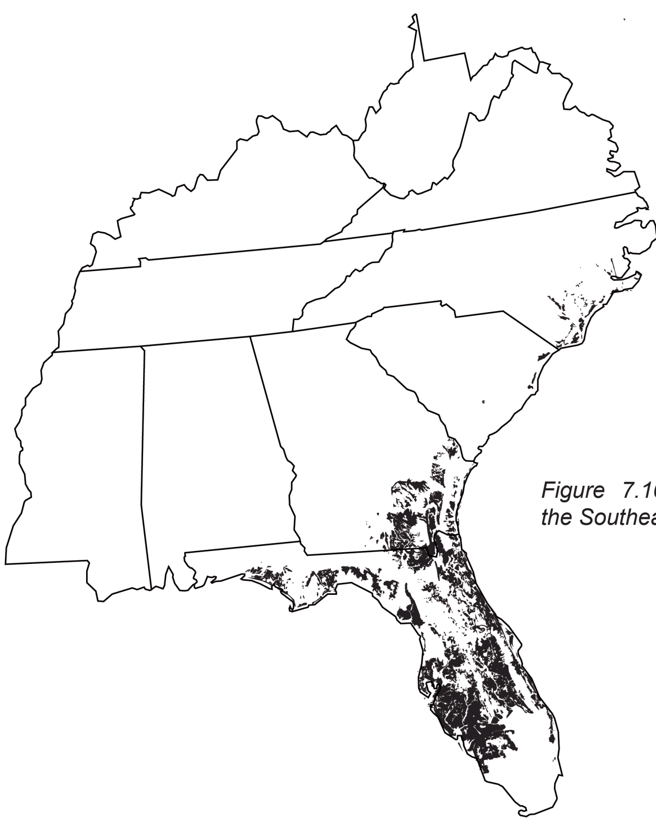


Figure 7.10: Spodosols of the Southeast.

7 Soils

Soil Orders

sandstone • *sedimentary rock formed by cementing together grains of sand.*

limestone • *a sedimentary rock composed of calcium carbonate ($CaCO_3$).*

shale • *a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.*

Paleozoic • *a geologic time interval that extends from 541 to 252 million years ago.*

inland sea • *a shallow sea covering the central area of a continent during periods of high sea level.*

suture • *the area where two continental plates have joined together through continental collision.*

terrane • *a piece of crustal material that has broken off from its parent continent and become attached to another plate.*

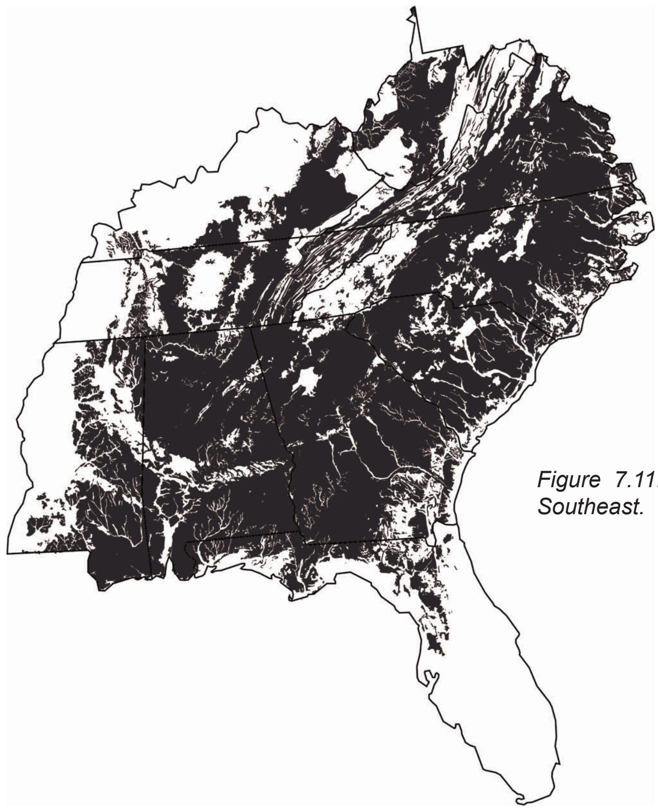


Figure 7.11: Ultisols of the Southeast.

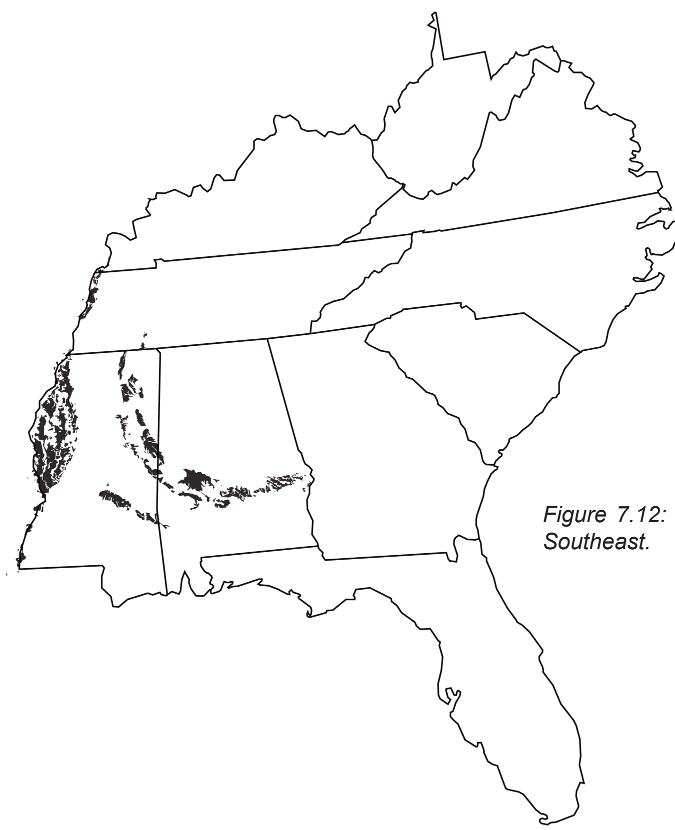


Figure 7.12: Vertisols of the Southeast.

Geology of the Southeast: Parent Material

The Southeast is home to a variety of parent materials—the minerals and organic matter from which its soils are derived (*Figure 7.13*). Mineral material determines a soil's overall fertility and the vegetation it supports.

Weathered sedimentary rock is one of the most ubiquitous parent materials in the Southeast. **Sandstone**, siltstone, **limestone**, and **shale** are common bedrocks throughout the Inland Basin and Coastal Plain; over time, erosional processes have contributed to the formation of soils from all of these sedimentary substrates. Much of this rock was laid down during the **Paleozoic,** when a shallow **inland sea** repeatedly flooded the landscape.

During the Paleozoic, the Blue Ridge and Piedmont was a **suture** zone for **terranes** and **volcanic islands**, and the site of multiple continent-continent collisions that folded and **faulted** rock layers to form igneous and metamorphic rocks. Today, an ancient core of erosion-resistant **Precambrian** rock is exposed in the Blue Ridge Mountains, and many soils there are derived largely from the erosion of these materials.

Alluvium makes up a portion of the parent material found along the Mississippi River, throughout Mississippi and western Tennessee. Glaciation during the **Quaternary** lead to the accumulation of loess deposits (*Figure 7.14*), which were carried by wind and deposited by river **systems**. These glacial sediments are responsible for the development of some extremely productive agricultural soils.

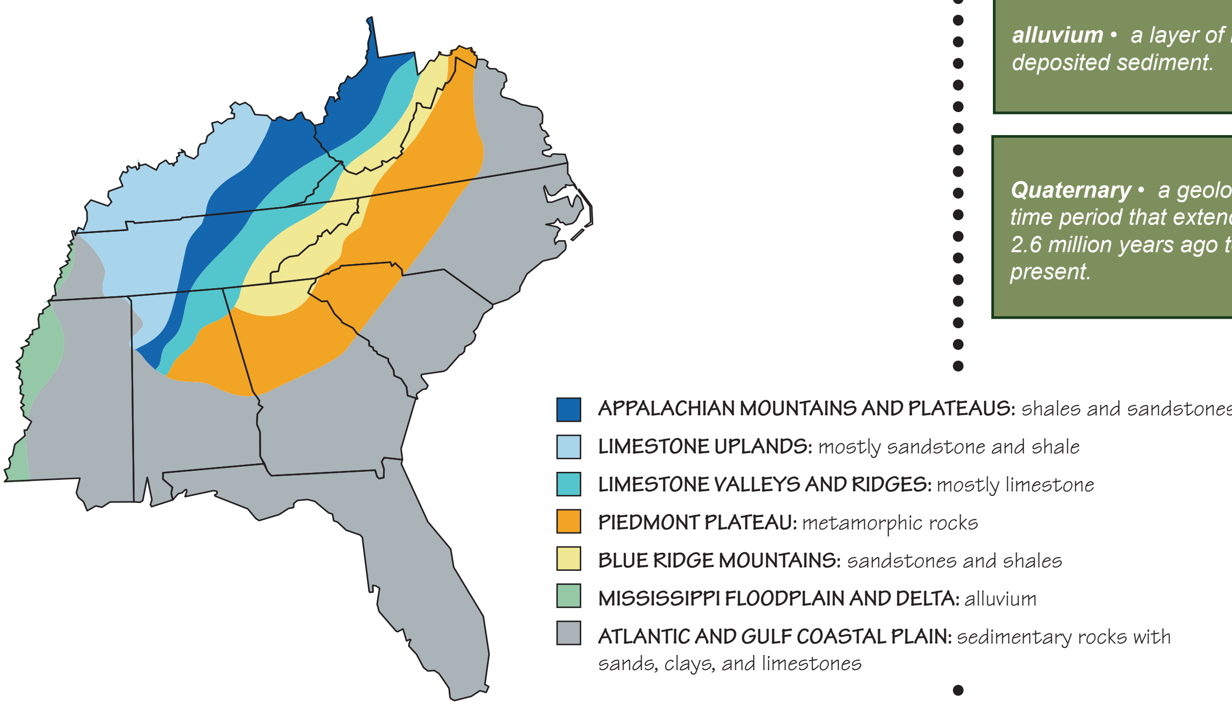


Figure 7.13: Physiographic and regolith map of the Southeast. (See TFG website for full-color version.)

Soil Orders

volcanic island • *one of a string of islands created when molten rock rises upward through oceanic crust.*

fault • *a fracture in the Earth's crust in which the rock on one side of the fracture moves measurably in relation to the rock on the other side.*

Precambrian • *a geologic time interval that spans from the formation of Earth (4.6 billion years ago) to the beginning of the Cambrian (541 million years ago).*

alluvium • *a layer of river-deposited sediment.*

Quaternary • *a geologic time period that extends from 2.6 million years ago to the present.*

relief • *the change in elevation over a distance.*

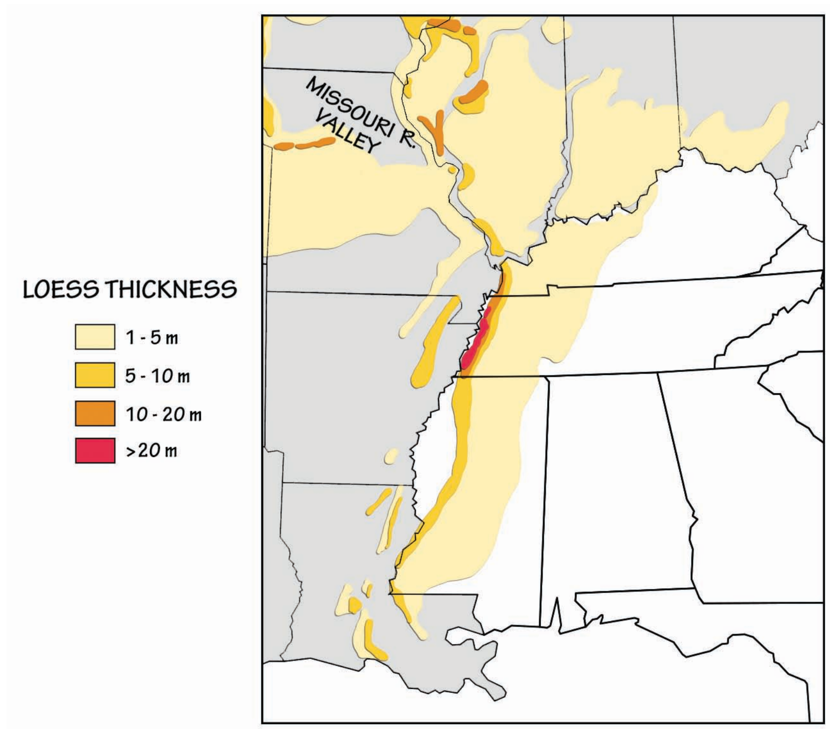
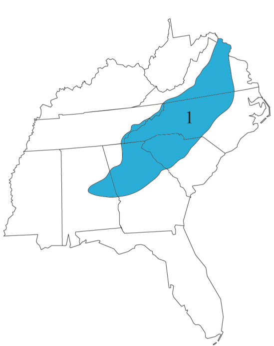


Figure 7.14: Loess deposits in the Southeast and surrounding states. (See TFG website for full-color version.)

Soils of the Blue Ridge and Piedmont
Region 1

The soils of the Blue Ridge and Piedmont are widely varied, reflecting differences in the region's **relief**, bedrock, and climate. The intense tectonic events that shaped the region's rocks and mountainous topography have directly contributed to the availability of specific parent materials and the formation of the Blue Ridge and Piedmont's different soils.

See Chapter 2: Rocks to learn about the metamorphic rocks of the Blue Ridge and Piedmont.



Soils that develop from bedrock in the Blue Ridge vary in quality with relief, parent material, and climate. Steeper topography often causes relatively higher rates of erosion, which contributes to thin soil cover and limits agriculture in some areas. Inceptisols, in particular, are found on reasonably steep slopes and arise from parent material that is quite resistant to weathering. Not surprisingly, they are concentrated in the Blue Ridge, and can be found beneath most of the region's coniferous and hardwood forest (*Figure 7.15*).

The Piedmont's gently rolling topography is much less rugged than that of the Blue Ridge (though also dominated by igneous and metamorphic rocks), and

Region 1

7.15: An example of an Inceptisol soil. These soils are formed from resistant rocks on steeper slopes and are prevalent in the Blue Ridge Mountains.

is generally deeply weathered, creating thick soil profiles. The Piedmont is characterized by fine soils that are utilized for grazing, as well as for row crops such as corn and tobacco. These soils are typically 15–20 meters (50–65 feet) thick, and can be as much as 100 meters (330 feet) thick in certain areas thanks to low rates of erosion.

See Chapter 4: Topography to learn how the Piedmont's landscape differs from that of the Blue Ridge.

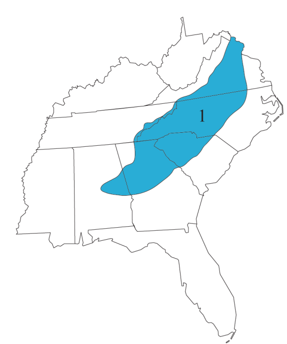
Ultisols, common throughout the Southeast, are rich in kaolinite, halloysite, and dickite clays formed by the intense weathering of **feldspar**-rich igneous and metamorphic rocks. These soils are well known in the Piedmont for their reddish color, caused by iron **oxides** in the clay (*Figures 7.16 and 7.17*). There is a tradition of handmade red clay pottery in central and northern Georgia, made from Ultisol clays. Ultisols tend to be acidic and are therefore poorly suited to agriculture, although they can be improved using fertilizer and **lime**.

Entisols in the Blue Ridge and Piedmont belong to the suborder Arents, which are defined by their homogenous nature due to plowing or other human-induced mixing. These soils are used mostly for pasture, cropland, or urban development. Moist Alfisols are found in a band hugging the boundary between the Piedmont and the Coastal Plain. These soils generally form in forested areas as a result of weathering processes that leach minerals from the surface layer into the subsoil, where nutrients are retained.

feldspar *• an extremely common group of rock-forming minerals found in igneous, metamorphic and sedimentary rocks.*

oxidation *• a chemical reaction involving the loss of at least one electron when two substances interact.*

lime *• an inorganic white or grayish-white compound made by roasting limestone (calcium carbonate, $CaCO_3$) until all the carbon dioxide (CO_2) is driven off.*

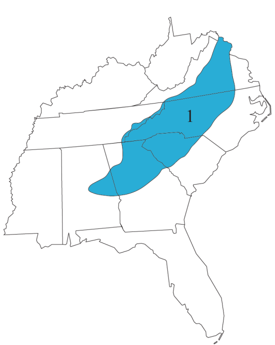


7 Soils

Region 1

Figure 7.16: Ultisols, commonly called red clay soils, are especially common in North Carolina's Piedmont.

Figure 7.17: Sweet potatoes grown in red Ultisol soils at Kirby Farms in Mechanicsville, Virginia lie ready for harvest,



Soils of the Inland Basin
Region 2

Most soils of the Inland Basin developed on a variety of marine sedimentary rocks, including limestone, sandstone, and shale. Soil cover here is thick along river valleys, and thinner in the region's eastern, more mountainous part. These variable influences have led to a wide array of agricultural land uses. For example, soils developed above **phosphate**-bearing limestone bedrock in central Kentucky are favored for pastureland, and are part of the reason for the success of the area's thoroughbred horse industry. Crops sustained in the Inland Basin region include corn, soybean, small grains, hay, and tobacco.

The prevalence of productive Alfisols in the Inland Basin has enabled a rich agricultural industry in the region, particularly in Kentucky and central Tennessee. These moisture-rich soils, members of the suborder Udalfs, consist of deep silty loam with a red clay subsoil and formed largely from a combination of loess and the underlying limestone bedrock (*Figure 7.18*).

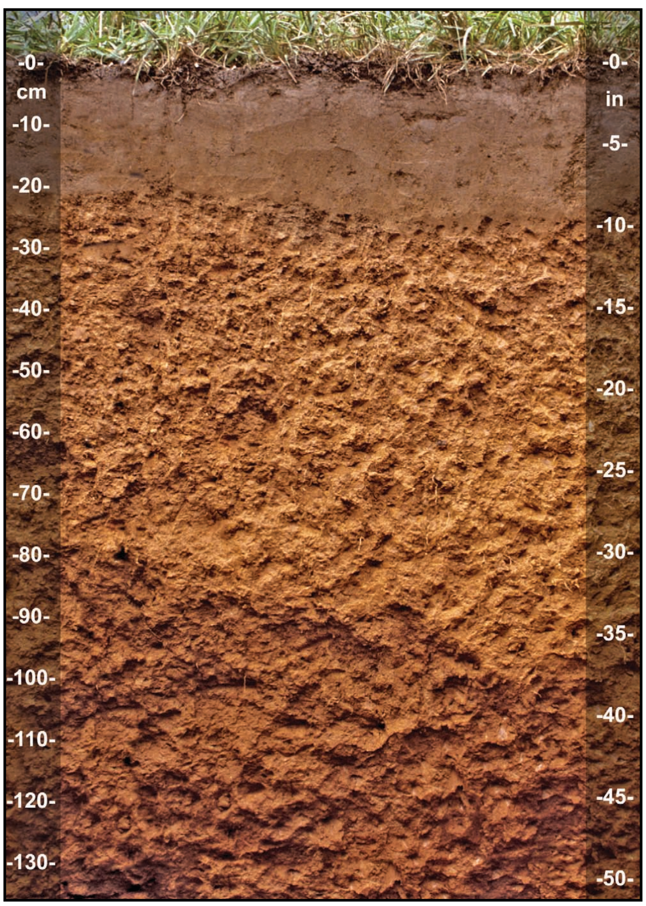
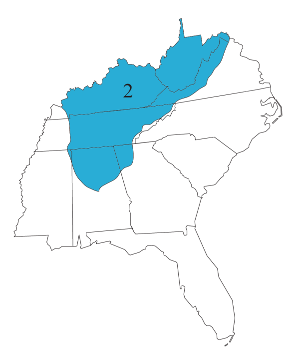


Figure 7.18: The Crider series, an Alfisol and the Kentucky state soil.

Region 2

phosphate *• an inorganic salt of phosphoric acid, and a nutrient vital to biological life.*



Region 2

Cretaceous • *a geologic time period spanning from 144 to 66 million years ago.*

Cenozoic • *the geologic time period spanning from 66 million years ago to the present.*

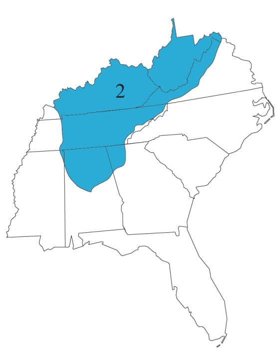
carbonate rocks • *rocks formed by accumulation of calcium carbonate, often made of the skeletons of aquatic organisms.*

Ultisols in the Inland Basin are typically found in or near more mountainous areas, where they originally weathered from exposed sedimentary rocks such as sandstone, siltstone, and shale. These soils, heavily leached and often acidic, are lower in fertility, with most nutrients concentrated in the uppermost horizon. They have little to no humus.

The steep slopes of the Appalachian Mountains in Kentucky, West Virginia, and Virginia are the perfect environment for the formation of Inceptisols, which support the region's dense mountain forests (*Figure 7.19*).

Figure 7.19: Inceptisol soils, rocky and poorly developed, carpet this forest path in Seneca Rocks, West Virginia.

Other soil types that appear in the Inland Basin are uncommon. Entisols, young soils lacking in horizons, are found scattered along streams and river valleys where unconsolidated sediment has been transported from the steep surrounding slopes. Wet Mollisols are found in central Tennessee, while a few fertile prairie Mollisols appear along Kentucky's northern border.



Soils of the Coastal Plain
Region 3

The soils of the Coastal Plain developed on loose, unconsolidated, generally flat layers of sediment, which resulted from **Cretaceous** and **Cenozoic** sea level fluctuation and the erosion of the Appalachian Mountains. Because of their young age and the nature of the underlying sediment, Coastal Plain soils are generally poorly developed. Although the Southeast's coastal climate is highly favorable for agriculture, production is dependent on the soils' variable characteristics (such as drainage, soil thickness, and weathering of minerals within the soil). In most parts of the Coastal Plain, areas rich in well- to moderately well-drained loamy soils are prime sites for agriculture including cotton, peanuts, soybean, tobacco, and corn.

As in the rest of the southeastern regions, Ultisols are the most prevalent soils in the Coastal Plain, covering large swaths of Virginia, North and South Carolina, Georgia, Alabama, and Mississippi with red-hued, clay-enriched soil.

Entisol soils are found where erosion and deposition occur faster than the rate of soil formation, and typically appear in floodplains where alluvial sediments are deposited. The western parts of Kentucky, Tennessee, and Mississippi contain Entisols that developed in deep loess deposits. Wind and water brought these materials to the area, and today water erosion serves to wash these deposits away (*Figure 7.20*). The consequences of soil erosion are a significant environmental issue for the western edge of the Coastal Plain. Conservation tillage and no-till practices are recommended when using these soils for agriculture, as the soil resource is highly sensitive to loss. Florida and other states along the Atlantic Coastal Plain also have significant deposits of shallow, sandy Entisols derived from **carbonate** and **siliciclastic** sediment (*Figure 7.21*).

See Chapter 2: Rocks for more about the interplay between carbonate and weathered siliciclastic sediments in the Coastal Plain.

In the coastal lowlands along the Atlantic and Gulf Coasts, poorly drained soils become common. The coastal lowlands are home to the largest swamps in the nation, including the Florida Everglades and the Okefenokee Swamp on the Georgia-Florida border. These swamps and many surrounding areas contain Spodosol soils, waterlogged mixtures of organic matter and aluminum characterized by a shallow, fluctuating **water table** (*Figure 7.22*). The Coastal Plain's Spodosols support water-loving plants, mosses, and **trees** such as cypress and palm; they are not good soils for most agriculture. Saturated Histosol soils filled with decomposing organic material are also found throughout Florida and the Carolinas' coastal plain. These soils form from the slow decomposition of organic detritus in wetland environments (*Figure 7.23*). Swampy, waterlogged soils are often drained to accommodate human settlement, which causes them to condense and **subside**. This is a particular problem near the Everglades

siliciclastic • *pertaining to rocks that are mostly or entirely made of silicon-bearing clastic grains weathered from silicate rocks.*

water table • *the upper surface of groundwater.*

tree • *any woody perennial plant with a central trunk.*

subsidence • *the sinking of an area of the land surface.*

Soils

Region 3

Figure 7.20: Unconsolidated loess-based Entisol soils blanket the Mississippi River valley and bluffs. Erosion is a major concern.

Figure 7.21: A gopher tortoise exits a burrow dug in Florida's sandy Entisols.

Figure 7.22: This alligator in Georgia's Okefenokee Swamp lies on mud composed of waterlogged Spodosols.

Figure 7.23: A mucky Histosol from South Carolina's coastal wetlands.

__chalk__ • a soft, fine-grained, easily pulverized, white-to-grayish variety of limestone, composed of the shells of minute planktonic single-celled algae.

__permeability__ • a capacity for fluids and gas to move through fractures within a rock, or the spaces between its grains.

in southern Florida, where extensive draining has contributed to severe soil loss and compromised the local ecosystem.

See Chapter 10: Earth Hazards to learn how draining and subsidence have affected the Florida Everglades.

Vertisol soils are rare in the Southeast, but can be found in a band running through central Mississippi and Alabama as well as throughout the Mississippi River floodplain. The Vertisols in the Gulf Coastal Plain contain high percentages of smectite clays, which shrink and form wide cracks at the surface during dry periods (*Figure 7.24*). The cracks, which can be up to a meter (three feet) deep, seal shut again when moisture enters the soil. Because these soils shrink and swell so readily, it is extremely difficult—and even dangerous—to build structures or roads on top of them. The action of shrinking and swelling within the soil also prevents the formation of distinct horizons. Vertisols along the Mississippi floodplain are saturated with water for extended periods and rarely form cracks. The Black Belt, an agricultural region that runs through Mississippi and Alabama, is dominated by drier soils that open and close depending upon the amount of precipitation. The area was named for its layer of organic-rich black topsoil that developed from underlying **chalk** sequences. Because the chalk is **impermeable** to groundwater, the overlying soils tend to dry out and crack during the summer.

Figure 7.24: Cracked Vertisols near Birmingham, Alabama.

Inceptisols are scattered along streams throughout the inland areas of the Coastal Plain. Moist Mollisols can be found throughout central Florida, where they are commonly used for agricultural purposes.

State Soils

Just as many states have official state flowers, birds, and **fossils**, they also have official soils. State soils are most often determined by a vote of soil scientists in the state, and, absent any political wrangling, usually represent the most productive soils and those that most closely resemble everyone's favorite soil: loam. As mentioned earlier, loam soils are almost equal parts sand, silt, and clay.

> ***fossil*** • *preserved evidence of ancient life.*

> ***hectare*** • *a metric unit of area defined as 10,000 square meters.*

Alabama

Bama soils are well-drained Ultisols that cover more than 146,000 **hectares** (360,000 acres) of western and central Alabama. These thick deposits of loamy **fluvial** or marine sediments are found parallel to major river systems, and are used in the cultivation of corn and cotton as well as pastureland.

Florida

The Myakka soil is native to Florida and does not occur in any other state. A type of Spodosol, it is the most extensive soil in the state and covers over 607,000 hectares (1.5 million acres) of land. This wet, sandy soil originates from marine deposits, and is a major component of flatwood ecosystems.

Georgia

The state soil of Georgia is the Tifton series, loamy Ultisols of marine origin. These soils are some of the most important agricultural soils in the state, found on more that 810,000 hectares (two million acres) of land and underlying about 27% of Georgia's prime farmland. The principle crops grown on Tifton soils include soybeans, corn, cotton, and peanuts.

Kentucky

Highly productive Crider soils are used for crops or pasture over nearly 200,000 hectares (500,000 acres) of Kentucky's uplands. Grain, corn, soybeans, tobacco, and hay are grown on these well-drained, moderately permeable Alfisols.

Mississippi

Found along the bluffs of the Mississippi Delta and throughout the full length of the state, Natchez soils are used mostly for woodlands and pastures. These Inceptisols formed in deep loess under a warm and humid woodland environment. They are fertile and, with the proper management, can be very productive.

North Carolina

Cecil soils are Ultisols that developed over igneous and metamorphic rocks, and contain a topsoil of brown sandy loam with a thick red clay subsoil. They make up over 607,000 hectares (1.5 million acres) of North Carolina's Piedmont, about half of which is cultivated for tobacco, corn, cotton, and grains. If undisturbed, these soils commonly support forests dominated by oak, hickory, and pine.

Soils

State Soils

South Carolina

The state soil of South Carolina is the Lynchburg series, which consists of deep and poorly drained Ultisols that formed from sandy and loamy marine sediment. These soils are found along the Coastal Plain in interstream divides and shallow depressions. If they are drained, Lynchburg soils can be used as prime farmland.

Tennessee

Tennessee's state soil is the Dickson series, deep, moderately well-drained Ultisols that formed in a thick mantle of limestone and silt. These soils are most often found on level and gently sloping uplands, and are used to support corn, soybeans, and pasture.

Virginia

Pamunkey soils were first identified at a farm near Jamestown, Virginia, considered the oldest tilled farm in the United States. They are named for the Pamunkey Indian tribe, who first used these fertile Alfisols to sustain their agriculture. These soils formed in the James River drainage basin from sediments that originated in every physiographic province of Virginia.

West Virginia

Monongahela soils are deep, moderately well-drained Ultisols that are found on unflooded alluvial stream terraces. They are well suited to crop production, and are considered prime farmland and pastureland. The name "Monongahela" is derived from a Native American word that means "high banks or bluffs, breaking off and falling down in places."

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The Twelve Soil Orders Soil Taxonomy, University of Idaho College of Agricultural and Life Sciences, http://www.cals.uidaho.edu/soilorders/.

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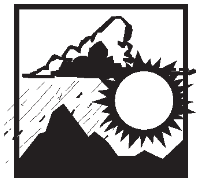

Chapter 8:
Climate of the Southeastern US

Climate is a description of the average temperature, range of temperatures, humidity, precipitation, and other **atmospheric**/hydrospheric conditions a region experiences over a period of many years. These factors interact with and are influenced by other parts of the Earth **system**, including geology, geography, insolation, currents, and living things.

Because it is founded on statistics, climate can be a difficult concept to grasp, yet concrete examples can be illuminating. Terms like "desert," "rain forest," and "tundra" describe climates, and we have gained a general understanding of their meaning. Climate can also encompass the cyclical variations a region experiences; a region with a small temperature variation between winter and summer—San Francisco, for example—has a different climate from one that has a large variation, such as Buffalo. Scientists have settled on 30 years as the shortest amount of time over which climate can be defined, but it can of course also define time periods millions of years in length.

You cannot go outside and observe climate. **Weather**, on the other hand, can be observed instantly—it is 57 degrees and raining *right now*. Weather varies with the time of day, the season, multi-year cycles, etc., while climate encompasses those variations. Our choice of clothing in the morning is based on the weather, while the wardrobe in our closet is a reflection of climate. Residents of the Southeast have a diverse wardrobe, for while the region's climate is generally mild, most areas of the Southeast experience frequent extreme summer **heat** and occasional extreme winter cold. Subfreezing temperatures are also common during the winter in the northern parts of the Southeast.

Past Climates

Climate, like other parts of the Earth system, is not static but changes over time, on both human and **geologic time scales**. Latitude, for example, has a very direct effect on climate, so as the continents shift over geologic time, the climates on them also shift. Furthermore, the conditions on Earth as a whole have varied through time, altering what kinds of climates are possible. Throughout its long history, parts of the Southeastern US have felt the chilly **winds** of winter, been filled with subtropical swamps and forests, and submerged in warm, shallow seas.

Ancient climates are reconstructed through many methods. Written records and **tree** rings go back hundreds of years, **glacial** ice cores hundreds of thousands of years, and **fossils** and rocks that indicate different climates go back hundreds of millions of years. These clues, coupled with modeling and a knowledge of physics and chemistry, help climatologists put together an increasingly detailed history of the Earth's climate, and of that of the Southeast. Unfortunately, we do not have as clear an understanding of climate for the earliest part of Earth

atmosphere • *a layer of gases surrounding a planet.*

system • *a set of connected things or parts forming a complex whole.*

weather • *the measure of short-term conditions of the atmosphere such as temperature, wind speed, and humidity.*

geologic time scale • *a standard timeline used to describe the age of rocks and fossils, and the events that formed them.*

wind • *the movement of air from areas of high pressure to areas of low pressure.*

glacier • *a body of dense ice on land that does not melt away annually and has sufficient mass to move under its own weight.*

CHAPTER AUTHORS

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Past

helium • *a gaseous chemical element (He), which is the second most abundant and second lightest element in the universe.*

volcanism • *the eruption of molten rock onto the surface of the crust.*

meteorite • *a stony or metallic mass of matter that has fallen to the Earth's surface from outer space.*

salt • *a mineral composed primarily of sodium chloride (NaCl).*

mineral • *a naturally occurring solid with a specific chemical composition and crystalline structure.*

energy • *the power derived from the use of physical or chemical resources.*

greenhouse gas • *a gas in the atmosphere that absorbs and emits heat.*

iron • *a metallic chemical element (Fe).*

history as we do for the later parts, because the oldest rocks are much more difficult to find. However, we can still say something about the climate of the ancient Earth, in large part due to our knowledge of atmospheric chemistry.

Ancient Atmosphere

Not long after the Earth first formed, more than 4.5 billion years ago, its atmosphere was composed mostly of hydrogen and **helium**. **Volcanic** activity and collisions with **meteorites** and comets added water vapor, carbon dioxide (CO_2), and nitrogen to the atmosphere. As the Earth cooled enough for liquid water to form, the vapor formed clouds from which the rain poured forth in such a deluge as the planet will never experience again. These torrential rains were constant for *millions* of years, absorbing **salt** and other **minerals** from the earth as the rainwater coursed to the lowest areas, forming Earth's oceans and seas.

At this time, the sun produced significantly less **energy** than it does today, so one might expect that once the oceans formed, they would continue to cool and eventually freeze. Yet temperatures stabilized, perhaps because there was a greater concentration of potent **greenhouse gases** in the atmosphere and less land surface to reflect light, so temperatures remained high enough for liquid water to exist. Indirectly, the ocean was responsible for the final ingredient of the modern atmosphere because it was home to the first life on Earth. Photosynthetic bacteria appeared perhaps as early as 3.5 billion years ago, but abundant **iron** and organic matter quickly absorbed the oxygen they produced. After hundreds of millions of years, these sinks were filled, and free oxygen could finally build up in the atmosphere. With this addition, the modern atmosphere was complete, though the relative amounts of the gases composing it would, and still continue to, shift. *The composition of the atmosphere and the huge volume of water on Earth are two of the most important factors affecting climate.*

Much of the light from the sun passes unimpeded through the atmosphere and hits the Earth. Approximately 70% of that light is absorbed and retransmitted from the surface as heat. The transmitted heat, which has a longer wavelength than light, is trapped by gases in the atmosphere including water vapor, carbon dioxide, and methane. The similarity between this process and that which warms a greenhouse earned these "greenhouse gases" their moniker.

While the atmosphere was forming about 3.7 billion years ago, the surface of the Earth was cooling to form a solid **crust** of rock (although there are indications that this process may have started as early as 4.4 billion years ago). Regardless of precisely when this took place, it represented the beginning of tectonic processes that have continued ever since. Molten rock from the **mantle** constantly wells up from deep fissures and solidifies into relatively **dense** rock, while more buoyant rock floats higher on the **magma** and is pushed around on

Past

the slow conveyor belts of mantle-formed rock (*Figure 8.1*). Denser rock forms oceanic **plates** that are lower and covered in water, and lighter rock forms continental plates, though part or all of a continental plate may be submerged under a shallow sea. The motion of these plates, the rearrangement of the continents, and the amount and types of minerals exposed to the atmosphere play a huge role in the climate. Not only do the continents and oceans move through different climate zones, but the continents also affect climate based on their size, and the **weathering** of rock on the continents plays a large role in the composition of the atmosphere. For example, rock that is enriched in organic matter will release abundant amounts of carbon dioxide as it weathers, while rock rich in **feldspar** and **mica** will take up carbon dioxide.

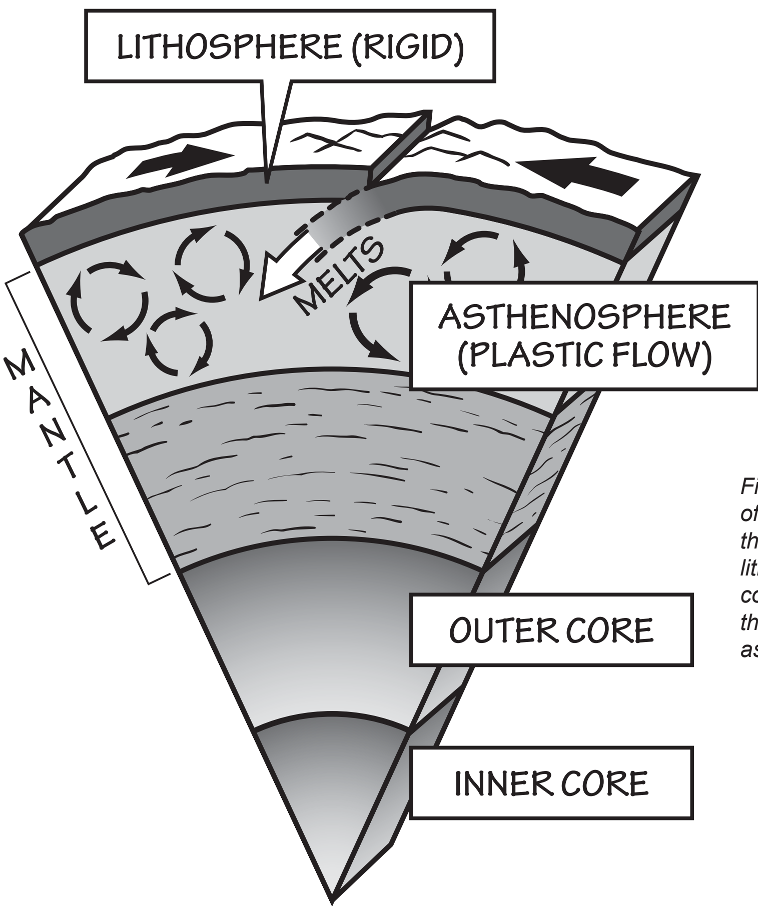

Figure 8.1: The layers of the Earth include the rigid crust of the lithosphere, which is constantly moving over the plastically flowing asthenosphere.

Nearly one billion years ago, the Earth began fluctuating between warm and cool periods lasting roughly 150 million years each. During cool periods, there is usually persistent ice at the poles, while during warm periods there is little or no glaciation anywhere on Earth. Today, we are still in a cool period—although the world has been cooler than it is at present, it has been far hotter for much of its history (*Figure 8.2*). Through the shifting global climate and the movement of the continents, what is now the Southeast has at times been at the bottom of a tropical sea, full of warm swamps, or home to cool temperate forests.

crust • *the uppermost, rigid outer layer of the Earth.*

mantle • *the layer of the Earth between the crust and core.*

density • *a physical property of minerals, describing the mineral's mass per volume.*

magma • *molten rock located below the surface of the Earth.*

plates • *large, rigid pieces of the Earth's crust and upper mantle, which move and interact with one another at their boundaries.*

weathering • *the breakdown of rocks by physical or chemical means.*

feldspar • *an extremely common group of rock-forming minerals found in igneous, metamorphic and sedimentary rocks.*

mica • *a large group of sheetlike silicate minerals.*

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Huronian glaciation • *a glaciation beginning about 2.4 billion years ago, that covered the entire surface of the Earth in ice for as long as 300 million years.*

plate tectonics • *the process by which the plates of the Earth's crust move and interact with one another at their boundaries.*

ice sheet • *a mass of glacial ice that covers part of a continent and has an area greater than 50,000 square kilometers (19,000 square miles).*

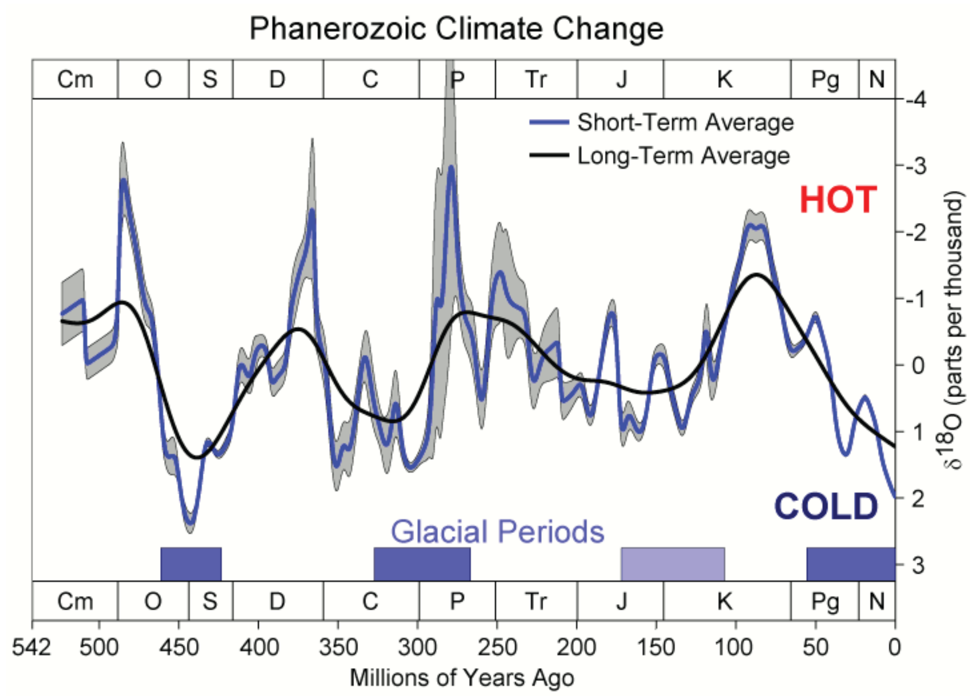


Figure 8.2: Changing global climate throughout the last 542 million years. These data were compiled using the ratios of stable oxygen isotopes found in ice cores and the carbonate skeletons of fossil organisms. (See TFG website for ful-color version.)

Snowball Earth

There is evidence suggesting that the entire surface of the planet has been covered in ice several times, a hypothesis called Snowball Earth (*Figure 8.3*). Glacial deposits discovered near Lake Huron and elsewhere show that starting about 2.4 billion years ago the entire surface of the Earth may have been covered in ice for as long as 300 million years, an event known in North America as the **Huronian glaciation**. At that time the continental plates made up less than half as much of the Earth's surface as they do today and were unified as the continent Arctica. It may have been early life's production of oxygen that reacted with and lowered the amount of the greenhouse gas methane in the atmosphere, tipping the Earth toward a series of cooling feedbacks and causing ice to spread from pole to pole.

An ice-covered planet would remain that way because almost all of the sun's energy would be reflected back into space, but this did not happen on Earth because of **plate tectonics**—the Snowball Earth cycle was eventually disrupted by volcanic activity. While the Earth was covered in ice, volcanoes continued to erupt, dumping carbon dioxide and methane into the atmosphere. While these gases are usually removed from the atmosphere by organisms and the weathering of rocks, this was not possible through miles of ice! After millions of years, the concentrations of methane and CO_2 increased to the point that greenhouse warming began to melt the **ice sheets**. Once the melting started, more of the sun's energy was absorbed by the surface, and the warming

Past

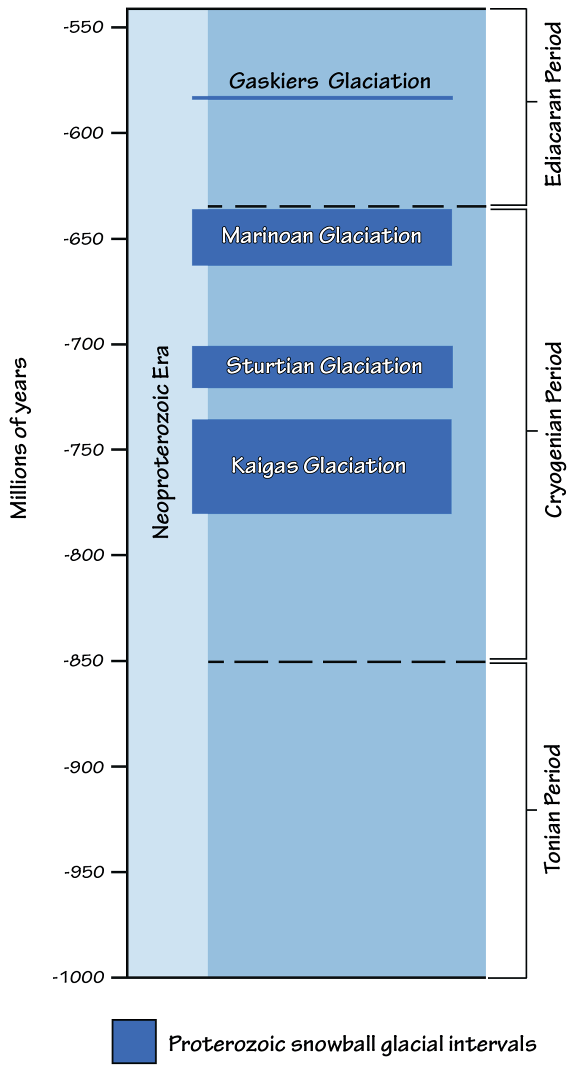


Figure 8.3: Snowball Earth periods during the Proterozoic.

feedbacks began. Because the oceans had been covered, nutrients derived from volcanic gases and chemical changes in the rocks accumulated in the waters. Once they were re-exposed to light, a population explosion of **cyanobacteria** produced more and more oxygen, which was capable of combining with freshly thawed carbon sources to make more carbon dioxide, further enhancing the warming.

For the next 1.5 billion years, the Southeast, free of ice, drifted around the surface of the Earth. A new supercontinent—**Rodinia**—formed, and the part that is now North America was stable, creating what is known as a **craton**, or continental interior relatively free of the folding and **faulting** that characterizes continental margins that are subjected to mountain building and other plate tectonic processes. Since the Southeast was part of that craton, it was probably underwater for most of this time. About 850 million years ago, during the **Cryogenian**, the Earth entered a 200-million-year **ice age**, during which there were two more Snowball Earth cycles. Although the part of Rodinia that would

cyanobacteria • *a group of bacteria, also called "blue-green algae," that obtain their energy through photosynthesis.*

Rodinia • *a supercontinent that contained most or all of Earth's landmass, between 1.1 billion and 750 million years ago, during the Precambrian.*

craton • *the old, underlying portion of a continent that is geologically stable relative to surrounding areas.*

fault • *a fracture in the Earth's crust in which the rock on one side of the fracture moves measurably in relation to the rock on the other side.*

Cryogenian • *a geologic period lasting from 850 to 635 million years ago, during the Precambrian.*

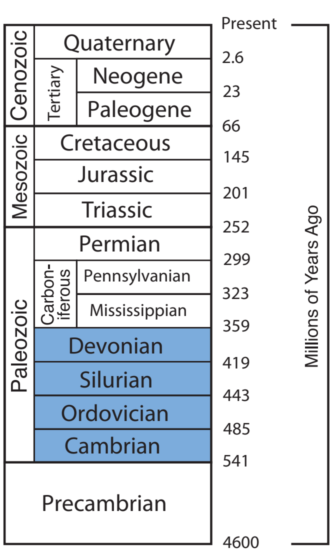
ice age • *a period of global cooling of the Earth's surface and atmosphere, resulting in the presence or expansion of ice sheets and alpine glaciers.*

archaeocyathid • *a vase-shaped organism with a carbonate skeleton, generally believed to be a sponge.*

trilobite • *an extinct marine invertebrate animal characterized by a three-part body and a chitinous exoskeleton divided longitudinally into three lobes.*

brachiopod • *a marine invertebrate animal characterized by upper and lower calcareous shell valves joined by a hinge, and a crown of tentacles (lophophore) used for feeding and respiration.*

mass extinction • *the extinction of a large percentage of the Earth's species over a relatively short span of geologic time.*



eventually become North America was located near the equator, the fact that North America was at such a low latitude, yet had glaciers, is strong evidence that the Earth really did freeze over completely. However, no direct evidence for any of the Snowball Earth cycles comes from rocks in the Southeast.

Life and Climate

With the start of the **Paleozoic** era, climates across the world were warm, and North America was located in the low and warmer latitudes of the Southern Hemisphere. As the **Cambrian** progressed, North America moved northward; by about 480 million years ago, what would become much of the Southeastern US was located near the Tropic of Capricorn (*Figure 8.4*). Cambrian fossils of **archaeocyathids**, **trilobites**, **brachiopods**, and mollusks reveal that most of the area was probably covered by warm, shallow seas that persisted into the **Ordovician**.

See Chapter 3: Fossils to learn more about Paleozoic fossils, including Cambrian archaeocyathids and trilobites.

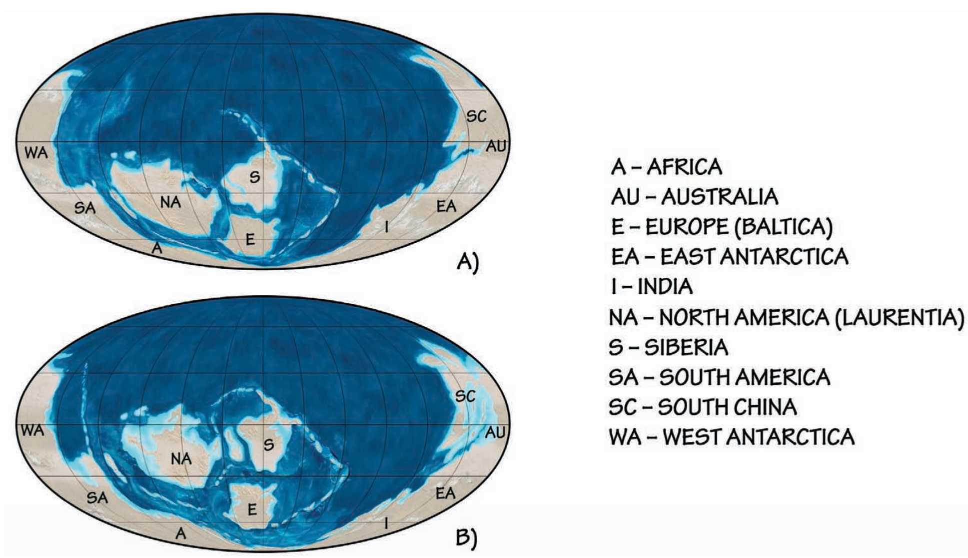


Figure 8.4: The location of the continents during the A) early and B) late Cambrian. Note the position of North America relative to the equator.

In the late Ordovician (about 460 to 430 million years ago), the Earth fell into another brief but intense ice age. Glaciers covered most of the southern landmasses, which were located over the South Pole. This led to global cooling, associated with the first of five major **mass extinctions** that have occurred over the last half-billion years. Although sea level dropped during this event, North America's position near the equator kept its climate relatively warm. **Limestones** throughout Tennessee and Kentucky contain **Silurian** and **Devonian** fossils (including trilobites, brachiopods, corals, and **crinoids**), which indicate that the Southeast still contained warm, shallow seas through the late Devonian. These shallow seas were especially productive, and plankton productivity grew so high that it depleted all the oxygen from the seafloor and sediments. The lack of oxygen allowed organic matter to accumulate instead of decay, leading to the deposition of black, carbon-rich **shale**. This rock occurs throughout the subsurface in east-central Kentucky and central West Virginia, and is one of the richest sources of **petroleum** in those states.

See Chapter 6: Energy to learn about oil-rich deposits in the Southeast.

From 430 to 300 million years ago, North America moved north across the equator, and the cycle of warming and cooling was repeated yet again. Glaciation in the Southern Hemisphere occurred during the late Devonian, while the supercontinent **Gondwana** was located over the South Pole. At the same time, while most of the Southeastern states were still submerged, the oceans between Gondwana and North America began to close (*Figure 8.5*). As fragments of the **Avalon microcontinent** collided with North America, the **Acadian Orogeny** formed a huge chain of mountains in what is now eastern North America. The remains of these high mountains include the southern Appalachians and the **igneous** and **metamorphic** rocks of the Piedmont. As these mountains rose, they blocked the equatorial easterly winds, forming a large **rain shadow**.

By the early **Carboniferous**, ice capped the South Pole and began to expand northward. Although the Earth's temperature fell during this time and glaciers growing far to the south caused sea levels to drop, the western Southeast was once again covered by a warm, shallow sea with limestone and abundant marine life, including heavily armored bony fish, **sharks**, **bryozoans**, corals, and **echinoderms**. Farther east, the **uplift** and **erosion** generated by mountain building caused the landscape to transition to a swampy coastal environment, with extensive forests containing many different kinds of plants including **lycopods**, **sphenopsids**, and ferns, as well as insects, amphibians, and early reptiles.

By the late Carboniferous, North America had collided with Gondwana, advancing the formation of **Pangaea**—a supercontinent composed of nearly all the landmass on Earth. Pangaea was so large that it created a strong **monsoonal** climate, much as Asia does today, which counteracted the eastern rain shadow's drying effect by bringing in moisture from the west. Large swamps that eventually became the rich **coal** beds of Tennessee, Kentucky, and West Virginia formed along broad **floodplains**. At the same time, global temperatures again declined, as glaciers re-formed near the South Pole, but temperatures remained warm in eastern and southeastern North America. Fossils from the Inland Basin provide evidence of a warm climate with primitive trees and swamp plants that experienced the repeated rising and falling of sea levels, as the glaciers waxed and waned. This ice age lasted well into the **Permian**, ending about 260 million years ago, during which time the swamps dried out permanently.

As the Triassic period began, the Southeast moved north from the equator. The Earth remained warm and ice-free at the poles through much of the Mesozoic era, although global temperatures began to dip again slightly around 150 million years ago. After reaching its greatest size during the Triassic period,

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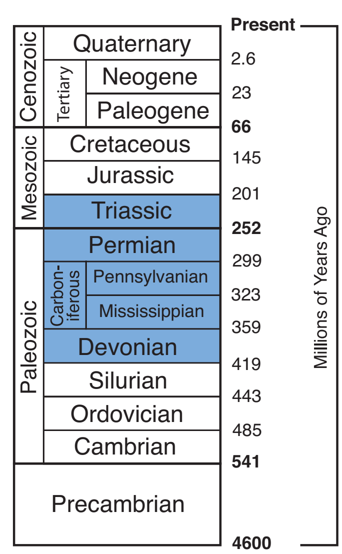
limestone • *a sedimentary rock composed of calcium carbonate ($CaCO_3$).*

crinoid • *a marine invertebrate animal characterized by a head (calyx) with a mouth surrounded by feeding arms.*

shale • *a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.*

petroleum • *a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface.*



8 Climate

Past

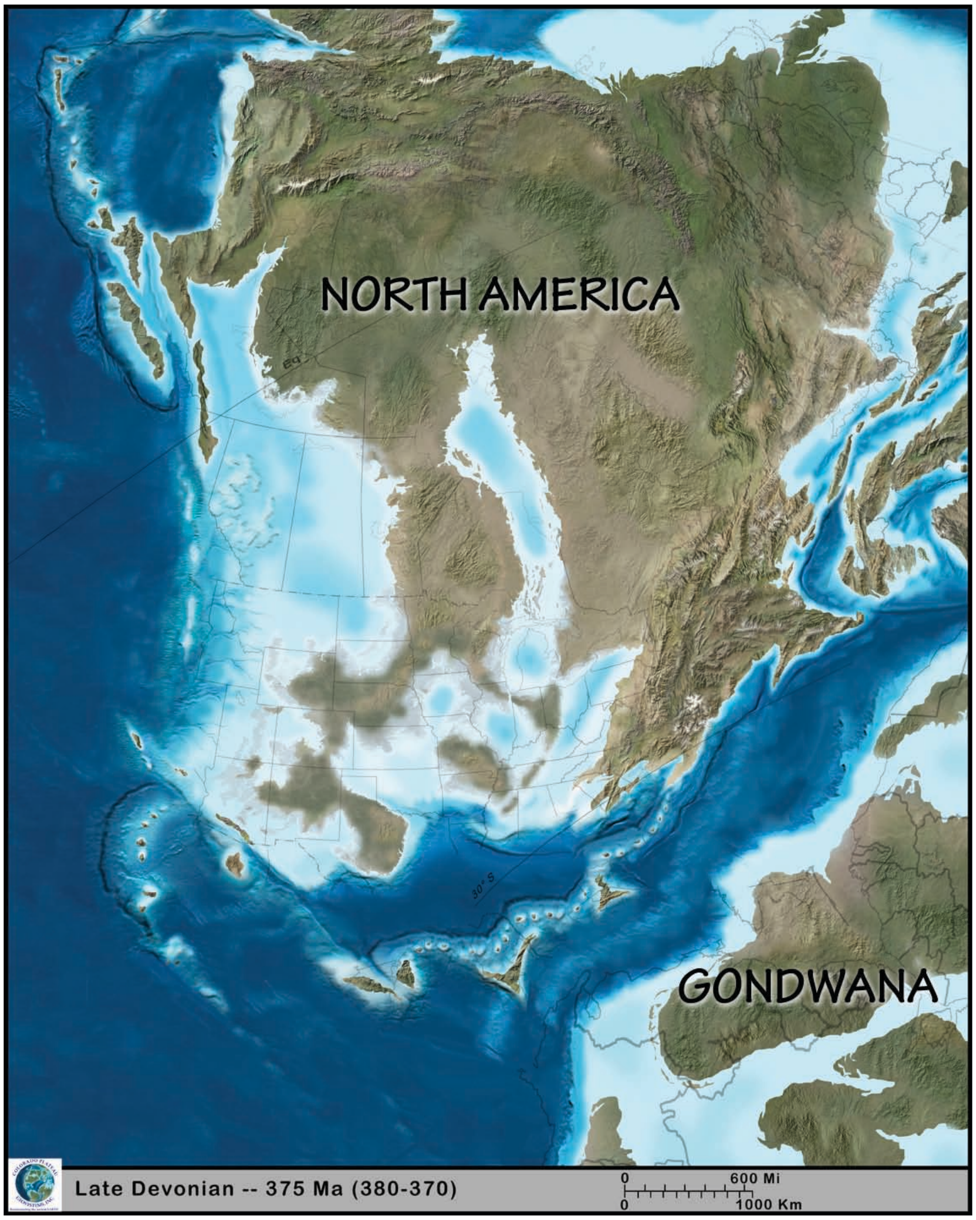


Figure 8.5: By the late Devonian (375 million years ago), the oceans between Gondwana and Euramerica had begun to close.

Pangaea began to rift apart into continents that would drift toward their modern-day positions (*Figure 8.6*), and the climate gradually shifted, becoming wetter and warmer. Triassic rocks are known only from the rift basins of Virginia and North Carolina, where they contain a rich terrestrial and lake fauna of fishes, amphibians, dinosaurs, and other reptiles. The breakup of Pangaea caused the Gulf of Mexico to open, flooding it with seawater. Because the climate was still relatively warm and dry, evaporation rates were high, and extremely thick deposits of salt accumulated there. These salt deposits have played a key role in trapping petroleum along the Gulf Coast. At the same time, the coastal portion of the

Era		Period	Millions of Years Ago
			Present
Cenozoic		Quaternary	2.6
Cenozoic	Tertiary	Neogene	23
Cenozoic	Tertiary	Paleogene	66
Mesozoic		Cretaceous	145
Mesozoic		Jurassic	201
Mesozoic		Triassic	252
Paleozoic		Permian	299
Paleozoic	Carbon-iferous	Pennsylvanian	323
Paleozoic	Carbon-iferous	Mississippian	359
Paleozoic		Devonian	419
Paleozoic		Silurian	443
Paleozoic		Ordovician	485
Paleozoic		Cambrian	541
		Precambrian	4600

Past

Southeast began to **subside**, and thick deposits of coastal and marine sediments began to accumulate, a process that continues to this day.

See Chapter 5: Mineral Resources for more about the exploitation of the Southeast's salt deposits.

subsidence • *the sinking of an area of the land surface.*

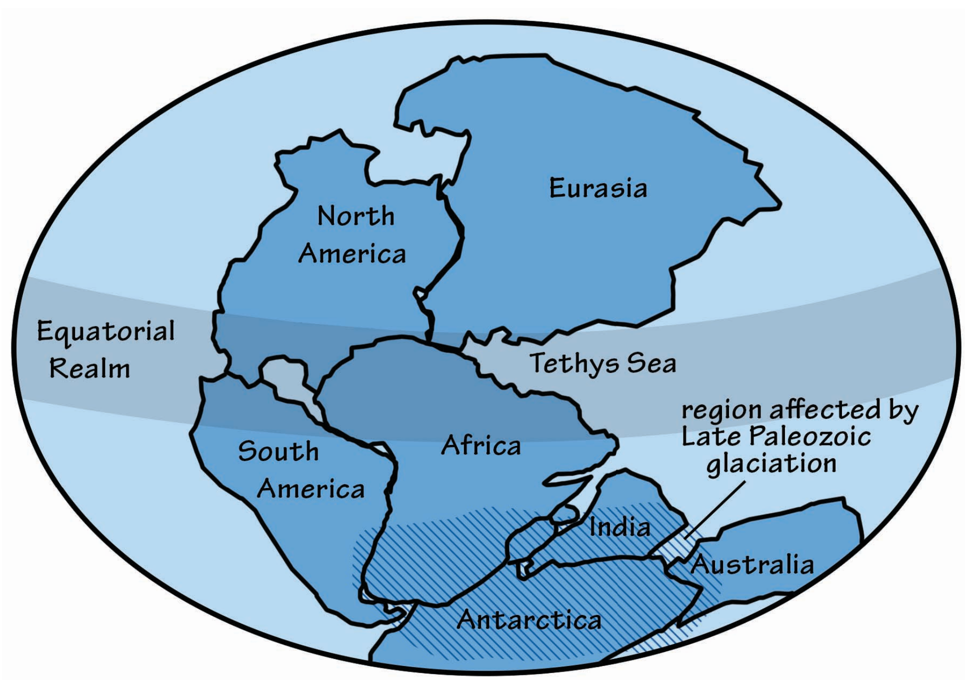
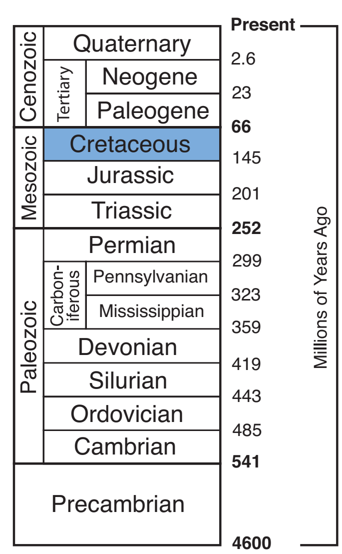


Figure 8.6: The breakup of Pangaea began around 220 million years ago.

inland sea • *a shallow sea covering the central area of a continent during periods of high sea level.*

Mississippi Embayment • *a topographically low-lying basin in the south-central United States, stretching from Illinois to Louisiana.*

The Earth warmed near the beginning of the **Cretaceous**, and sea level rose. Throughout the Cretaceous, sea level was as much as 100 meters (330 feet) higher than it is today, largely as a result of water displacement by continental rifting and rapid sea-floor spreading. Shallow seaways spread over many of the continents, and by the start of the late Cretaceous, North America was divided in two by an **inland sea** known as the Western Interior Seaway (*Figure 8.7*). A rich record of this warm, shallow sea is found in Mississippi, Alabama, and Georgia, where marine fossils range from tiny coccolithophores, mollusks, and crabs to sharks and large marine reptiles. The seaway extended far to the north in Mississippi, and its margin is marked by the **Mississippi Embayment**. Global temperatures during the Cretaceous were very warm, as much as 10°C (18°F) above present. There was likely little or no glacial ice anywhere on Earth, and temperatures were highest in lower latitudes. As the continents moved closer to their modern positions, the Southeast experienced a hot and humid tropical climate.



Past

Eocene *• a geologic time period extending from 56 to 33 million years ago.*

snail *• see gastropod: a marine, freshwater, or terrestrial invertebrate animal charac-terized by a single, coiled, calcareous shell, a muscular foot for gliding, and internal asymmetry caused by torsion.*

Paleocene *• a geologic time interval spanning from about 66 to 56 million years ago.*

extinction *• the end of species or other taxonomic groups, marked by death of the last living individual.*

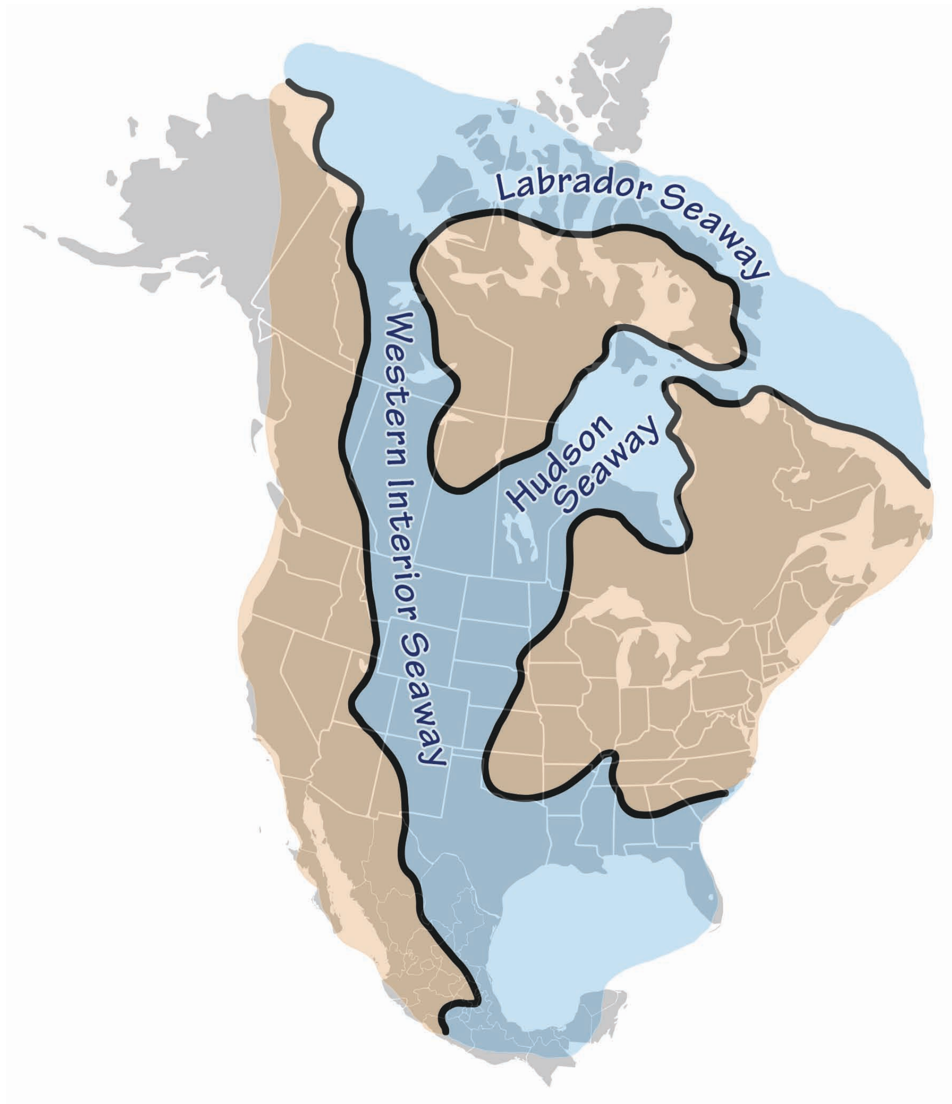
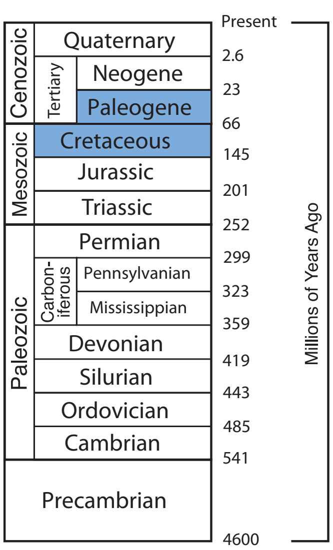


Figure 8.7: The Western Interior Seaway.

At the very end of the Cretaceous, the Gulf Coast experienced an enormous disruption when an asteroid or comet collided with Earth in what is now the northern Yucatán Peninsula in Mexico, just a few hundred miles away from the Southeastern US. The impact vaporized both water and rock, blocking out sunlight for weeks to years, which led to a collapse of photosynthesis and food webs on land and in the oceans. After this event, the climate may have cooled briefly, but it soon rebounded to a warmer state.

As the **Cenozoic e**ra began, global temperatures remained high, and rose even further into the early **Eocene**. This is reflected in the land plants and diversity of marine life—especially clams, **snails**, and echinoderms—represented by fossils in the Southeast Coastal Plain. Right at the boundary between the **Paleocene** and Eocene epochs (around 56 million years ago), temperatures spiked upward



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in what geologists call the Paleocene-Eocene Thermal Maximum. During this event, which lasted perhaps only around 10,000 years, the atmosphere and ocean warmed by as much as 8°C (14°F) in as little as 4000 years, and deep oceans became acidic, with low levels of dissolved oxygen. The causes remain unclear, but may have involved the sudden release of methane from sediments on the seafloor. The resulting greenhouse effect persisted for 100,000 years. This abrupt climatic change was associated with major migrations, the **extinction** of plants and animals on land, and a mass extinction in the deep sea, but its effects on life in the shallow seas that surrounded the Southeast were apparently not as marked.

In the late Eocene, the Earth began cooling, and global temperatures fell sharply at the boundary between the Eocene and **Oligocene** epochs (around 35 million years ago), due in part to the separation of the southern tip of South America from Antarctica. This allowed for the formation of the Antarctic Circumpolar Current, which insulated Antarctica from warm ocean water coming from lower latitudes and led to the formation of the continent's glaciers. The rocks and fossils of the Southeast show that the area did not cool as much as areas farther north did. The oldest rocks in Florida, from the Eocene, are coral-rich limestones that clearly formed in warm seas.

Climates warmed slightly during the **Miocene**, and this is reflected in the diverse marine and terrestrial fossils of the Atlantic Coastal Plain (from Maryland to Florida). Global temperatures fell in the late Miocene, and this was possibly associated with the continuing collision of India with Asia, which was forming the Himalayas. This event had a significant impact on global climate, as weathering of the newly exposed rock began to serve as a sink to take up atmospheric CO_2. With the reduction of this greenhouse gas, temperatures cooled worldwide, and this cooling has continued more-or-less to the present day. These changes are also visible in the Southeast's fossil record, with species that had lived farther north retreating southward over time.

Around 3.5 million years ago, glacial ice began to form over the Arctic Ocean and on the northern parts of North America and Eurasia. Surprisingly, a major contributing factor to this event was a geological change that occurred half a world away. The Central American Isthmus, which today makes up most of Panama and Costa Rica, rose out of the ocean at around this time, formed by undersea volcanoes. The new dry-land isthmus blocked the warm ocean currents that had been flowing east-to-west from the Atlantic to the Pacific for more than 100 million years, diverting them into the Gulf of Mexico and ultimately into the western Atlantic Gulf Stream. The **reefs** that make up the bulk of Florida's **carbonate** platform formed in this warm tropical sea. The strengthened Gulf Stream carried more warm, moist air with it into the northern Atlantic, which caused increased snowfall in high latitudes, leading to accelerating cooling. These changes in ocean circulation throughout the Caribbean and Gulf of Mexico also affected nutrient supplies in the coastal ocean, which may have contributed to an increase in the extinction of marine animals (including everything from mollusks and corals to whales and dugongs) during the late **Pliocene**.

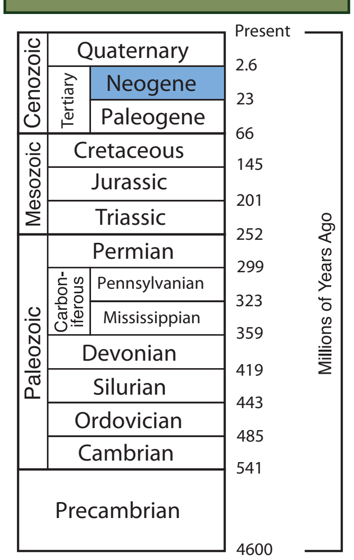
Oligocene *• a geologic time interval spanning from about 34 to 23 million years ago.*

Miocene *• a geological time unit extending from 23 to 5 million years ago.*

reef *• a feature lying beneath the surface of the water, which is a buildup of sediment or other material built by organisms, and which has positive relief from the sea floor.*

carbonate rocks *• rocks formed by accumulation of calcium carbonate, often made of the skeletons of aquatic organisms.*

Pliocene *• a geologic time interval extending from roughly 5 to 2.5 million years ago.*



Climate

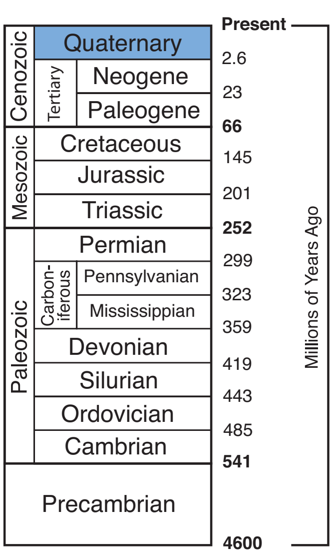
Past-Present

silica • *a chemical compound also known as silicon dioxide (SiO_2).*

clay • *the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.*

ice cap • *an ice field that lies over the tops of mountains.*

Pleistocene • *a subset of the Quaternary, lasting from 2.5 million to about 11,700 years ago.*



***Silicate* and carbonate rocks both weather chemically in reactions that involve CO_2 and water, typically creating *clays*, bicarbonate, and calcium ions. Silica weathering occurs relatively slowly, taking place on a large scale in the weathering and erosion of mountain ranges, and it may have an impact on atmospheric carbon dioxide levels on time scales of tens or hundreds of millions of years. On the other hand, carbonate rocks weather (in this case, dissolve) quickly, relative to silicates. In both cases, the products of weathering often end up in seawater, where they may be used in the *calcium carbonate* skeletons of marine organisms or taken up during photosynthesis. Skeletal material and organic matter often sink to the sea floor and become buried, effectively removing carbon from the global carbon cycle (and thereby the atmosphere) for many millions of years.**

Eventually, a sheet of sea ice formed over the Arctic, and ice sheets spread over northern Asia, Europe, and North America, signaling the start of the most recent ice age. Since just 800,000 years ago, a type of equilibrium has been reached between warming and cooling, with the **ice caps** growing and retreating primarily due to the influence of astronomical forces (i.e., the combined gravitational effects of the Earth, Sun, moon, and planets). The ice sheets in the Northern Hemisphere did not extend into the Southeast, even at their largest. The Southeast's climate was, however, affected by the presence of ice to the north. Studies of pollen and plant fossils from South Carolina's coastal plain indicate that between 19,000 and 12,800 years ago, the climate was suited to trees typical of much colder climates today. During glacial intervals, the area was also somewhat wetter than it is today, with wetlands and forests covering much of what would later become grassland. **Pleistocene** deposits in Tennessee, West Virginia, North Carolina, Florida, and Alabama contain abundant fossils of terrestrial vertebrates such as horses, camels, bison, **mastodons**, **mammoths**, and ground sloths—animals we associate with cold climates.

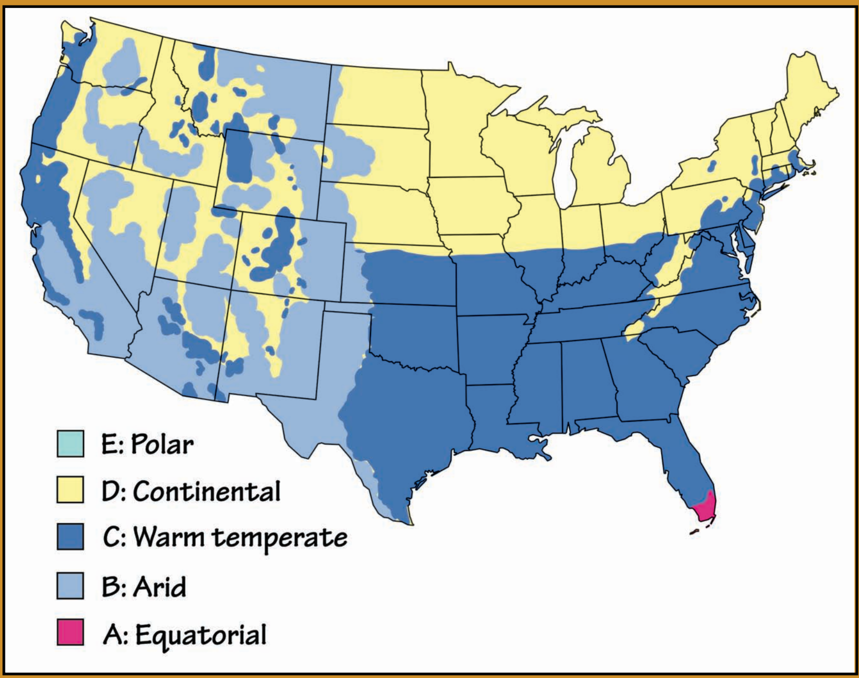
Present Climate of the Southeast

The location of the Southeast and its direct relationship to the Gulf of Mexico and Atlantic Ocean strongly influence the area's weather. Since it encompasses locations along the coast as well as areas farther inland, the Southeast experiences nearly every variety of extreme weather. Heat and cold waves, droughts, floods, blizzards, **tornados**, and **hurricanes** are all considerations for residents of the Southeast.

See Chapter 9: Earth Hazards for more information on extreme weather in the Southeast.

The Köppen Climate Map

Wladimir Köppen developed a commonly used system of climate categorization based on the kinds of vegetation areas sustain. He defined 12 climate types, many of which are familiar: rainforest, monsoon, tropical savanna, humid subtropical, humid continental, oceanic, Mediterranean, steppe, subarctic, tundra, polar ice cap, and desert. Updated by Rudolf Geiger, it has been refined to five groups, each with two to four subgroups.



(See TFG website for full-color version.)

In a broad sense, the Southeast's climate is mostly mild and humid, with much of the region characterized as warm temperate (represented by "C" in the Köppen system). The Southeast does contain other climate zones, however, with a tropical equatorial climate (represented by "A") in southern Florida and areas of moist, continental climate (represented by "D" at higher elevations in the Appalachians.

Present

mastodon • *an extinct terrestrial mammal belonging to the Order Proboscidea, characterized by an elephant-like shape and size, and massive molar teeth with conical projections.*

mammoth • *an extinct terrestrial mammal belonging to the Order Proboscidea, from the same line that gave rise to African and Asian elephants.*

tornado • *a vertical funnel-shaped storm with a visible horizontal rotation.*

hurricane • *a rapidly rotating storm system with heavy winds, a low-pressure center, and a spiral arrangement of thunderstorms.*

8 Climate

Past

topography • *the landscape of an area, including the presence or absence of hills and the slopes between high and low areas.*

Although much of the Southeast falls within the category of a warm temperate zone, using a single label to describe the Southeast's climate would belie its diversity. The main features that influence the Southeast's climate are latitude, the presence of the Atlantic Ocean and the Gulf of Mexico, and regional **topography**. For example, the Florida peninsula has a distinct summer rainy season, while other inland areas receive uniform precipitation all year round, and the highest elevations in North Carolina and Tennessee can receive as much snow as parts of New England.

Average temperatures in the Southeast tend to decrease northward, which is simply the influence of latitude: lower latitudes receive more heat from the sun over the course of a year. The warmest temperatures are found in Florida, Georgia, and Mississippi, while the coolest are found in West Virginia and Virginia (*Figure 8.8*). The Southeast's overall average high temperature of 22°C (72°F) and average low of 9°C (48°F) are indicative, on the whole, of a more uniform climate than that found in most other parts of the United States. By comparison, the average high and low temperatures for the entire United States are 17°C (63°F) and 5°C (41°F), respectively.

Another factor besides latitude that influences temperature in the Southeast is proximity to the ocean, which has a moderating influence. Air masses that have passed the Gulf of Mexico rarely get either extremely hot or extremely cold, and the Gulf Stream current that travels northward past the Atlantic seaboard carries warm tropical water with it, influencing temperatures on land. Thus the most extreme temperatures in the Southeast are found toward the center of the continent: record high and low temperatures are both held by Kentucky, which has experienced a high of 46°C (114°F) and a low of −38°C (−37°F). Of course, major temperature fluctuations can occur in every state. In July, average daily maximum temperatures range from 35°C (95°F) in southern Georgia and Florida to 24°C (75°F) in mountainous parts of West Virginia. Wintertime has a broader range of temperatures, with average daily minimums in January varying from around −7°C (20°F) in northern Kentucky to 16°C (60°F) in South Florida. Although the Southeast's climate is subtropical, it can get cold, and sub-freezing temperatures are sometimes a concern for Florida orange growers.

Average Annual Temperatures			
	Overall (ºC [ºF])	**Low (ºC [ºF])**	**High (ºC [ºF])**
Florida	22.0 (71.6)	16.7 (62.1)	27.5 (81.5)
Georgia	17.3 (63.1)	11.0 (51.8)	23.7 (74.7)
Mississippi	17.2 (63.0)	10.9 (51.6)	23.4 (74.1)
South Carolina	16.9 (62.4)	10.6 (51.1)	23.2 (73.8)
Alabama	15.8 (60.4)	9.7 (49.5)	22.1 (71.8)
North Carolina	14.6 (58.3)	8.5 (47.3)	20.8 (69.4)
Tennessee	14.2 (57.6)	7.9 (46.2)	20.5 (68.9)
Kentucky	13.3 (55.9)	7.0 (44.6)	19.6 (67.3)
Virginia	12.3 (54.1)	6.2 (43.2)	18.5 (65.3)
West Virginia	10.9 (51.6)	4.5 (40.1)	17.0 (62.6)

Present

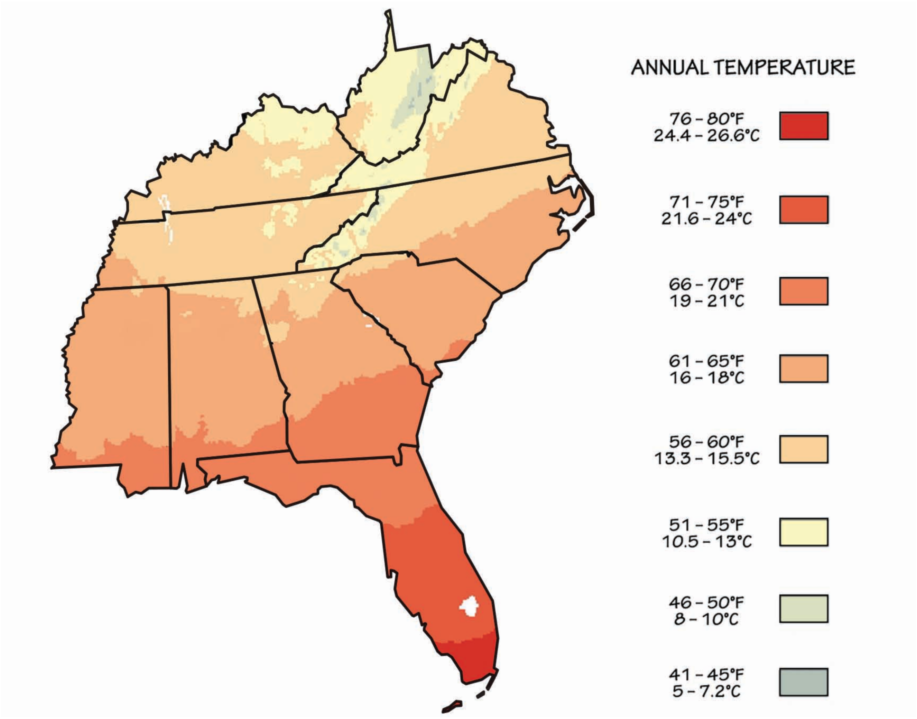


Figure 8.8: Mean annual temperature for the Southeastern states. (See TFG website for full-color version.)

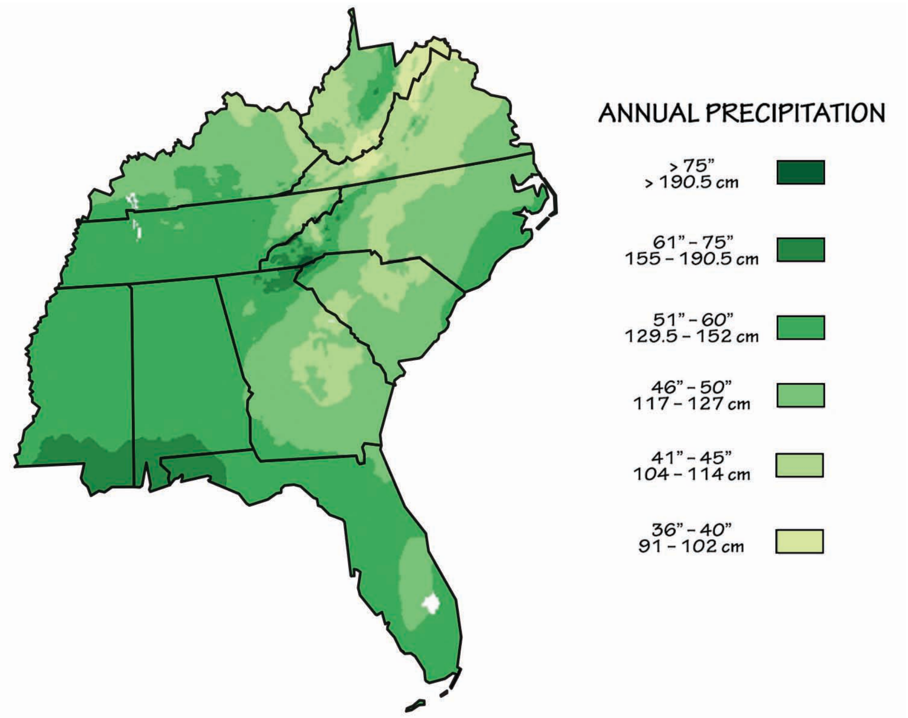


Figure 8.9: Mean annual precipitation for the Southeastern states. (See TFG website for full-color version.)

8 Climate

Present

convection • *the rise of buoyant material and the sinking of denser material.*

The average amount of precipitation for the United States is 85.6 centimeters (33.7 inches). In the Southeast, however, average annual precipitation typically ranges from about 100 to 125 centimeters (40 to 50 inches) inland to over 150 centimeters (60 inches) along the Gulf Coast of Mississippi, Alabama, and the Florida Panhandle (*Figure 8.9*), demonstrating the impact of moisture carried inland from the adjacent Gulf of Mexico. Some pockets of high precipitation also occur in the Appalachian Mountains (along the Eastern Continental Divide, a topographical high point where air is forced upward from both sides of the mountain range), and along the Atlantic coast.

Snow is not unusual during winter in the northern parts of the Southeast, and in the summer and fall tropical cyclones (hurricanes) often bring heavy rains to the Gulf and Atlantic coasts. Some of these cyclones, such as Hurricane Andrew in 1992, are extremely powerful and have devastated communities in the Southeast. Thousand-year weather events, referring to the 1-in-1000 chance of intense events happening in a given year, have increased in frequency in recent years, and climate models predict a continuation of that increase. One such event occurred in the fall of 2015 when heavy rains associated with Hurricane Joaquin (but not actually part of the hurricane) brought over 50 centimeters (20 inches) of rain to parts of South Carolina, causing over one billion dollars in damage.

See Chapter 9: Earth Hazards to learn more about hurricanes, tornadoes, and other severe storm events.

Severe thunderstorms and tornados are an additional threat—the geography and climate of the Southeast are nearly ideal for their formation, especially in the summer. Only Kansas has more tornados per square mile than Florida, and several other Southeastern states rank in the top ten for tornado frequency (*Figure 8.10*). Tornados often accompany severe thunderstorms, so where tornados occur, thunderstorms are likely. Storms occur when there is strong **convection** in the atmosphere. Because warm air can hold more moisture than cool air can, convective mixing with cool air forces moisture to condense out of warm air, as vapor (clouds) and precipitation. It is hypothesized that the formation of precipitation causes the electrical charging that produces lightning. Of course, air cannot mix without moving, and that movement is caused by the wind.

A strong temperature difference at different heights creates instability—the warmer the air near the surface is relative to the air above it, the more potential energy it has to move up. The Southeast receives warm, moist air moving north from the Gulf of Mexico, and cold, dry air moving in from the Rocky Mountains and the northern US. Where these air masses meet, vigorous mixing causes storms. Typically, a storm blows itself out once the warm air has moved up and the cool air down—a vertical column turning over as a unit. But because the lower air from the Gulf is moving north (or in Florida, to the north or the east) while air higher up is moving west, more heat and moisture is constantly added to the system, allowing the storm to persist and strengthen. This movement in different directions is also the reason for the Southeast's unusually high incidence of powerful tornados.

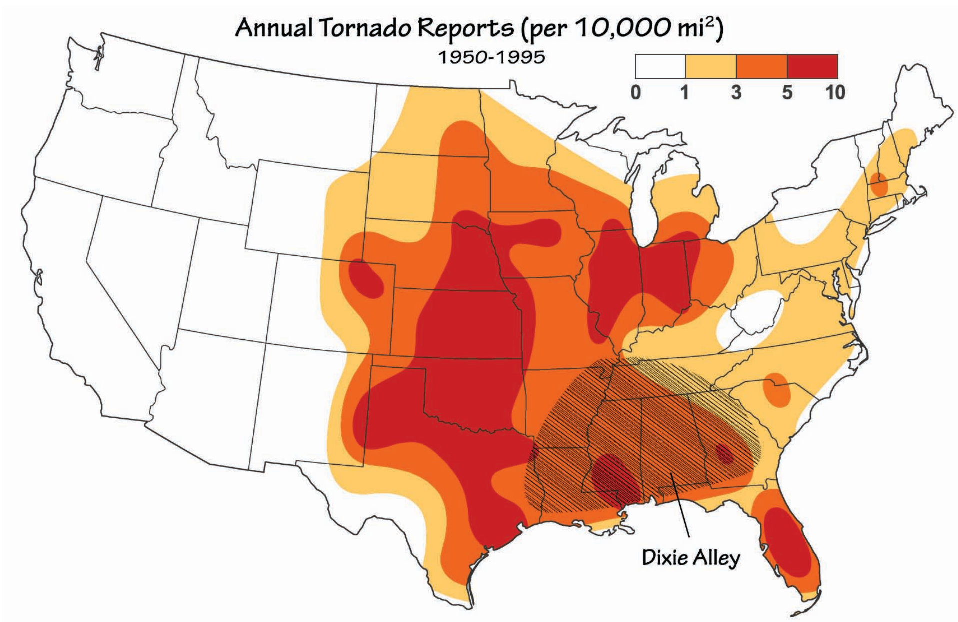


Figure 8.10: Frequency of tornados in the continental US. "Dixie Alley" is an area of the Southeast known for its violent tornados. (See TFG website for full-color version.)

Florida is commonly in the path of hurricanes and tropical storms that move across the Mid-Atlantic and Gulf. The climate of the state's north and central parts is humid subtropical, while southern Florida has a tropical savanna climate. There is a defined rainy season from May through October, when thunderstorms built in the heat of day drop heavy but brief summer rainfall.

In much of the lower Southeast, the climate is typical of a humid subtropical zone, characterized by temperate winters, long, hot summers, and rainfall that is fairly evenly distributed through the year. In Georgia, as elevations in the state range from sea level at the Atlantic coast to the summit of Brasstown Bald at 1458 meters (4784 feet), the climate varies considerably, but snow and prolonged freezing temperatures are uncommon throughout the state. In Mississippi and Alabama, thunderstorms occur throughout the year, most commonly in the summer, but are most destructive in the fall and spring. These states are also commonly in the path of tropical storms and hurricanes moving northward off of the Gulf. Freezing temperatures reach to the Gulf Coast in most winters, but they rarely persist. South Carolina's humid subtropical climate arises from the combination of the state's relatively low latitude, its generally low elevation, the proximity of the warm Gulf Stream, and the Appalachian Mountains, which in winter help to block cold air from the interior of the United States. Most precipitation falls in spring and summer. While cold weather occurs each winter, its duration tends to be brief; snow is uncommon and generally occurs only in the mountains and upper Piedmont.

See Chapter 4: Topography for a list of highest and lowest elevations by state.

8 Climate

Present

In North Carolina, the climate varies from the Atlantic coast in the east to the Appalachian Mountains in the west. As in South Carolina, the Appalachians help to block cold air from the interior of the United States and storms from the Midwest from entering the Piedmont of North Carolina. Most of the state has a humid subtropical climate, except in the higher elevations of the Appalachian Mountains, which have a subtropical highland climate.

Tennessee's varied topography leads to a wide range of climatic conditions, though generally the state has a temperate climate, with warm summers and mild winters. Most of the state has a humid subtropical climate, with the exception of some of the higher elevations in the Appalachian Mountains, which are classified as having a mountain temperate climate or a humid continental climate. Severe storms occur infrequently. The state has hot summers and mild to cool winters with generous precipitation throughout the year, with the highest average monthly precipitation generally occurring in the winter and spring months, between December and April. Snowfall varies and is more prevalent in eastern Tennessee than in the western section; Nashville gets about 25 centimeters (10 inches) a year, Memphis only 13 centimeters (5 inches).

Kentucky experiences four distinct seasons, with substantial variations in the severity of summer and winter, but extreme cold is rare. Fall is normally the state's dry season, while the spring season is typically the wettest, but precipitation does not vary greatly throughout the year. Thunderstorms are responsible for much of Kentucky's summer rainfall, and they often bring intense rain that may be highly localized. Generally, Kentucky experiences relatively humid rainy and warm summers, and moderately cold winters where snow is not especially uncommon, with occasional extreme snows. Snow cover seldom persists for more than a week in the south or for more than two weeks in the north.

The climate of Virginia is considered mild for the United States. Most of Virginia east of the Blue Ridge Mountains, the southern part of the Shenandoah Valley, and the Roanoke Valley, all have a humid subtropical climate, though the range of topography yields a range of climate types. According to the University of Virginia Climate Office, the state has five different climate regions: the Tidewater, Piedmont, Northern Virginia, Western Mountain, and Southwestern Mountain regions. Some localities, including Charlottesville, have long growing seasons and infrequent subzero temperature minimums, while winters on the northern Blue Ridge frequently produce bitterly cold temperatures like those of Chicago. Similarly, annual rainfall totals can vary from a fairly dry 84 centimeters (33 inches) typical of the Shenandoah Valley to more than 150 centimeters (60 inches) in the mountains of southwestern Virginia. Severe weather, in the form of tornados, tropical storms, and winter storms, impacts the state on a regular basis. Areas of Virginia have seen substantial snowstorms in recent years.

Future Climate of the Southeast

By using techniques that help to reconstruct past climates, and by tracking trends in the present, we can predict how current climates might change. Overall, the world is warming, yet, as we are still in an ice age, eventually the current **interglacial** period should end, allowing glaciers to advance towards the equator again (although likely not for about 100,000 years). However, because the Earth is already getting warmer, the effects of **anthropogenic** warming are amplified through feedback. Some scientists worry that, if not curbed, human activity could actually disrupt the cycle and knock the planet entirely out of the interglacial period, melting all the ice on Earth.

interglacial • *a period of geologic time between two successive glacial stages.*

anthropogenic • *caused or created by human activity.*

fossil fuels • *fuel for human use that is made from the remains of ancient biomass.*

Causes of Change

While astronomical and tectonic forces will continue to cause climatic shifts, they act so slowly that they will be overshadowed in the near term by human- induced effects. In 1956, NOAA established the Mauna Loa Observatory (MLO) in Hawai'i to measure a variety of atmospheric parameters, including carbon dioxide (CO_2) concentration. The CO_2 record extends from 1958 to present, and it shows the influence of both natural and anthropogenic processes (*Figure 8.11*). The zigzag pattern is the result of seasonal photosynthesis in the Northern Hemisphere. In spring and summer, the growth and increased photosynthetic activity of plants draws CO_2 out of the atmosphere. Conversely, it accumulates in the atmosphere during fall and winter when plants are dormant. The overall upward trend is caused by human activity. Industrialization, **fossil fuel** combustion, and deforestation all contribute CO_2 to the atmosphere, adding it at a rate much faster than natural processes can remove it. Analyses of ancient atmosphere samples preserved in glacial ice cores show CO_2 levels to be 180 parts per million (ppm) at the height of the last ice age and 280 ppm at its end. The amount of CO_2 in the atmosphere has been increasing at a rapid rate since the start of the industrial revolution, and it has accelerated since the end of World War II. In May 2013, measurements at MLO reached 400 ppm CO_2 for the first time.

The Earth's orbit, tilt, and wobble alter its position with respect to the Sun, affecting the global climate. These changes in the Earth's movement are cyclical, and the changes in Earth's climate associated with them are known as *Milankovitch cycles.*

While some atmospheric carbon dioxide is necessary to keep Earth warm enough to be a habitable planet, the unprecedentedly rapid input of CO_2 to the atmosphere by human beings is cause for concern. Everything we know about atmospheric physics and chemistry tells us that increased CO_2 leads to a warmer planet. Multiple paleoclimate data sets verify this conclusion, and modern measurements confirm that we are living in an increasingly warmer world. The increasing heat is causing glaciers and sea ice around the globe to melt, and as the ground and ocean they covered is exposed, these darker surfaces absorb and re-radiate increasing amounts of heat.

Climate

Future

permafrost • *a layer of soil below the surface that remains frozen all year round. Its thickness can range from tens of centimeters to a few meters.*

soil • *the collection of natural materials that collect on Earth's surface, above the bedrock.*

aerosol • *tiny solid or liquid particles in the air.*

petroleum • *a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface.*

fuel • *a material substance possessing internal potential energy that can be transferred to the surroundings for specific uses.*

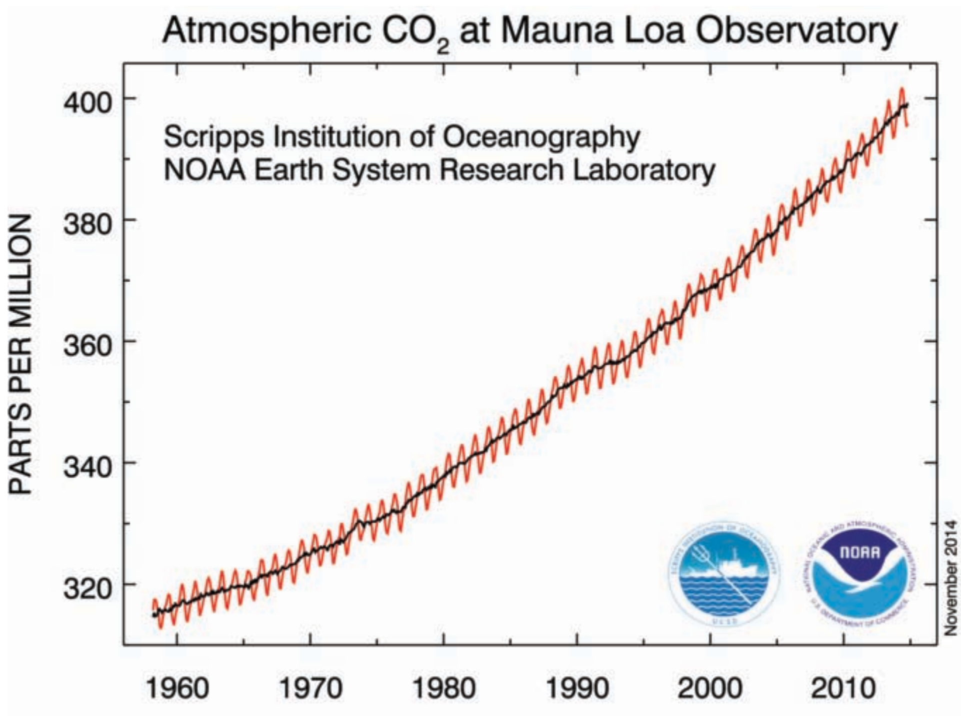


Figure 8.11: Measured concentration of atmospheric carbon dioxide (1958 to present) at MLO.

As **permafrost** in high latitudes melts, carbon in the **soil** becomes free to enter the atmosphere and, worse, buried organic material can be converted by bacteria into the even more potent greenhouse gas, methane. Less directly, higher temperatures lead to more frequent and severe droughts, which, in turn, lead to more wildfires that release carbon and **aerosols** into the atmosphere. Aerosols can have a cooling effect as they reflect away radiation from the sun, but they can also pose a public health hazard.

Water is extremely good at absorbing heat: water vapor is actually the most effective greenhouse gas. Higher temperatures increase evaporation and allow the air to retain more water. While water vapor feedback is the most significant reinforcer of climate warming, water tends to move out of the atmosphere in a matter of weeks—other greenhouse gases, such as carbon dioxide and methane, linger in the atmosphere for years.

The Southeast contributes significantly to climate change. The population of any industrialized and particularly wealthy country produces pollution; the majority of these emissions come from the use of **petroleum**. The more than 70 million residents of the Southeast use carbon-rich fossil **fuels** to provide electricity for lighting, cooling, and appliances, to fuel their transportation and industry, and to make the products they use. Burning those fossil fuels releases carbon into the atmosphere, which warms the Earth. Of the Southeastern states, Florida emits the most greenhouse gases, releasing 218 million metric tons of carbon dioxide per year—the fourth highest in the nation (Texas, the highest producer, releases nearly 656 million metric tons of CO_2 per year). Greenhouse gas emissions continue to grow in some areas; over the last decade, Kentucky's emissions have increased by about 2% thanks to the state's reliance on coal as an energy source.

On the other hand, Southeastern states are making changes to reduce human impact on the climate. Virginia, Tennessee, and North Carolina have all reduced their CO_2 emissions by more than 22 metric tons in the last decade. The city of Richmond, Virginia and the County of Sarasota, Florida were early adopters of the 2030 Challenge, an effort to reduce fossil fuel use in buildings so that both new and renovated buildings would qualify as carbon neutral by the year 2030. Additionally, many states are stepping up their use and production of **renewable energy**. As of 2014, Tennessee ranks 19th in the nation for renewable energy production, much of which it produces from hydroelectricity and **biomass**.

Trends and Predictions

Studies show that the Southeast's climate is changing right now, and that change has accelerated in the latter part of the 20th century. These changes include the following:

- The number of days with temperatures above 35°C (95°F) and nights above 24°C (75°F) has been steadily increasing since 1970 (*Figures 8.12 and 8.13*).
- In 2007, severe drought cost Georgia's agricultural industry over $339 million in crop losses.
- Rising seas and storm surges jeopardize the infrastructure of coastal cities. Southern Florida and the Chesapeake Bay are ranked the first and third most vulnerable US areas to sea level rise, respectively.
- The Floridian aquifer system, which provides fresh water to the majority of Florida as well as southern Georgia, has dropped by more than 18 meters (60 feet) in some areas, and is threatened by saltwater intrusion.
- Locations along the Gulf of Mexico have experienced over 20 centimeters (8 inches) of sea level rise in the last 50 years.
- The minimum annual rate of streamflow in many areas of the Southeast has decreased by as much as 50%.
- Altered flowering patterns due to more frost-free days have increased the Southeast's pollen season for ragweed, a potent allergen.
- Unique ecosystems in the Southeast, such as the Ice Mountain Preserve in West Virginia (a unique **boreal** zone), face adverse effects from warming temperatures.

Future

renewable energy • *energy obtained from sources that are virtually inexhaustible (defined in terms of comparison to the lifetime of the Sun) and replenish naturally over small time scales relative to human life spans.*

biomass • *organic material from one or more organisms.*

boreal • *a cold temperate region relating to or characteristic of the sub-Arctic climatic zone.*

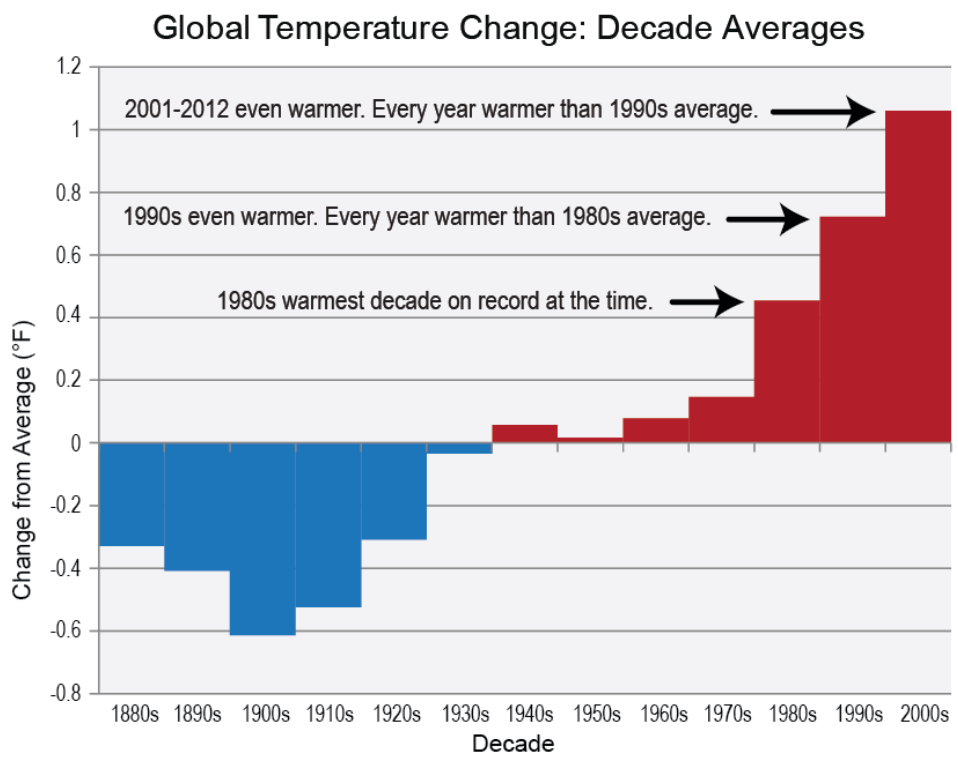


Figure 8.12: Global temperature change since the 1880s. The Earth's average surface temperature has progressively risen over the last five decades.

Climate models predict that the Southeast's climate will continue to warm, and that the average annual temperature in most of the area will rise 1° to 6°C (2° to 11°F) by the end of the 21st century. The strongest warming is projected to occur inland, in the Southeast's northwestern corner. Winter temperatures have risen the most—today, most of the Southeast experiences four to seven fewer freezing days than it did in the 1970s. By the middle of the 21st century one can expect 20 to 30 more days of freeze-free weather each year (*Figure 8.13*). Currently, the northern part of the Southeast typically has ten days a year with temperatures below −12°C (10°F). By the middle of the 21st century we can expect no days with temperatures that low. These increased temperatures lead to a whole host of other effects, including drier soils from more evaporation, and the increased likelihood of drought and fires.

Precipitation has become more variable from year to year, and heavy downpours have increased in the last 20 years. Because higher temperatures mean greater evaporation and warmer air can hold more water, precipitation will occur in greater amounts at a time, but less frequently (*Figure 8.14*) Some models predict as much as 20% more winter precipitation in the Southeast's northern and southern extremes. These models also predict more rain in the spring and fall but less in the summer, except along the Coastal Plain (excluding Florida). The causes of specific weather events such as hurricanes and severe thunderstorms are incredibly complex, although climate change has enhanced

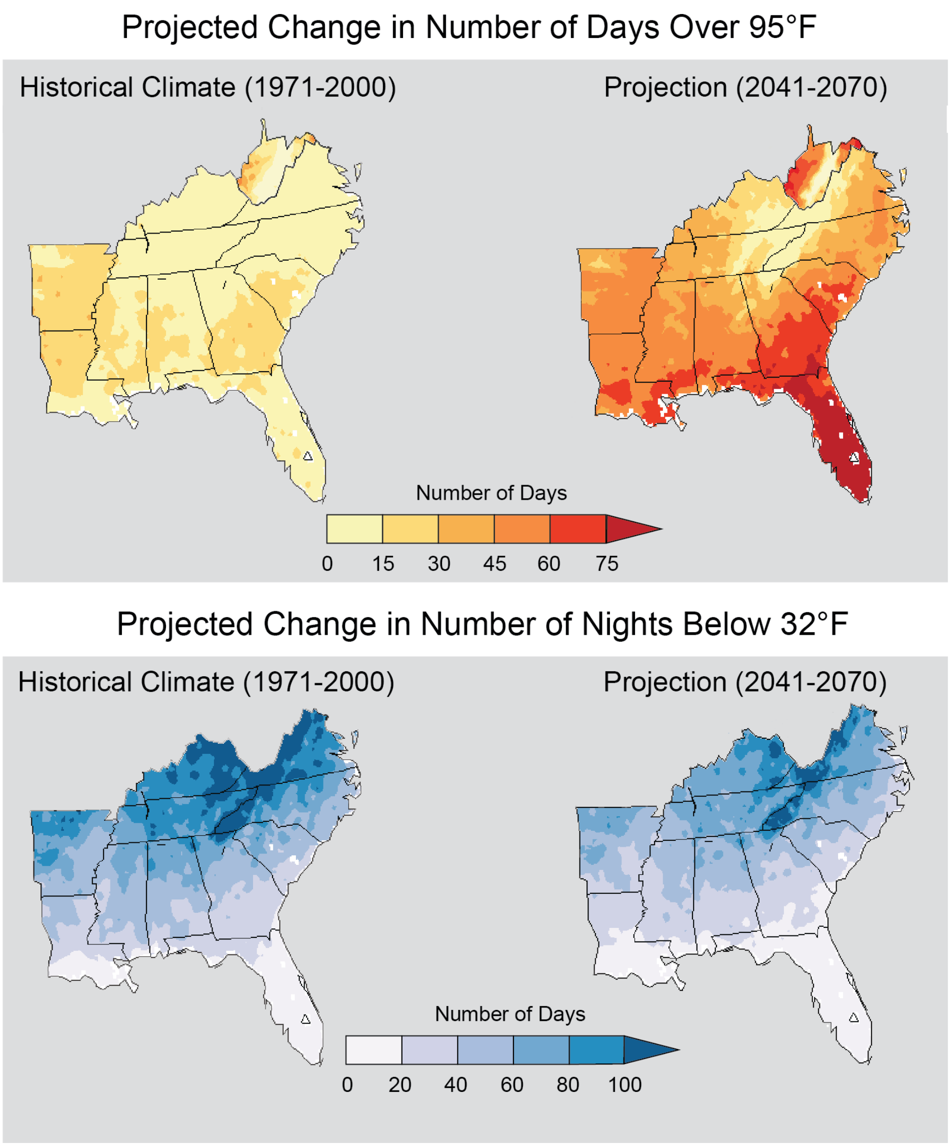


Figure 8.13: Projected changes in number of days over 35°C (95°F) and number of nights below 0°C (32°F) for the Southeast over the next several decades.

some correlated factors, such as increased wind speed and an unstable atmosphere. Higher atmospheric moisture content has also been correlated with an increased incidence of tornados and winter storms. However, although climate change is predicted to enhance the intensity of severe weather, there is currently no way to calculate what effect climate change will have on the frequency of specific storm events—for example, we might see more powerful tornados, but we do not know if we will see *more* of them.

Water supply is an important issue in the Southeast, and communities will need to adapt to changes in precipitation, snowmelt, and runoff as the climate changes. Drier days and higher temperatures will amplify evaporation, increasing the

Future

aquifer • *a water-bearing formation of gravel, permeable rock, or sand that is capable of providing water, in usable quantities, to springs or wells.*

global warming • *the current increase in the average temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere.*

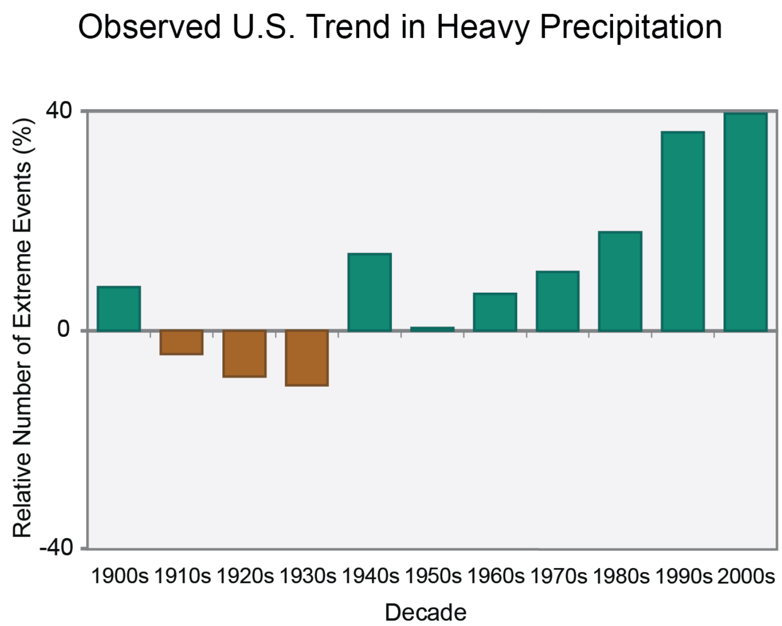


Figure 8.14: Changes in heavy precipitation events from the 1900s to the 2000s. Each event is defined as a two-day precipitation total that is exceeded, on average, only once every five years. The occurrence of such events has become increasingly common.

desertification of already arid areas and affecting natural ecosystems as well as increasing pressure on the water supply for agriculture and cities. In low-lying areas, especially Florida, important **aquifers** are at extreme risk of being contaminated by saltwater thanks to rising sea levels.

More than 50% of the American population currently lives in coastal areas. With increased **global warming**, sea level rise and the likelihood of increased incidences of extreme weather are expected, including an increase in hurricane intensity and associated storm surge. Sea level rise from melting glaciers and the thermal expansion of a warmer ocean is a major concern in the Southeast, with its extensive coastline and many low-lying areas, including major cities such as Miami, Tampa, and Charleston (*Figure 8.15*). A rising sea leads to retreating tidal forests, coastal erosion, larger and more damaging storm surges, inundation of populated areas, and stresses on municipal water and sewer systems. Increased inland flooding will impair stormwater drainage systems that empty into the ocean and destroy tidal wetlands, reducing environmental protection against storm surge and decreasing important fishery habitat. Oil and gas production infrastructure located in areas protected by barrier islands will be at greater risk to storm surge, affecting our ability to develop energy resources. Regional studies project that by 2030, climate change could cause $4.6 billion in damages to coastal property and assets on the Gulf Coast alone. By the year 2060, the sea level in Key West, Florida is expected to be between 23 and 61 centimeters (9 and 24 inches) higher than in 2010. By the end of the 21st century, the sea level around the Southeast is predicted to rise by as much as one meter (3 feet) (*Figure 8.16*).

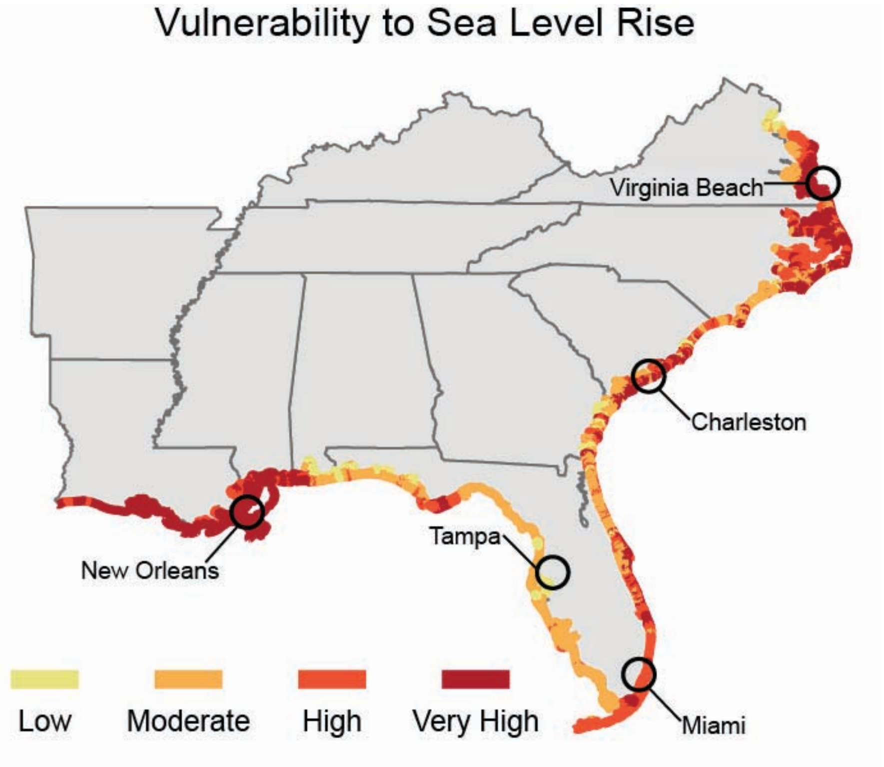


Figure 8.15: The Coastal Vulnerability Index displays the relative risk that physical changes will occur along southeastern coastlines as sea level rises. (See TFG website for full-color version.)

Figure 8.16: Projected land loss in Florida and the Southeast, marked by areas in blue, following a one-meter (three-foot) rise in sea level. (See TFG website for full-color version.)

Resources

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Chapter 9: Earth Hazards of the Southeastern US

Natural hazards or earth hazards are events or processes that have significant impacts on human beings and the environment. Extreme **weather** conditions or geologic activity can cause substantial short-term or long-term changes to our environment. These changes can influence many aspects of the world around us, including crops, homes, infrastructure, and the **atmosphere**. The 4.6-billion-year-old Earth has experienced many naturally generated hazards, while other events are byproducts of human activities, created during mineral and **energy** extraction or in construction practices that modify the landscape.

The Southeast is subject to a variety of earth hazards. Most famously, the area happens to have just the right combination of conditions for tornados that cross the region and hurricanes that impact the Gulf and Atlantic Coastal plains. Modifications of the Mississippi River and its mouth, as well as the Southeast's coastline, have exacerbated the impacts of storms and floods. **Limestone**, **gypsum**, and **salt** deposits are responsible for significant areas of **karst topography** and sinkholes. Like many parts of the country, **landslides** from expansive soils and exposure to radioactivity from **radon** are present, depending upon the nature of the local bedrock. Perhaps most surprisingly, despite being far from a plate boundary, certain areas of the Southeast are at risk from large **earthquakes** due to occasional movement along large ancient **faults**.

Earthquakes

Earthquakes occur when a critical amount of stress is applied to the Earth's **crust** and the crust responds by moving. According to the elastic rebound theory, rocks can bend elastically up to a point, until they finally break. The rocks then snap apart, releasing energy in the form of **seismic waves** (*Figure 9.1*). The plane defined by the rupture is known as a fault, and the surrounding rock layers become offset along it.

Many earthquakes, including most of those that occur in the Southeastern US, arise along pre-existing faults. In cases such as these, stress may accumulate from lateral **compressive** pressure, as the rocks are temporarily locked in position by friction and other constraints, until sufficient strain energy has built up to cause sudden slippage along the fault (i.e., an earthquake).

There are two common ways to measure the size of earthquakes: **magnitude** and intensity. Magnitude (M) is the measure of the energy released by the earthquake, whereas the intensity is what people actually experience. The

weather • *the measure of short-term conditions of the atmosphere such as temperature, wind speed, and humidity.*

atmosphere • *a layer of gases surrounding a planet.*

energy • *the power derived from the use of physical or chemical resources.*

limestone • *a sedimentary rock composed of calcium carbonate ($CaCO_3$).*

gypsum • *a soft sulfate mineral that is widely mined for its use as fertilizer and as a constituent of plaster.*

CHAPTER AUTHOR

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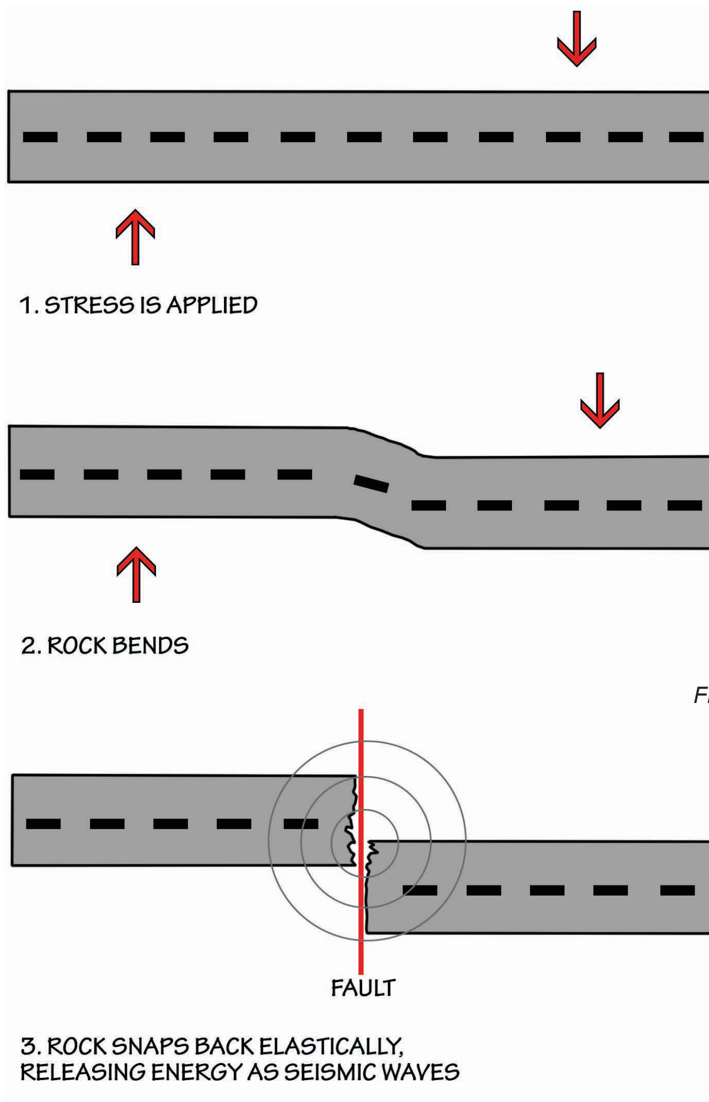

Figure 9.1: Elastic rebound.

first scale used to measure magnitude was the Richter scale (abbreviated M_L), which measures the amplitude of a seismic wave at a defined distance from the source of the earthquake. The Richter scale was designed to classify earthquakes at a local scale, but it does not do a very good job of describing the energy released by very large earthquakes. Geologists therefore developed another measurement, the Moment Magnitude scale (abbreviated M_w), which was introduced in 1979. The Moment Magnitude estimates the total energy released by an earthquake along an entire fault surface.

Both the Richter and Moment Magnitude scales are logarithmic, meaning that an M9.0 earthquake has 10 times the amplitude, and releases 32 times the energy, of an M8.0 earthquake. Accordingly, an M9.0 earthquake would have 100 times the amplitude and 1024 times the energy of an M7.0 earthquake.

Both scales may appear to reach maximum values of 10 (since the largest recorded earthquakes are slightly greater than 9), but technically there is no upper limit. The United States Geological Survey (USGS) describes earthquakes as *minor* (M3.0–3.9), *light* (M4.0–4.9), *moderate* (M5.0–5.9), *strong* (M6.0–6.9), *major* (M7.0–7.9), and *great* (M8.0 and higher). The largest recorded earthquake in US history was the 1964 Alaskan earthquake, which had an M_w of 9.2. By comparison, the largest recorded earthquake in the Southeast occurred in 1886 in Charleston, South Carolina (M7.3).

The 1964 Alaskan earthquake and the 1906 San Francisco earthquake had roughly the same Richter magnitudes, but based on the size of the affected areas and geological movement, the Alaskan earthquake clearly released more energy than the San Francisco earthquake did. Geologists recalculated the magnitudes of these major quakes using the Moment Magnitude scale: the 1964 Alaskan earthquake, which originally had an M_L of 8.3, was found to have had an M_W of 9.2, whereas the 1906 San Francisco earthquake had an M_L of 8.3 and an M_W of 7.9.

Notable Earthquakes of the Southeastern States		
Date	**Location**	**M_w**
08-31-1886	Charleston, SC	7.3
05-31-1897	Giles County, VA	5.9
08-23-2011	Louisa County, VA	5.8
02-21-1916	Waynesville, NC	5.2
07-27-1980	Sharpsburg, KY	5.2
10-18-1916	Irondale, AL	5.1
08-17-1865	Memphis, TN	5.0
12-16-1931	Charleston, MS	4.6
11-19-1969	Glen Lyn, WV	4.5

Earthquakes are much less common in the eastern US than in the west. This is primarily because the east coast of North America is a **passive margin**; that is, it is located in the center of a tectonic **plate** rather than at an **active plate margin**. All earthquakes that occur in the eastern US are therefore referred to as "intraplate" earthquakes. Eastern quakes, however, are typically felt over a much larger region than western quakes of similar magnitude. For example, in the Southeast an earthquake of magnitude 5.5 can usually be felt as far as 480 kilometers (300 miles) from where it occurred, and sometimes causes damage as far away as 40 kilometers (25 miles). This appears to be because the bedrock that makes up most of the eastern US is older, colder, drier, and less **fractured** than rocks in the western US. As a result, although earthquakes

passive margin • *a tectonically quiet continental edge where crustal collision or rifting is not occurring.*

plates • *large, rigid pieces of the Earth's crust and upper mantle, which move and interact with one another at their boundaries.*

active plate margin • *the boundary between two plates of the Earth's crust that are colliding, pulling apart, or moving past each other.*

fracture • *a physical property of minerals, formed when a mineral crystal breaks.*

Earthquakes

density • *a physical property of minerals, describing the mineral's mass per volume.*

intensity • *a subjective measurement that classifies the amount of shaking and damage done by an earthquake in a particular area.*

here release the same amount of energy as other earthquakes, the shaking affects a much larger area because the seismic waves travel through **denser**, more solid bedrock.

The magnitude of an earthquake does not tell us how much damage it causes. The amount of shaking and damage is known as the earthquake's **intensity**, and it can be measured by the Modified Mercalli Intensity (MMI) scale. This scale uses the Roman numerals I–XII to describe the effects of the earthquake in a particular location. For example, near the epicenter of a small earthquake, or at a location far from a large earthquake, the intensity may be described with an MMI of II: "*Felt only by a few persons at rest, especially on the upper floors of buildings. Delicately suspended objects may swing."* Unlike the Moment Magnitude scale, the MMI scale is a subjective gauge, and the USGS has attempted to improve the accuracy of MMI shake maps by soliciting data from the public. *Figure 9.2* shows the intensities felt in surrounding areas after the 1886 earthquake in Charleston, South Carolina, which is the largest earthquake known to have occurred in the state.

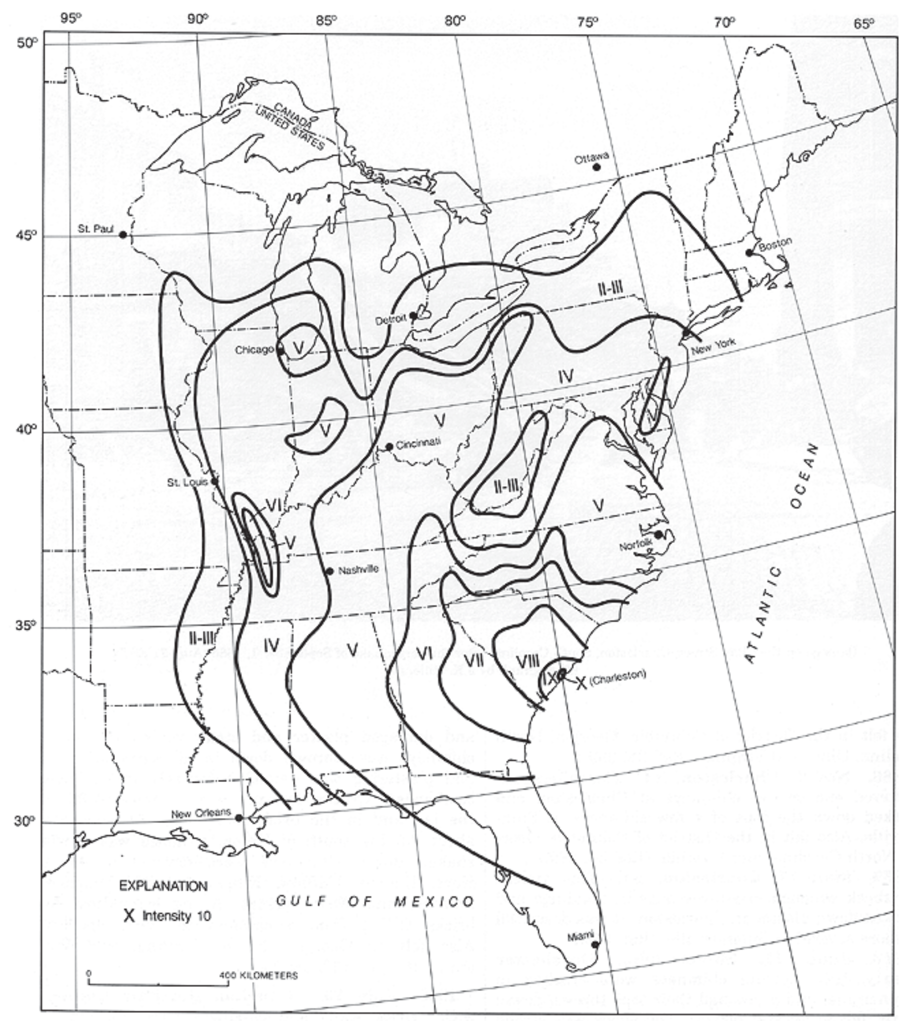

Figure 9.2: Intensity map of the 1886 Charleston earthquake.

Earth Hazards

9

Earthquakes

There are four major **seismic zones** in the Southeastern states (*Figure 9.3; see also Figure 9.5*): the New Madrid Seismic Zone, the Southern Appalachian Seismic Zone, the South Carolina Seismic Zone, and the Virginia Seismic Zone. The *New Madrid Seismic Zone* (NMSZ, also called the New Madrid Fault Line or Fault System) is a 240-kilometer (150-mile) set of subsurface faults thought to have formed during the breakup of the supercontinent **Rodinia** in the late **Precambrian** (about 750 million years ago). Although this rift did not split the continent, it remains an underground weak point—most of the zone's seismicity is located 5–24 kilometers (3–15 miles) beneath the surface. Faults in the NMSZ are occasionally reactivated by the relatively small east-west compressive forces associated with continuing continental drift of the North American plate, making the area unusually prone to earthquakes.

seismic zone • *a regional zone that encompasses areas prone to seismic hazards, such as earthquakes or landslides.*

Rodinia • *a supercontinent that contained most or all of Earth's landmass, between 1.1 billion and 750 million years ago, during the Precambrian.*

Precambrian • *a geologic time interval that spans from the formation of Earth (4.6 billion years ago) to the beginning of the Cambrian (541 million years ago).*

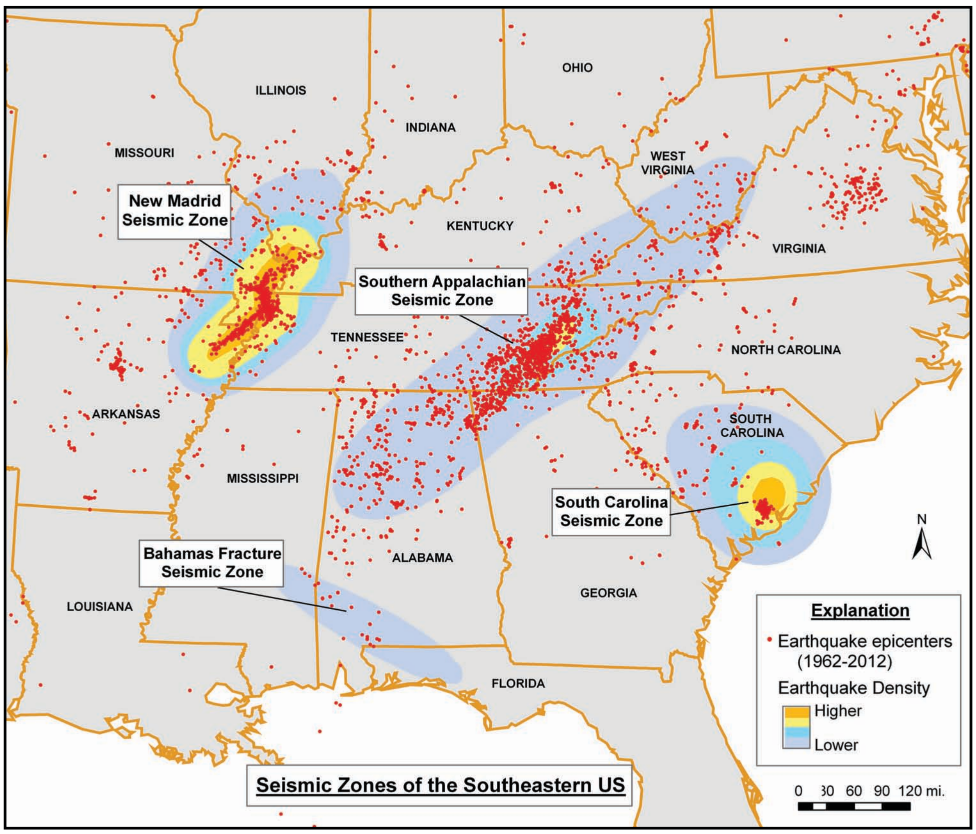

Figure 9.3: Seismic Zones in the Southeastern US. (See TFG website for full-color version.)

The NMSZ has been the source of numerous earthquakes in western Kentucky, Tennessee, and Mississippi. Four of the largest earthquakes in North American history—the New Madrid Sequence—occurred in the NMSZ on three days over a period of three months: December 16, 1811, January 23, 1812, and February 7, 1812. The quakes, with estimated magnitudes between 7.0 and 8.0, occurred along the Mississippi River in southeastern Missouri and northern Arkansas. While much of the damage was confined to Missouri and Arkansas, the tremors shook the Mississippi Valley and much of the eastern United States, destroying buildings and warping the ground. In Kentucky and Tennessee, landslides

Earthquakes

occurred along the Mississippi River bluffs and ground **subsidence** brought on by **soil liquefaction** spread across the Mississippi River **floodplain**. Shaking was felt as far away as New Orleans and Boston, where it is said to have caused church bells to ring, and the waters of the Mississippi River appeared to flow backward for several days due to local **uplift** and waves flowing upstream. Hundreds of aftershocks followed over a period of a several years, and were felt regularly until 1817.

The *South Carolina Seismic Zone* is located in the mid-coast area of South Carolina, and is believed to be caused by faults formed during the break-up of Pangea, beginning around 200 million years ago. These faults are very difficult to study, however, because they are buried beneath as much as three kilometers (two miles) of sediment. The South Carolina Seismic Zone was the site of the 1886 Charleston earthquake, which had an estimated magnitude of 7.3 and was the most damaging earthquake to occur in the Southeastern states. The quake damaged and destroyed hundreds of buildings (*Figure 9.4*), killed at least 60 people, destroyed kilometers (miles) of railroad tracks, and generated extensive craters and fissures for 1300 kilometers (810 miles) surrounding the epicenter.

The *Southern Appalachian Seismic Zone* (and its extension, the *Eastern Tennessee Seismic Zone*) runs along the Appalachian Mountains, from easternmost Tennessee to northeastern Alabama. The faults in this zone formed as a result of continental collisions that created the Appalachian Mountains in the mid- to late **Paleozoic**.

Figure 9.4: Rubble and collapsed buildings line the streets of Charleston, South Carolina, after the devastating 1886 earthquake.

***subsidence** • the sinking of an area of the land surface.*

***soil** • the collection of natural materials that collect on Earth's surface, above the bedrock.*

***liquefaction** • a process by which water-saturated unconsolidated sediment temporarily loses strength and behaves as a fluid when vibrated.*

***floodplain** • the land around a river that is prone to flooding.*

***uplift** • upward movement of the crust due to compression, subduction, or mountain building.*

***Paleozoic** • a geologic time interval that extends from 541 to 252 million years ago.*

The *Central Virginia Seismic Zone* is located in central Virginia (*Figure 9.5*), and has been a site of earthquakes at least since the 1700s. This zone is also a result of the continental collisions that created the Appalachian Mountains; its faults have been reactivated as a result of subsequent rifting and continental movement. Most recently, the Virginia earthquake of August 2011 (M5.8) occurred along a north- or northeast-striking fault in the Piedmont of Louisa County, 61 kilometers (38 miles) northwest of Richmond. No deaths and only minor injuries were reported, but minor damage to buildings was widespread and included the National Cathedral and Washington Monument in Washington, DC. The 2011 earthquake, along with a magnitude 5.8 quake on the New York-Ontario border in 1944, is the largest to have occurred in the US east of the Rocky Mountains since an 1897 temblor centered in western Virginia (M5.9). Research following the 2011 Virginia quake revealed that the farthest landslide from the epicenter was 240 kilometers (150 miles) away, by far the greatest landslide distance recorded from any other earthquake of similar magnitude (previous studies of worldwide earthquakes indicated that landslides occurred no farther than 58 kilometers [36 miles] from the epicenter of a magnitude 5.8 quake). It remains unclear exactly why this occurred.

See Chapter 1: Geologic History to learn about the tectonic events that formed North America's mountains and generated fractures and faults.

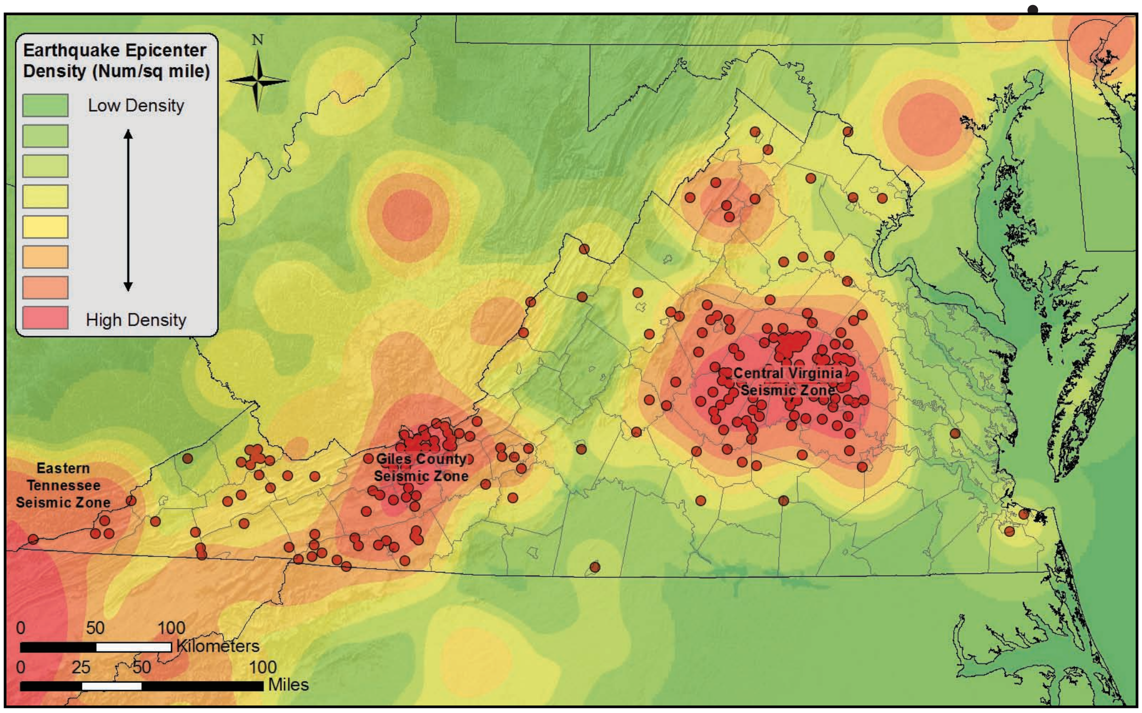

Figure 9.5: Seismic zones in Virginia. Red dots indicate known earthquake epicenters. (See TFG website for full-color version.)

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Earthquakes

Mississippi Embayment • *a topographically low-lying basin in the south-central United States, stretching from Illinois to Louisiana.*

sand • *rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

power • *the rate at which energy is transferred, usually measured in watts or, less frequently, horsepower.*

tsunami • *a series of ocean waves that are generated by sudden displacement of water, usually caused by an earthquake, landslide, or volcanic explosions.*

In the Southeast, the Coastal Plain region (including the **Mississippi Embayment**, the Gulf Coastal Plain, and the Atlantic Coastal Plain) is considered the most vulnerable since many sizeable cities in those areas have been built upon unconsolidated earth materials susceptible to liquefaction, a process by which water-saturated, unconsolidated sediment temporarily loses strength and behaves as a fluid when vibrated. This phenomenon is similar to that observed when you wiggle your toes in the wet **sand** near the water at a beach. Liquefaction brought on by an earthquake is capable of causing structures to collapse due to loss of support.

Networks of seismograph stations have improved geologists' ability to detect and accurately locate earthquake hazards (*Figure 9.6*), and specific fault zones are being studied throughout the Southeast. This information on earthquake risk can lead to better designs for high-risk infrastructure like dams, high-rise buildings, and **power** plants—and it can also be used to inform the public of potential hazards to lives and property. The hazards associated with earthquakes are mainly related to collapsing buildings and other structures, fire related to broken gas lines and other utilities (and broken water lines preventing fire-fighting), and in some instances **tsunamis**—seismic sea waves. Tsunamis are not known to occur along the coastal areas of the Southeast—they tend to be more common along active plate boundaries.

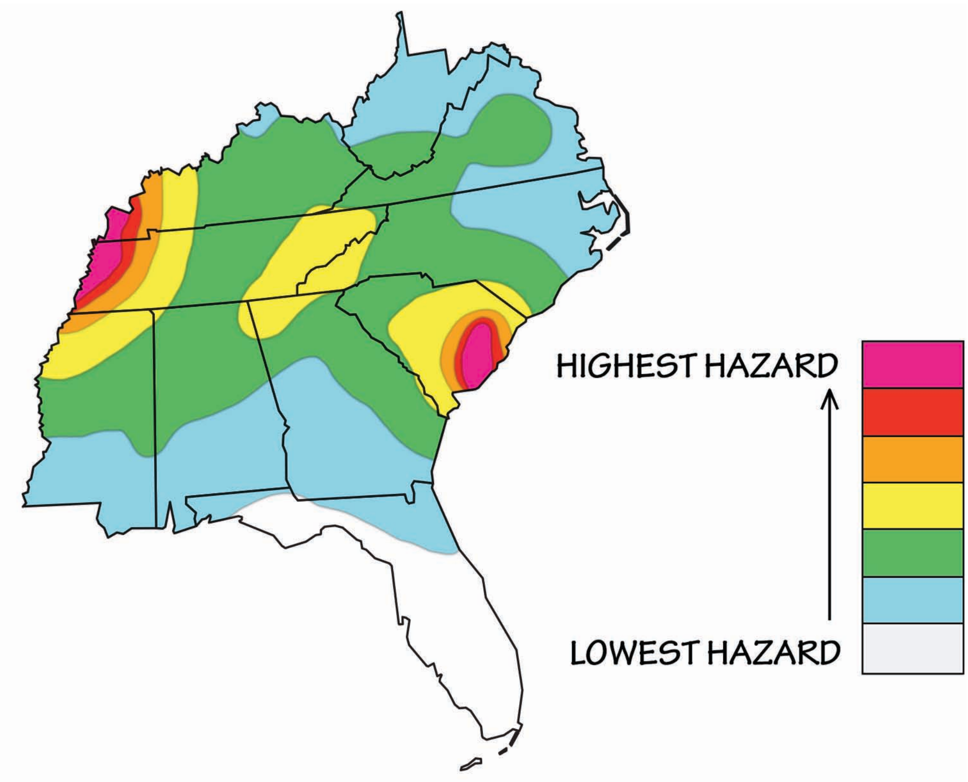


Figure 9.6: Seismic hazard map of the Southeastern US, based on 2014 data. (See TFG website for full-color version.)

Landslides

The term "landslide" refers to a wide range of **mass wasting** events that result in rock, soil, or fill moving downhill under the influence of gravity (*Figure 9.7*). These events occur when friction between the earth material (i.e., rock and soil) and the slope is overcome, allowing the earth material to fail and move downslope. Mass wasting events can also dam streams and rivers, creating lakes. Landslides may be triggered by high rainfall, earthquakes, **erosion**, deforestation, groundwater pumping, or **volcanic** eruptions. They range in size from the simple raveling of a stream embankment to the collapse of an entire mountainside that involves tens of thousands of cubic meters (yards) of material. Not all mass wasting events are rapid—slow land movement, known as soil **creep**, is generally not hazardous, but can impact structures over a long period of time. Mud and **debris flows** are very fast landslides likely to kill anyone unfortunate enough to be caught in their path, as they can reach speeds exceeding 32 kilometers per hour (20 miles per hour).

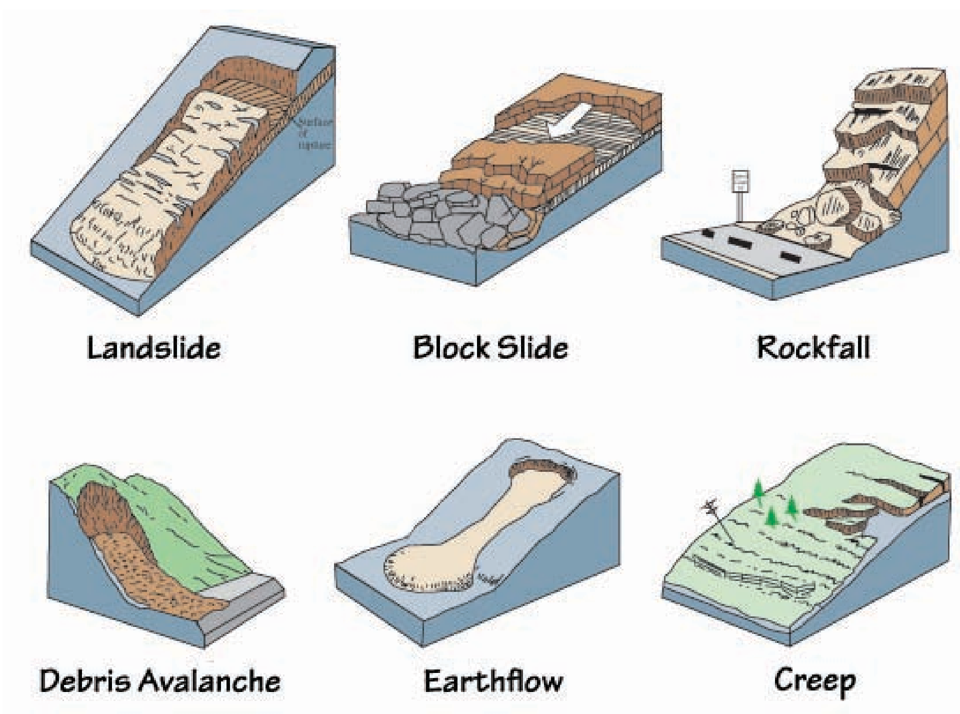


Figure 9.7: Common types of landslides.

mass wasting • *a process in which soil and rock move down a slope in a large mass.*

erosion • *the transport of weathered materials.*

volcanism • *the eruption of molten rock onto the surface of the crust.*

creep • *the slow movement or deformation of a material under the influence of pressure or stress.*

debris flow • *a dangerous mixture of water, mud, rocks, trees, and other debris that can move quickly down valleys.*

9 Earth Hazards

Landslides

slump • *a slow-moving landslide in which loosely consolidated rock or soil layers move a short distance down a slope.*

climate • *a description of the average temperature, range of temperature, humidity, precipitation, and other atmospheric/hydrospheric conditions a region experiences over a period of many years (usually more than 30).*

topography • *the landscape of an area, including the presence or absence of hills and the slopes between high and low areas.*

relief • *the change in elevation over a distance.*

tree • *any woody perennial plant with a central trunk.*

hurricane • *a rapidly rotating storm system with heavy winds, a low-pressure center, and a spiral arrangement of thunderstorms.*

Landslides and **slumps** are common problems in parts of the Southeast that have a wetter **climate** and considerable **topographic relief**, especially in and around the Appalachian Mountains (*Figure 9.8*). They can also occur in areas with low relief, as with the mass movement of sediments in the Mississippi River drainage basin. Heavy rain, snowmelt, groundwater percolation, and water level changes along coastlines, earthen dams, and the banks of water bodies are conditions under which landslides can occur. These flood-related conditions are associated with precipitation, runoff, and saturation of the ground. Human activity can also lead to mass wasting events, especially where excavation, blasting, or construction occur on unstable or steep surfaces. For example, in March 2015 a massive landslide occurred along the steep edge of fill below the runway of Yeager Airport in Charleston, West Virginia (*Figure 9.9*). The airport was built on seven million cubic meters (nine million cubic yards) of engineered fill, due to the lack of suitable flat land for an airport. The landslide occurred after a spell of warm, wet weather following a freeze; it destroyed a church and damaged several homes, caused flooding, and blocked Keystone Road.

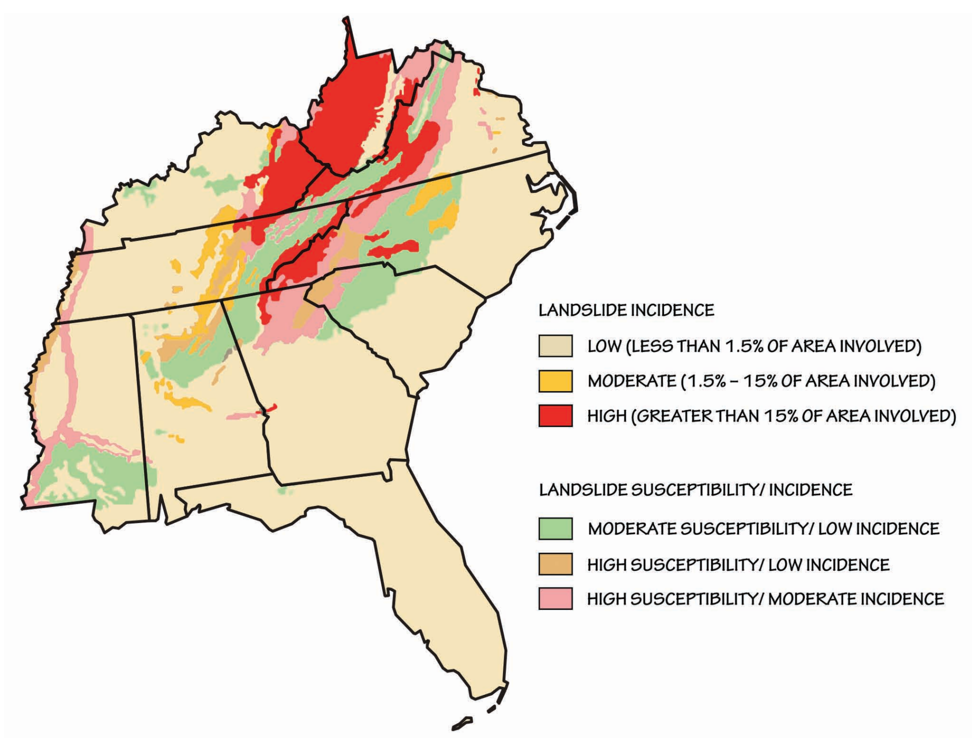


Figure 9.8: Landslide incidence and risk in the Southeastern US..
(See TFG website for full-color version.)

Debris flows are a dangerous mixture of water, mud, rocks, **trees**, and other debris that moves quickly down valleys. Rapid slides and flow movement happens without warning, triggered by heavy rainfall, snowmelt, or high levels of ground water flowing through cracked bedrock. In September 2005, heavy rainfall from two consecutive **hurricanes** dislodged a deadly debris flow from

Landslides

Figure 9.9: The landslide below Yeager Airport in Charleston, West Virginia damaged houses, blocked a creek, and covered a road.

the top of Fishhawk Mountain in Franklin, North Carolina. In only 30 minutes, the flow of debris cleared a 150–300-meter-wide (500–1000-foot-wide) swath of trees, rock, and dirt as it traveled 4 kilometers (2.5 miles) down Peeks Creek at roughly 50 kilometers per hour (30 miles per hour), destroying a housing community and killing four people in a matter of seconds (*Figure 9.10*).

In the Blue Ridge, where the bedrock contains many discontinuities (folded bedding planes, faults, **joints**, and **cleavage**) resulting from several episodes of mountain building (the **Taconic**, **Acadian**, and **Alleghanian orogenies**), rock slides and rockfalls are common, especially along transportation routes running east to west through the mountains. US Route 64 in Tennessee and I-40 where it crosses the Tennessee-North Carolina border are often impacted by rockfalls, leading to frequent road closures (*Figure 9.11*). Often, stretches of highway remain closed for periods of several months.

joint • *a surface or plane of fracture within a rock.*

cleavage • *a physical property of minerals that occurs when it breaks in a characteristic way along a specific plane of weakness.*

Taconic Orogeny • *a late Ordovician mountain-building event involving the collision and accretion of a volcanic island arc along the eastern coast of North America.*

Acadian Orogeny • *a Devonian mountain-building event involving the collision of the eastern coast of North America and the accreted terrane of Avalon.*

Alleghanian Orogeny • *a Carboniferous to Permian mountain-building event involving the collision of the eastern coast of North America and the northwestern coast of Africa.*

orogeny • *a mountain-building event generally caused by colliding plates and compression of the edge of the continents.*

Figure 9.10: A pile of trees, debris, and homes detached from their foundations after the Peeks Creek landslide in Franklin, North Carolina. Inset shows the track of the landslide, from the start (blue arrow) to the Peeks Creek community (yellow arrow). (See TFG website for full-color version.)

Figure 9.11: This rockslide across US 64 in Polk County, Tennessee, resulted in an eight-week-long road closure while the rocks were removed.

Landslides

In some low-lying areas of the Coastal Plain, especially southern Mississippi, saturated soils and heavy rains can combine to cause soil liquefaction, which can result in laterally moving mudslides. This can be triggered by storm runoff or by rapid earth movement during an earthquake. Earthquakes along the New Madrid Seismic Zone commonly contribute to landslide incidence along the Mississippi River Valley in Tennessee and Kentucky.

Slumps and creep are common problems in parts of the Southeast with a wetter climate and/or the presence of unstable slopes or unconsolidated sand, especially in the Coastal Plain and the foothills of the Appalachians. Many areas in the Southeast contain expansive soils generated from **clay**-rich **shales**. Certain clay **minerals** can absorb water and swell up to twice their original volume. The pressures exerted through expansion of the minerals in the soil can easily exceed 22 metric tons per square meter (5 tons per square foot)—a force capable of causing significant damage to highways and buildings. An estimated $9 billion of damage to infrastructure built on expansive clays occurs each year in the United States, making swelling soils one of the costliest hazards. In addition, when the clay dries and contracts, the particles settle slightly in the downhill direction. This process can cause soil creep, a slow movement of land that causes fences and telephone poles to lean downhill, while trees adjust by bending uphill (*Figure 9.12*). Human development can exacerbate this process when homes are built along river bluffs, disturbing vegetation that would otherwise stabilize the slope and adding water to the land in the form of yard irrigation or septic systems.

See Chapter 7: Soils for more information about clay-rich Vertisol and Ultisol soils.

Expansive soils can be found all over the US, and nearly every state in the Southeast has bedrock units or soil layers that are possible sources (*Figure 9.13*). Clay minerals that expand and contract when hydrated and dehydrated due to their layered molecular structure are generically referred to as smectite; soils that tend to form deep cracks during drought are often indicative of the presence of smectite. The Coastal Plain region has the highest risk of damage caused by swelling soils (clay), but the residual soils of some Paleozoic **carbonate rocks** may contain smectite, and some Paleozoic **pyritic** shale formations in the Valley and Ridge can form expansive minerals. Significant or repeated changes in moisture, which can occur in concert with other geologic hazards such as earthquakes, floods, or landslides, greatly increase the hazard potential of expansive soils. The key to reducing this hazard is to keep the water content of the soil constant. There are also chemical stabilizers, including **lime**, potassium, and ionic agents, that can reduce the potential for soil volume changes by increasing the clay's structural stability.

See Chapter 4: Topography to learn more about the Valley and Ridge and other physiographic subregions within the Southeast.

clay • *the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.*

shale • *a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.*

mineral • *a naturally occurring solid with a specific chemical composition and crystalline structure.*

carbonate rocks • *rocks formed by accumulation of calcium carbonate, often made of the skeletons of aquatic organisms.*

pyrite • *the iron sulfide mineral (FeS_2) with a superficial resemblance to gold, known commpnly as "fool's gold."*

lime • *an inorganic white or grayish-white compound made by roasting limestone (calcium carbonate, $CaCO_3$) until all the carbon dioxide (CO_2) is driven off.*

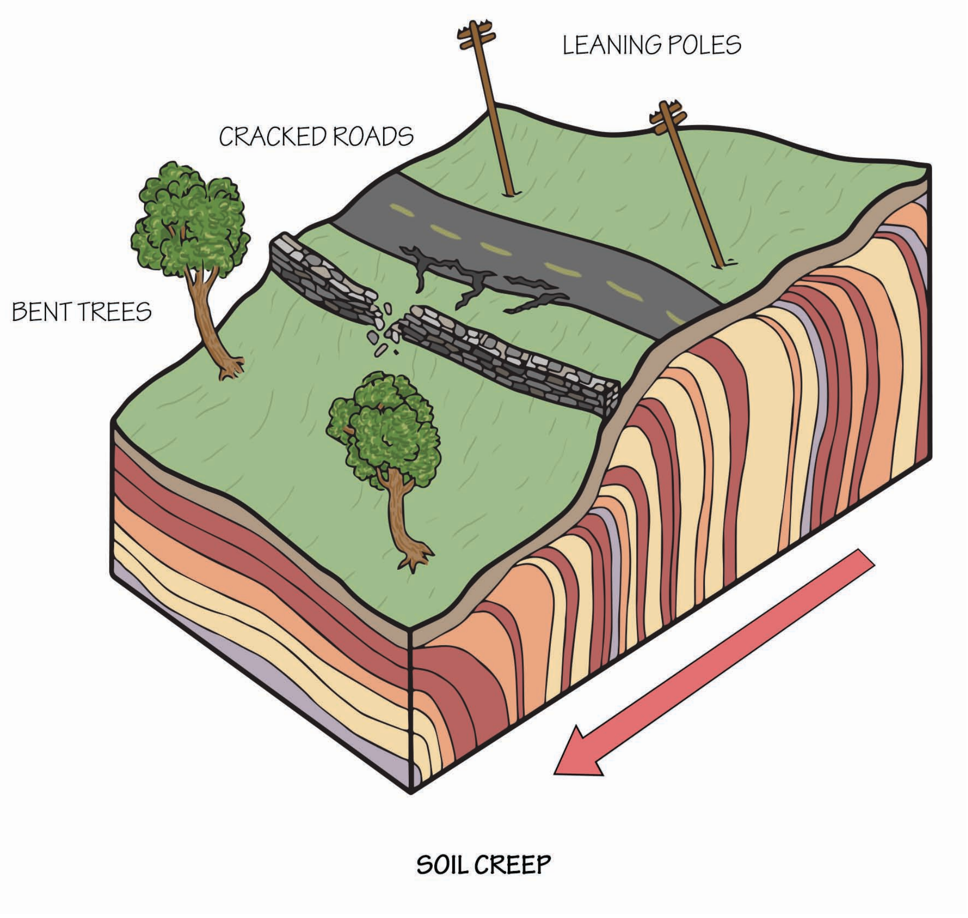


Figure 9.12: Some influences of soil creep on surface topography.

Slumping occurs when expansive minerals are present on steeper slopes, and involves the downward movement of a larger block of material along a surface that fails when the weight of the saturated soils can no longer be supported. Slumping is common near roads and highways, thanks to the presence of steeper hills, roadcuts, and construction (*Figure 9.14*). On steep, high slopes, slumping often precedes earthflows and mudflows that develop farther downslope as water is added to the slump while it mixes the moving material.

Damage to life and property from mass wasting events can be reduced by avoiding landslide hazard areas or by restricting access to known landslide zones. Hazard reduction is possible by avoiding construction on steep slopes or by stabilizing the slopes. There are two main ways to accomplish stabilization: (1) preventing water from entering the landslide zone through runoff, flooding, or irrigation and (2) stabilizing the slope by placing natural or manmade materials at the toe (bottom) of the landslide zone or by removing mass from the top of the slope.

Landslides

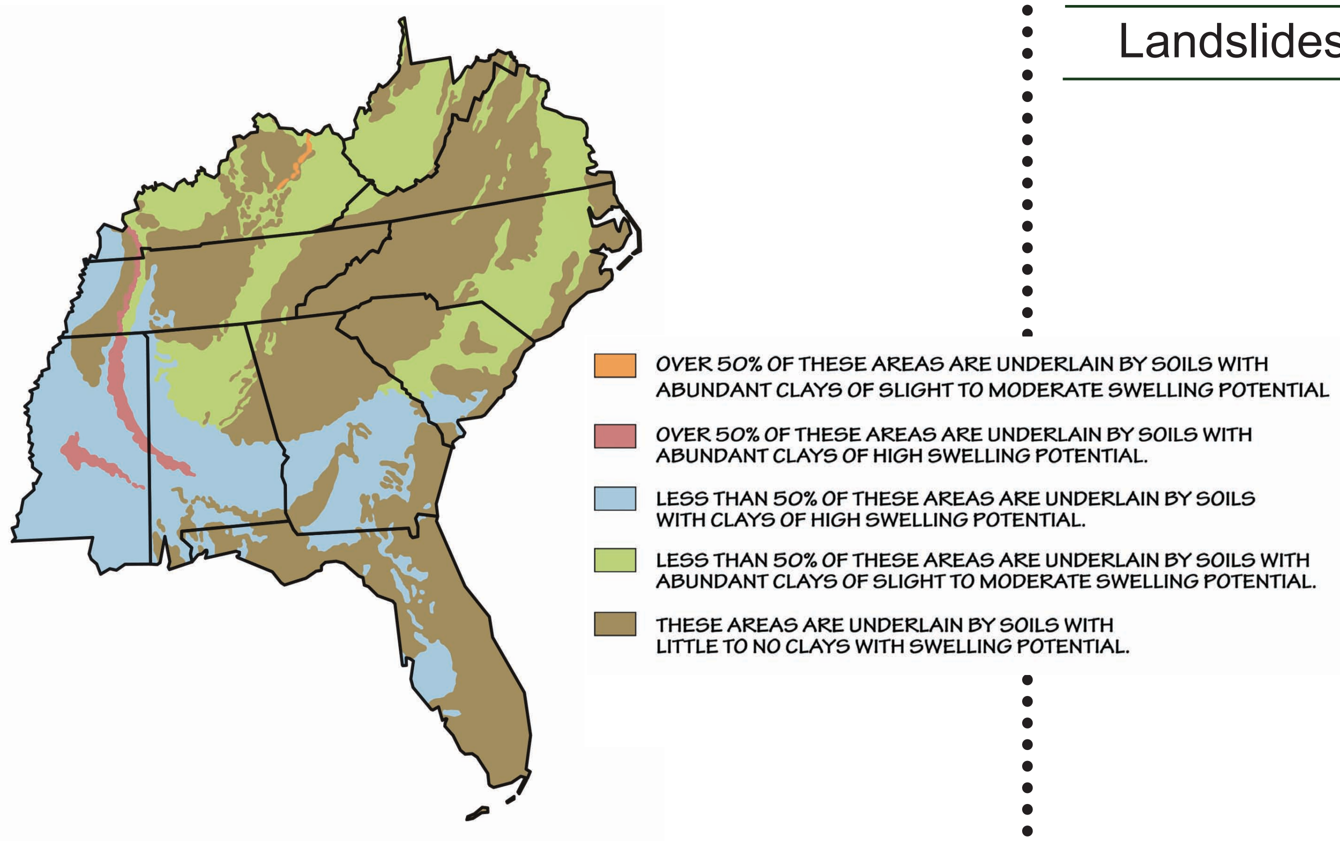


Figure 9.13: Approximate distribution of expansive soils in the Southeastern US. This map is based on the distribution of types of bedrock, which are the origin of soils produced in place. (Where substantial fractions of the soil have been transported by wind, water, or ice, the map will not be as accurate.) (See TFG website for full-color version.)

Figure 9.14: A small slump in a road embankment along KY-421 in Franklin County, Kentucky.

9 Earth Hazards

Karst

sedimentary rock • *rock formed through the accumulation and consolidation of grains of broken rock, crystals, skeletal fragments, and organic matter.*

dolomite • *a carbonate mineral, consisting of calcium magnesium carbonate ($CaMg(CO_3)_2$).*

system • *a set of connected things or parts forming a complex whole.*

dolostone • *a rock primarily composed of dolomite, a carbonate mineral.*

Karst and Sinkholes

Karst topography forms in areas where the underlying bedrock is composed of material that can be slowly dissolved by water. Examples of this type of **sedimentary rock** include carbonate rocks such as limestone, halite, gypsum, **dolomite**, and anhydrite. Carbonate rocks may develop karst and other dissolution features due to the effects of circulating groundwater that has been made slightly acidic through the presence of dissolved carbon dioxide (which creates carbonic acid that reacts with the rock, dissolving it). Sinkholes and caverns can form, creating potential hazards (i.e., the land surface could subside or collapse into the underground openings). This may principally occur in areas where cavities filled with water are emptied through groundwater withdrawal or other natural processes, resulting in the cavities being filled with air and reducing support for the overlying rock. Many parts of the Southeast are underlain by karst and carbonates (*see Figure 9.17*). Karst areas, which are often connected to the natural groundwater circulation **system**, can also be subject to flooding when sinkholes are plugged with refuse or covered over by parking lots, driveways, or buildings.

See Chapter 4: Topography for more information about the formation of karst.

Central and southern Kentucky, including most of the Interior Basin, is one of the most famous karst areas in the world. About 55% of the state is underlain by limestones and **dolostones** that are capable of developing karst, and 25% of the state already has well-developed karst features. This is evident in the large number of commercialized caverns advertised throughout the state (*Figure 9.15*). In Tennessee and northern Alabama, especially the Nashville Basin and Highland Rim, Paleozoic limestones are abundant, with significant karst and related dissolution hazards. Southern Alabama and Mississippi contain karst formations related to the dissolution of subsurface salt, and the entire state of Florida is underlain by karstic limestone.

Sinkholes are funnel-shaped depressions in the land surface formed by the dissolution of near-surface rocks or by the collapse of underground channels and caverns. Sinkholes can form by several different mechanisms, but all require dissolution of rock beneath the surface (*Figure 9.16*). Sinkhole formation commonly damages roads, buildings, and utilities (*Figures 9.18 and 9.19*), and it is a major environmental problem in the Southeast, especially Florida, as well as parts of Kentucky, Tennessee, and Alabama. Many of the thousands of lakes across Florida are sinkholes.

Sinkholes may be very small or large enough to swallow even hectares (acres) of land, along with any structures that had been built upon the surface. The early stages of sinkhole development may be indicated by signs of mass wasting such as "pistol-grip"-shaped trees, cracked building foundations, and leaning fence posts. Structural damage from sinkholes can be mitigated, but usually only at significant cost. It is therefore often far more prudent to avoid building in such

Figure 9.15: Mammoth cave in Kentucky is the longest known cave system in the world, spanning more than 640 kilometers (400 miles) of vast chambers and complex labyrinths in karstic rock.

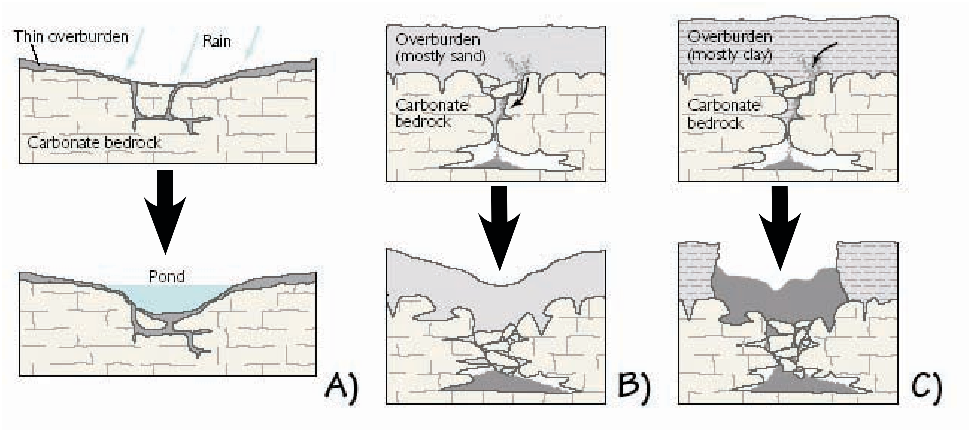


Figure 9.16: Three mechanisms of sinkhole formation.

A) Dissolution: Rain and surface water percolate through carbonate bedrock, dissolving a hole from the top down.

B) Cover-subsidence: Carbonate bedrock dissolves beneath a permeable overlying layer such as sand. As the sand falls into the hole below, slow downward erosion leads to a depression.

C) Cover-collapse: Carbonate bedrock dissolves beneath an overlying layer made largely of clay. The clay collapses from beneath into the cavity below, abruptly forming a dramatic sinkhole when the surface is breached. This type of sinkhole causes the most catastrophic damage, as it is not easily detected before it forms.

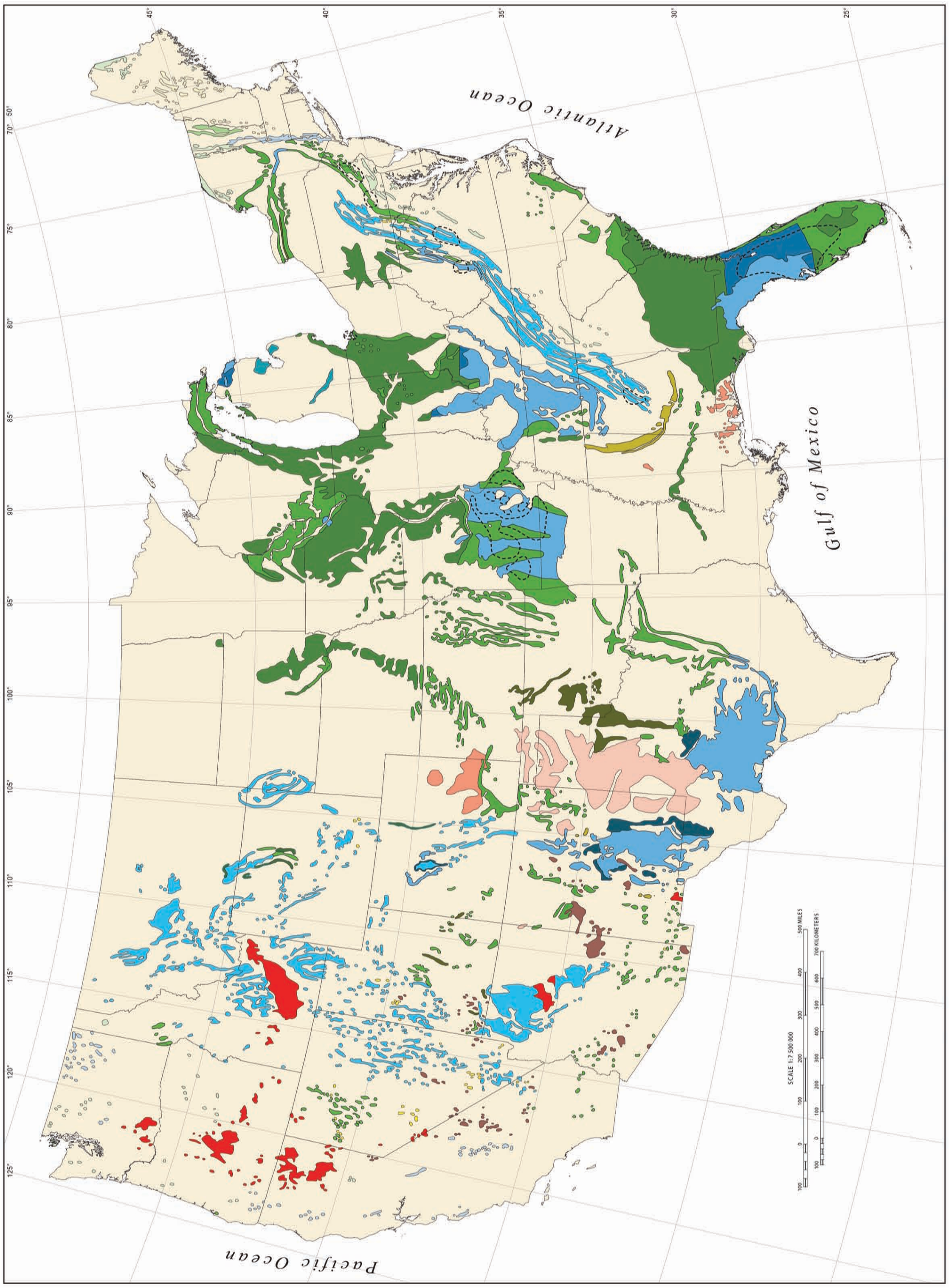


Figure 9.17: Areas of karst in the continental US, associated with carbonate and evaporate rocks. See Key on facing page. (See TFG website for full-color version.)

FISSURES, TUBES, AND CAVES OVER 1,000 FT (300 M) LONG; 50 FT (15 M) TO OVER 250 FT (75 M) VERTICAL EXTENT

- In metamorphosed limestone, dolostone, and marble
- In moderately to steeply dipping beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock beneath an overburden of noncarbonate material 10 ft (3 m) to 200 ft (60 m) thick
- In moderately to steeply dipping beds of gypsum
- In gently dipping to flat-lying beds of gypsum

FISSURES, TUBES, AND CAVES GENERALLY LESS THAN 1,000 FT (300 M) LONG; 50 FT (15 M) OR LESS VERTICAL EXTENT

- In metamorphosed limestone, dolostone, and marble
- In crystalline, highly siliceous intensely folded cabonate rock
- In moderately to steeply dipping carbonate rock
- In gently dipping to flat-lying carbonate rock
- In gently dipping to flat-lying beds of carbonate rock beneath an overburden of noncarbonate material 10 ft (3 m) to 200 ft (60 m) thick
- In moderately to steeply dipping beds of gypsum
- In gently dipping to flat-lying beds of gypsum
- In gently dipping to flat-lying beds of gypsum beneath and overburden of nongypsiferous material 10 ft (3 m) to 200 ft (60 m) thick
- In carbonate zones in highly calcic granite (Alaska only)
- In moderately to steeply dipping beds of carbonate rock with a thin cover of glacial till and frost-derived residual soil (Alaska only)

FISSURES, TUBES, AND CAVES GENERALLY ABSENT; WHERE PRESENT IN SMALL ISOLATED AREAS, LESS THAN 50 FT (15 M) LONG; LESS THAN 10 FT (3 M) VERTICAL EXTENT

- In crystalline, highly siliceous intensely folded carbonate rock
- In moderately to steeply dipping beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock

FEATURES ANALOGOUS TO KARST

- Fissures and voids present to a depth of 250 ft (75 m) or more in areas of subsidence from piping in thick unconsolidated material
- Fissures and voids present to a depth of 50 ft (15 m) in a[illegible] of subsidence from piping in thick, unconsolidated mate[illegible]
- Fissures, tubes, and tunnels present to a depth of 250 ft (75 m) or more in lava
- Fissures, tubes, and tunnels present to a depth of 50 ft (15 m) in lava

- Areas in which extensive historical susidence has occurred

Figure 9.18: This 100-meter-wide (320-foot-wide) sinkhole formed in Winter Park, Florida, in 1981. It swallowed 190,000 cubic meters (250,000 cubic yards) of earth as well as vehicles and buildings. Today, it has been filled with water and is called Lake Rose.

Figure 9.19: The "Golly Hole" or "December Giant" is Alabama's largest sinkhole, at roughly 90 meters (300 feet) wide and 37 meters (120 feet) deep. It is located in an area of Shelby County with an extensive history of sinkhole formation.

locations altogether. Evaluating sinkhole risk commonly involves foundation testing by drilling or remote sensing (for example, measuring electrical resistivity) prior to construction. Unfortunately, many structures have been built without such testing, resulting in frequent catastrophic damage. Many state agencies provide sinkhole risk maps, which provide generalized risk assessment based on local geology (*Figure 9.20*).

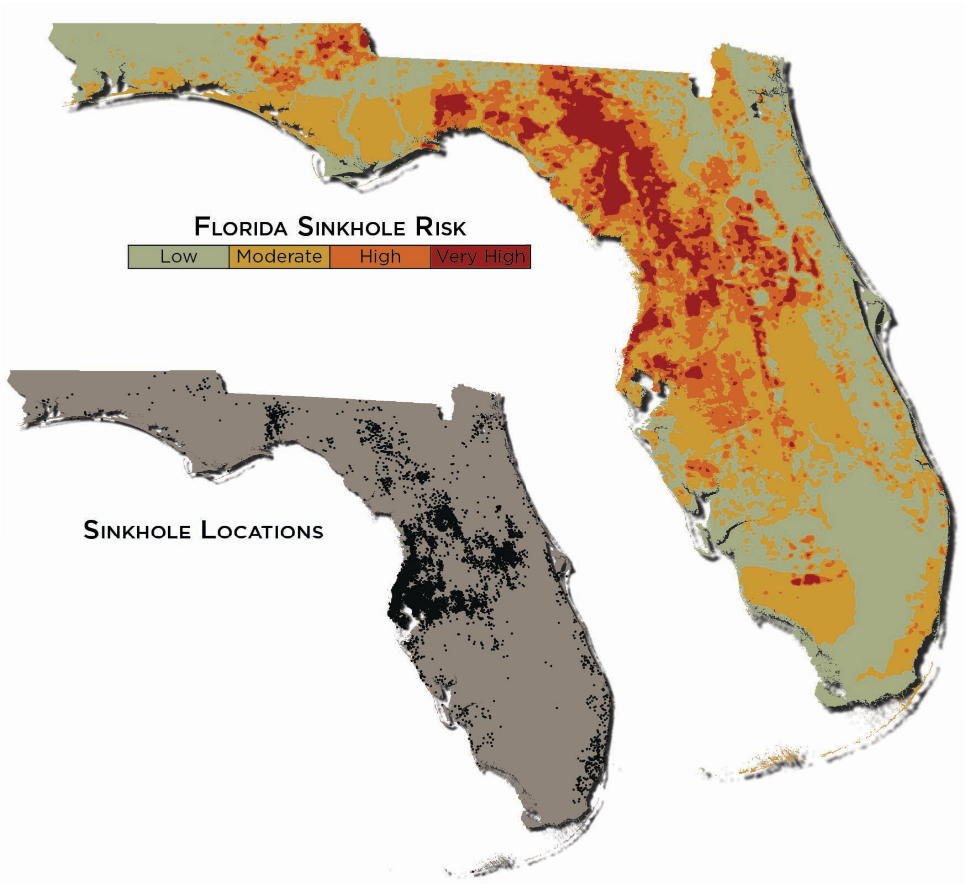


Figure 9.20: Sinkhole risk in Florida.
(See TFG website for full-color version.)

Portions of the Gulf Coastal Plain are noted for subsurface **salt domes** that formed from **Jurassic** salt beds compressed into dome-like intrusions by the weight of overlying sediment. Salt domes offshore and on-shore have long been exploited for hydrocarbons trapped in the strata deformed by the intrusions, but they have also been exploited for other resources, including the salt itself. Dissolution of the salt by hydraulic mining creates subsurface voids capable of collapse, resulting in hazardous depressions on the land surface.

salt dome • *a largely subsurface geologic structure, consisting of a vertical cylinder of salt embedded in horizontal or inclined sedimentary strata.*

Jurassic • *the geologic time period lasting from 201 to 145 million years ago.*

Radon

> **radioactivity** • *the emission of radiation by an unstable atom.*

> **granite** • *a common and widely occurring type of igneous rock.*

Radon

Radon is a naturally occurring **radioactive**, colorless, odorless gas. It is the leading cause of lung cancer in American non-smokers, and the second leading cause of lung cancer overall. It can collect in homes, buildings, and even in the water supply. Radon gas is formed naturally when uranium-238 undergoes radioactive decay, producing energy and several radioactive products such as radon-222 and thorium-232. (The thorium later decays to emit energy and radon-220.) Radon is more commonly found where uranium is relatively abundant in bedrock at the surface, often in **granite**, shale, and limestone. The EPA produced a map of the US showing geographic variation in radon concentrations, divided into three levels of risk: high, medium, and low (*Figure 9.21*).

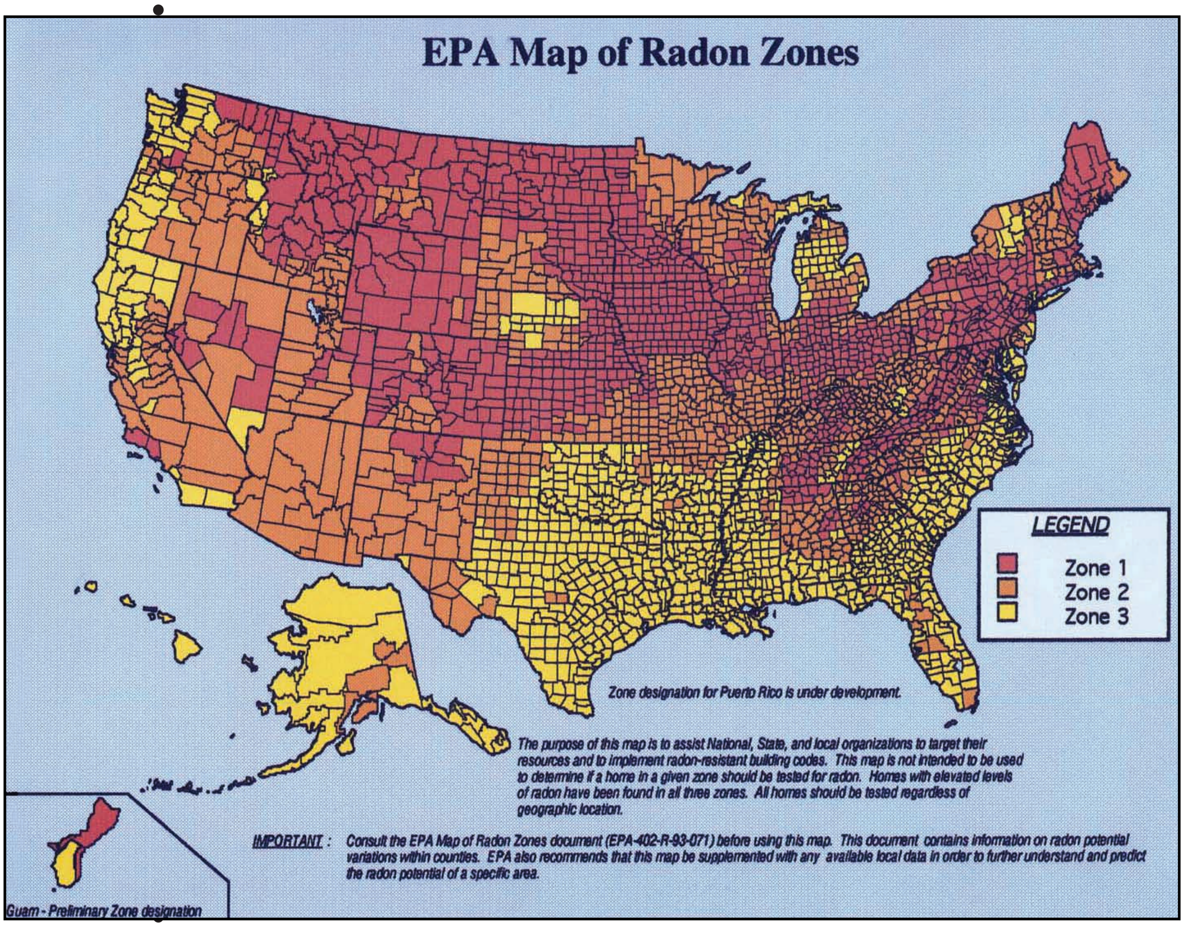


Figure 9.21: Radon zone map of the US. (Note: Zone 1 contains the highest radon levels.) (See TFG website for full-color version.)

> **color (mineral)** • *a physical property determined by the presence and intensity of certain elements within the mineral.*

Although radon is more or less universally present, high levels of radon are associated with areas containing uranium-rich bedrock. Most rocks have a small amount of uranium, but certain rocks tend to have higher concentrations

Radon

The number following the name of an element (U-238) refers to the mass number of the element. Though any two atoms of the same element will have the same number of protons and electrons, the number of neutrons may vary. Variation in the number of neutrons will change the mass of an atom. Atoms of the same element with different numbers of neutrons are called *isotopes*. For example, uranium-238 and uranium-235 are both isotopes of uranium.

of the radioactive element, such as light-**colored** volcanic rocks, granites, dark shales, sedimentary rocks with **phosphates**, and **metamorphic rocks**. The granitic **basement rocks** of the Blue Ridge and Piedmont (formed during the **Grenville Orogeny**) and the metasedimentary rocks that form the present Appalachian Mountains (derived from the ancient Grenville Mountains) are the greatest sources of radon in the Southeast (*Figure 9.22*). Areas in the Interior Lowlands with **Devonian**-**Mississippian** black shale bedrock are also subject to high levels of risk.

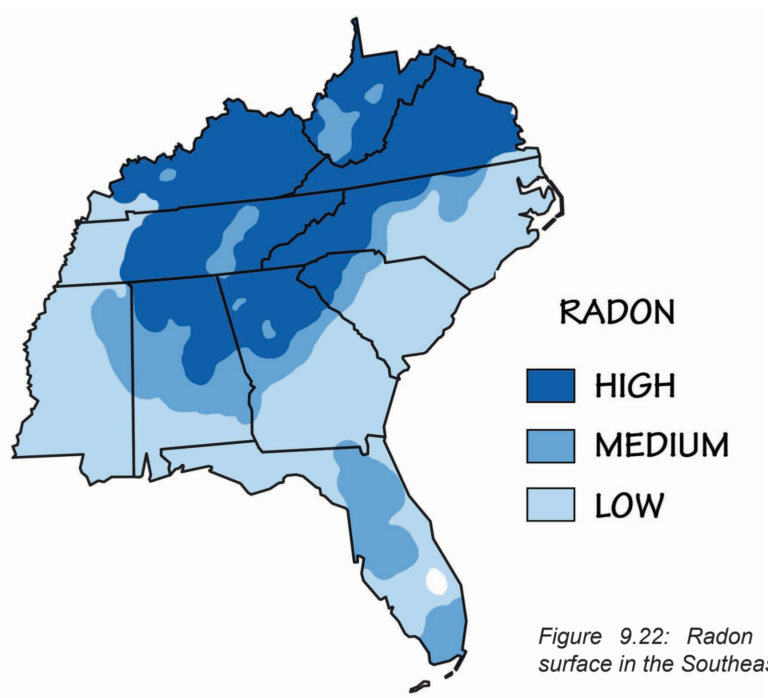


Figure 9.22: Radon risk levels at the surface in the Southeastern US.

Radon is chemically inert, meaning that it does not react or combine with elements in the ground, and it can move up through rocks and soil into the atmosphere. It is dangerous primarily when it accumulates indoors, creating a health hazard similar to that of secondhand smoke. Radon gas finds its way through cracks in basement foundations, sump pump wells, dirt floor crawlspaces, and basement

phosphate • *an inorganic salt of phosphoric acid, and a nutrient vital to biological life.*

metamorphic rocks • *rocks formed by the recrystallization and realignment of minerals in pre-existing sedimentary, igneous, and metamorphic rocks when exposed to high enough temperature and/or pressure.*

basement rocks • *the foundation that underlies the surface geology of an area, generally composed of igneous or metamorphic crystalline rock.*

Grenville Orogeny • *a mountain-building event, about 1.3 to 1 billion years ago, that played a role in the formation of the supercontinent Rodinia.*

Devonian • *a geologic time period spanning from 419 to 359 million years ago.*

Mississippian • *a subperiod of the Carboniferous, spanning from 359 to 323 million years ago.*

floor drains. It can also be found in well and municipal water. Since radon is more easily released from warm water than from cold water, one of the greatest forms of exposure likely occurs while showering in water with high radon levels.

Radon cannot be detected by sight or smell, so there is no way that the body can sense its presence. Fortunately, with proper monitoring and mitigation (reduction) techniques, radon gas can be easily reduced to low levels. One technique that is often used in homes involves sealing cracks in the basement floor, covering drains, and installing ventilation systems. A well-ventilated space will prevent the radon from accumulating and will reduce the risk of exposure. Most states have licensed radon mitigation specialists who are trained in the proper testing and mitigation of radon levels in buildings. The EPA has also published a homebuyer's guide designed to help citizens make informed decisions about radon gas. For radon in water, filtration systems can be installed to mitigate exposure in the home.

Floods

Floods are controlled by the rate of precipitation, run-off, stream flow, and shape of the land surface. They may occur as water overflows the banks of a standing water body (such as a lake) or flowing water (such as a stream), or when rainwater accumulates in an area that normally has neither standing nor flowing water. Areas near rivers, tributaries, creeks, and streams are likely to experience flooding during periods of heavy rainfall. Low-lying coastal areas can experience flooding associated with major storms, which can combine high rainfall with surging waves.

Flooding can occur at any time of the year and is caused when more water enters a stream/river channel than the channel can contain. This situation can develop when water is unable to soak into the ground and instead runs off into a river channel. Runoff can occur if the ground is already saturated (full of water) or if the ground is too dry, hard, or frozen. The slope of a river (i.e., the topography of the land) can also contribute to flooding. If rivers have a steep slope, water can quickly move through the channel and continue downstream. If rivers have a shallow slope, water moves slowly through the river channel and remains in the area instead of moving downstream. Large floods typically result from unusually rapid regional melting of snow in the spring or from major weather systems such as hurricanes that bring heavy rainfall over a large region. Flash floods—rapid flooding of low-lying areas—are often associated with heavy rain, which can quickly waterlog soil and lead to mudslides on steep terrain, resulting in damage to roads and property. In areas of lower elevation, flash floods can be produced when slow-moving or multiple thunderstorms occur over the same area. When storms move more quickly through an area, flash flooding is less likely. Although flash floods may be of only a short duration, they can cause major damage—flash floods have been known to wash coffins out of graveyards, destroy structures, and demolish manmade dams.

Floods

levee • *a deposit of sediment built up along the sides of a river's floodplain, or an artificial embankment along a waterway to prevent flooding.*

watershed • *an area of land from which all water under or on it drains to the same location.*

Floodplains are areas adjacent to rivers and streams that occasionally flood but are normally dry, sometimes for many years. When storms produce more runoff than a stream can carry in its channel, waters rise and inundate adjacent lowlands, leaving behind layers of settled sediment. Significant damage and sometimes loss of human life can occur when buildings and other human infrastructure are built on floodplains, under the assumption that future floods may never occur or will only occur in the distant future. Floods can occur at any time, but major floods are more frequent in spring and fall after periods of heavy or sustained rains when stream levels rise rapidly. For example, torrential rains in May of 2010 resulted in "thousand-year floods"—an event thought to occur only once every thousand years— along the Cumberland River in Tennessee, Kentucky, and Mississippi. As much as 480 millimeters (19 inches) of rain fell over a two-day period; in Nashville, the river reached a height of 16 meters (52 feet), and 31 people were killed throughout the flood zone.

Major floods in the Southeast often occur along the Mississippi River and its tributaries (*Figure 9.23*). The 1927 Mississippi Flood was the greatest flood on the lower Mississippi River in modern history. From the summer of 1926 until the spring of 1927, heavy rains fell in eastern Kansas, Oklahoma, and the Ohio Valley. Between February and April 1927, numerous **levees** broke along the Mississippi River from Illinois to Louisiana, inundating numerous towns in the Mississippi Valley. The break at Mounds Landing near Greenville, Mississippi was the single greatest levee rupture to ever occur along the Mississippi River. It flooded an area 80 kilometers (50 miles) wide and 160 kilometers (100 miles) long with up to 6 meters (20 feet) of water. Heavy spring rains caused a second major flood that June. In all, 73,500 square kilometers (28,400 square miles)—home to more than 931,000 people—were inundated. The Mississippi River floods in April and May 2011 were also among the largest and most damaging along this US waterway in the past century, rivaling major floods in 1927 and 1993. In April 2011, two major storm systems dumped record rainfall on the Mississippi River **watershed**. Areas along the Mississippi from Illinois and Iowa to Mississippi and Louisiana experienced heavy flooding (*Figure 9.24*).

The Southeast's Coastal Plain is topographically low and flat and contains numerous rivers, and is therefore more prone to flooding—from a variety of sources—than many other areas of higher elevation farther inland. Major flooding can be caused by high rainfall, which can swell rivers, and by major coastal storms, especially tropical storms and hurricanes. The catastrophic floods that struck South Carolina in October 2015 were caused by extraordinary rainfall from an easterly moving storm, combined with Hurricane Joaquin, which struck the Atlantic coast. The first week of October saw one of the most prolific rainfall events in the modern US history: five-day totals exceeded 500 millimeters (20 inches) in many places in South Carolina (*Figure 9.25*). On the coast, flooding can occur not just because of rainfall, but also because of storm surge, another form of

See the "Storms" section later in this chapter for more information about hurricanes and other types of severe weather.

Floods

wind • the movement of air from areas of high pressure to areas of low pressure.

recurrence interval • the time elapsed between major events, such as floods.

Figure 9.23: The Mississippi River and its tributaries in the Southeastern states. (See TFG website for full-color version.)

flooding associated with the Coastal Plain. Strong offshore **winds** can drive water and even boats across beaches and far upstream in rivers, especially during times of high tide. The inland surge of ocean water is often of a disastrous proportion, especially when it is associated with hurricanes (*Figure 9.26*).

While floods are always considered a hazard to life and property, they present a compound threat when they trigger mudslides or contribute to the conditions that cause expansive soils and karst topography. While there is no way to completely avoid the destructive impacts of flooding, good community planning and informed decision-making can greatly reduce the safety concerns and economic impacts of these events. Flood control is part of the mission statements of many government agencies, including the National Resource Conservation Service (NRCS), US Corps of Engineers (USCE), Tennessee Valley Authority (TVA), and US Geological Survey (USGS). These agencies and others maintain gauges on most large rivers and streams in the Southeast from which flow data are gathered. Using historical records and flow data collected over a long period of time, hydrogeologists can apply statistics to calculate the frequency and **recurrence intervals** of flows of different magnitude. These data have been used by the USGS to produce special topographic maps showing flood-

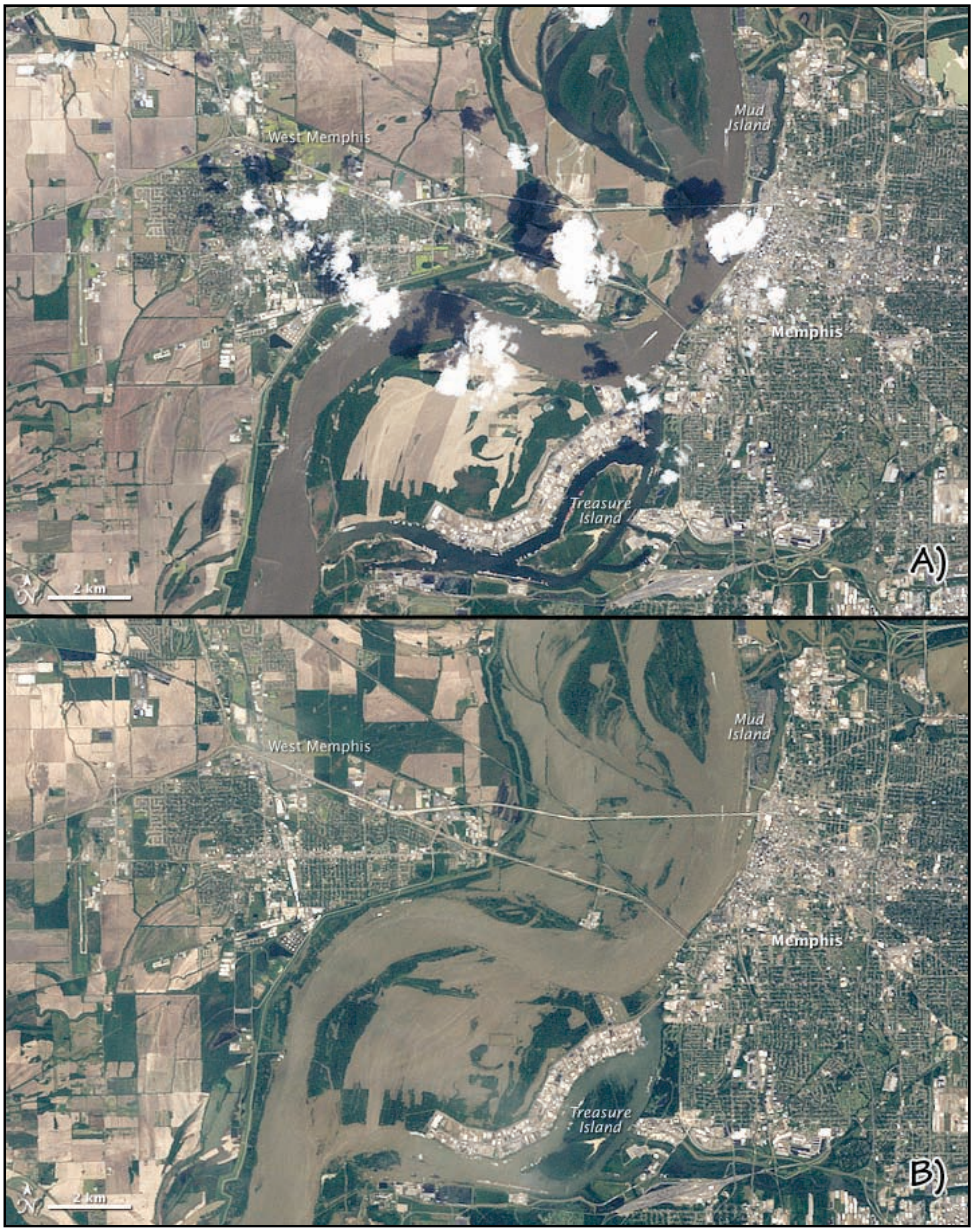


Figure 9.24: Flooding in Memphis, Tennessee in May 2011, before (A) and after (B). On May 10, the Mississippi River reached 14.59 meters (47.87 feet) above normal level, the highest water level in Memphis since 1937.

prone areas. The Federal Emergency Management Agency (FEMA) provides guidelines for communities that are planning mitigation strategies designed to minimize the impacts of natural hazards such as flooding.

Figure 9.25: Flooding inundates houses along the Black River in Sumpter County, South Carolina, after Hurricane Joaquin passed through the area in October 2015.

Figure 9.26: A beach house is undermined and destroyed by storm surge from Hurricane Dennis in 1999, at Kitty Hawk, North Carolina.

Sea Level Rise, Coastal Erosion, and Subsidence

The total linear coastline of the Southeastern US measures 4094 kilometers (2544 miles); out of 23 states with coasts, Florida is ranked second in terms of coastal area, North Carolina is seventh, South Carolina is eleventh, and Virginia, Georgia, Alabama, and Mississippi are ranked fifteenth through nineteenth, respectively. Property losses from coastal hazards are extremely high and are likely to increase as shorelines become more developed and sea levels continue to rise.

Sea level changes affect the balance between erosion and deposition along the coast. About 20,000 years ago during the **ice age**, the waterfront along the coast of the present United States extended about 320 kilometers (200 miles) farther into the Atlantic Ocean. As the continental **glaciers** melted, water drained back into the oceans, causing sea level to continually rise over the past 2000 years. The continual rise in sea level alone poses hazards, but it also increases the effects of storm surge on coastal communities. Although various estimates have been made for the rate of sea level rise, the general consensus is that it is within the range of 1 to 3 millimeters (0.04 to 0.12 inches) per year, but these values may actually be increasing.

See Chapter 8: Climate for more information about sea level rise and its effect on the Coastal Plain.

While coastal hazards related to sea level fluctuations are important when considering the long term, it is short-term events such as storm surges that pose major threats to property and life (*see Figure 9.26*). The sudden rise in sea level generated by a storm surge and high winds causes water to flow over low-elevation coastlines and spill into low coastal river valleys. Hurricanes are by far the most common cause for surges; however, severe storms not reaching hurricane magnitude can still create hazardous surges. Most lives lost in a storm surge are a result of drowning or the collapse of structures. The property damage from a single event can range into billions of dollars.

The coastal areas of the Southeastern US are typically sandy beaches with dunes. Many of these beaches are barrier islands built of sand. Longshore currents cause constant shifting of the sand found on these barrier islands by eroding it in one location and depositing it in another (*Figure 9.27*). At present, erosion seems to be more dominant than deposition as sea level slowly rises. In just the last 25 years, for example, more than 480 **hectares** (1200 acres) have been eroded from the barrier islands in South Carolina's Cape Romain National Wildlife Refuge. So much sand has been removed from many beaches in the Southeast that sand is often borrowed from other sites in order to make the beaches suitable for recreation and to prevent buildings from being eroded away. Devices such as constructed islands, walls, breakwaters, groins, and piers that are exposed to waves and wave-generated currents are capable of

ice age • *a period of global cooling of the Earth's surface and atmosphere, resulting in the presence or expansion of ice sheets and alpine glaciers.*

glacier • *a body of dense ice on land that does not melt away annually and has sufficient mass to move under its own weight.*

hectare • *a metric unit of area defined as 10,000 square meters.*

Sea Level Rise

anthropogenic • *caused or created by human activity.*

being eroded and destroyed if not constructed upon sound foundations. Erosion also takes a critical toll on wildlife habitat, especially turtles and birds that use sandy shores and dunes for nesting.

The Coastal Plain is threatened by the triple risk of coastal erosion, sea level rise, and subsidence, with subsidence exacerbating the effects of the first two. Subsidence is the local sinking of land, involving little or no horizontal motion. It is induced through either the natural or **anthropogenic** removal of underlying support. Subsidence in the Southeast is common due to the abundance of soluble carbonate rocks (limestone and dolostone) and the area's warm, humid climate.

Figure 9.27: These houses on Cedar Island, a barrier island off Virginia's coastline, were originally built on solid ground. As sand on the island migrated, the buildings were left behind (shown by the yellow arrow).

Compaction of sediment, extraction of water and minerals from the soil, and collapse along fault lines are combining to increase the rate of subsidence. A combination of coastal erosion, sea level rise, subsidence, and increased storm intensity could have catastrophic impacts on the Coastal Plain region.

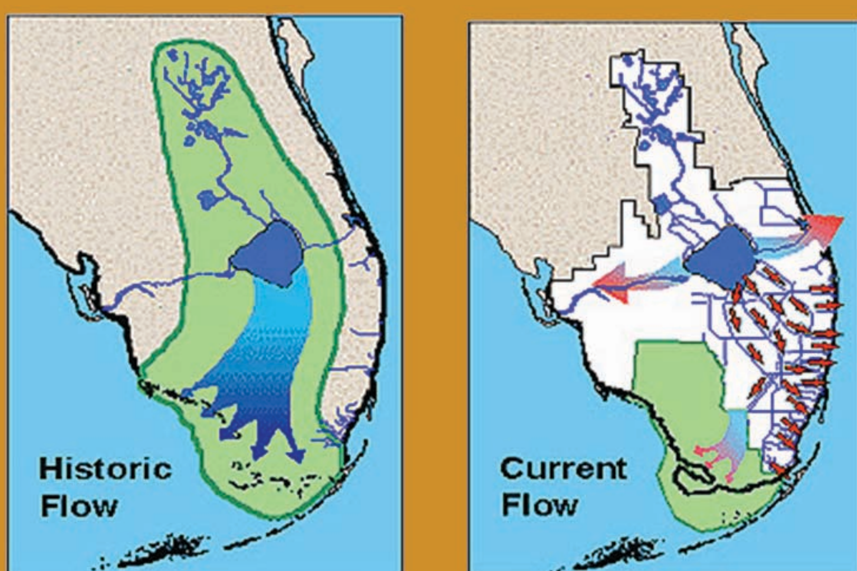
Sea Level Rise

oxidation • *a chemical reaction involving the loss of at least one electron when two substances interact.*

peat • *an accumulation of partially decayed plant matter.*

Subsidence in the Everglades

The Everglades is a vast wetland system in southern Florida, extending from Lake Okeechobee and its tributary areas, to the southern tip of the Florida peninsula at Florida Bay. Since 1900 much of the Everglades has been drained for agriculture and urban development; today only about 50% of the original wetlands remain. This draining, and the related *oxidation* of *peat* deposits, has caused extensive land subsidence, which has contributed to a local rise in sea level. Combined with the intensive exploitation of the major freshwater aquifers beneath the Everglades, this has increased salinity in the normally fresh-to-brackish surface waters of the Everglades and Florida Bay. This trend will only continue as sea level rises due to ongoing climate change.



Changes in drainage flow from the Everglades as a result of human activity over the past 200 years.

(See TFG website for full-color version.)

tornado • *a vertical funnel-shaped storm with a visible horizontal rotation.*

derecho • *a set of powerful straight-line winds that exceed 94 kilometers per hour (58 miles per hour) and can often approach 160 kilometers per hour (100 miles per hour).*

wind shear • *when wind speed and/or direction changes with increasing height in the atmosphere.*

cold front • *the boundary between the warm air and the cold air moving into a region.*

Weather Hazards

Weather is the measure of short-term atmospheric conditions such as temperature, wind speed, and humidity. The Southeast is an extremely active location for high-energy atmospheric events such as **tornados** and hurricanes. It also experiences a variety of other weather hazards, including high temperatures and drought. In 2013, the National Oceanic and Atmospheric Administration (NOAA) reported that since 1980, the Southeast had experienced more billion-dollar weather disasters than any other part of the US.

Storms, Tornados, and Derechos

Rainstorms occur where colder air from higher latitudes abruptly meets warmer air. This often happens in the mid-latitudes, including the Southeastern US, where air may warm up as it passes over flat open spaces or when warm, moist air is delivered off the Gulf of Mexico. At the boundary between warmer and cooler air, buoyant warm air rises and then cools because air pressure decreases with increasing height in the atmosphere. As the air cools, it becomes saturated with water vapor; condensation occurs and clouds begin to form. Because liquid water droplets in the clouds must be very small to remain suspended in the air, a significant amount of condensation causes small water droplets to come together, eventually becoming too large to remain suspended. Sufficient moisture and energy can lead to dramatic rainstorms. Because warm air has a lower pressure relative to cold air, and the movement of air from areas of high pressure to areas of low pressure generates wind, the significant difference in air pressure associated with these boundaries and rainstorms also generates strong winds. Flat regions, such as the Coastal Plain, allow winds to move unimpeded by topography, and are often subject to severe thunderstorms.

While severe thunderstorms are common in some parts of the Southeast, two less common storm hazards have the potential to cause serious property damage and endanger lives: **derechos** and tornados. Both of these storm events are associated with **wind shear**, which occurs when the wind's speed or direction changes with increasing height in the atmosphere. Wind shear can happen when a **cold front** moves rapidly into an area with very warm air. There, the condensing water droplets mix with the cooler, drier air in the upper atmosphere to cause a downdraft. When these downdrafts are very powerful, they can cause a derecho, or a set of powerful straight-line winds that exceed 94 kilometers per hour (58 miles per hour) and can often approach 160 kilometers per hour (100 miles per hour). These powerful windstorms can travel over 400 kilometers (250 miles) and cause substantial wind damage, knocking down trees and causing widespread power outages. The lightning associated with these intense storms can cause both forest fires and house fires. Approximately one derecho every year or two will occur in Mississippi, Alabama, northwest Georgia, Tennessee, Kentucky, and West Virginia (*Figure 9.28*), with fewer along the Gulf and Atlantic coastlines.

The differences between tornadoes and derechos are indicated in their names: *derecho* is the Spanish word for straight ahead, while the word tornado has its roots in the Spanish word *tonar*, which means to turn. Both types of storm

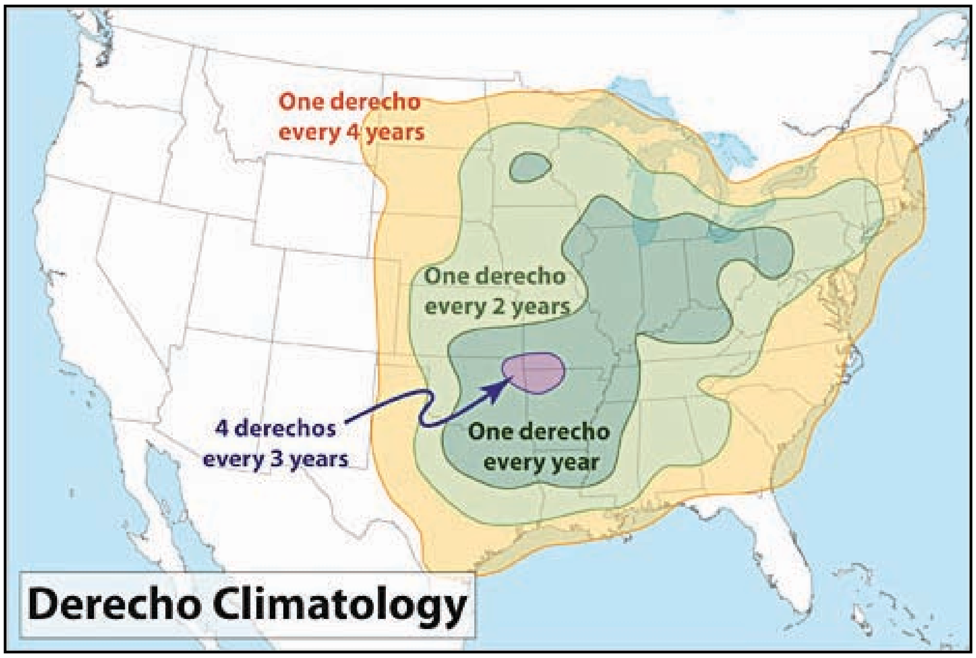


Figure 9.28: Derecho frequency in the continental US.

events can be associated with the same major cold front boundary because they require similar conditions to get started. However, tornado formation is more complicated. At the frontal boundary, warm, moist air rapidly rises as cooler, dry air descends; in the meantime, the pressure differences between the warm and cold air masses cause strong winds. Clouds with a visible horizontal rotation can appear, appearing to roll like waves crashing on the shore of a beach. This horizontal motion can tilt, lifting the rotating cloud vertically, and the rolling cloud will form a tornado. Most tornados will last a few seconds to several minutes. During that time, many tornado-prone areas will use tornado sirens to alert residents of the danger. A smaller tornado might generate flying debris that can cause injury or damage to buildings, while larger tornados can cause buildings and houses to be completely broken apart. Tornados are classified by their ranking on the Enhanced Fujita scale, or EF scale. These classifications are estimates of wind speeds based on the type of damage that is observed following the storm.

"Dixie Alley" is the nickname for an area, extending from Louisiana and Arkansas east to Georgia, which is known for its large number of strong tornados associated with flat topography and severe thunderstorms (*Figure 9.29*). The boundaries of Dixie Alley may vary in application, depending on whether the frequency, intensity, or number of events per location are used to determine the area's borders. In the Southeast it encompasses Mississippi, Alabama, Georgia, and parts of Tennessee, leading to more tornados in these states. From 1991 to 2010, for example, an annual average of 44, 43, 33, and 26 tornados occurred in Alabama, Mississippi, Georgia, and Tennessee, respectively. To the east and north of Dixie Alley, fewer tornado strikes occur, with an annual average of 31 in North Carolina, 27 in South Carolina, 21 in Kentucky, 18 in Virginia, and 2 in West Virginia. While Florida is not typically considered part of Dixie Alley, it is

waterspout • *a spinning funnel-shaped cloud over a body of water.*

convection • *the rise of buoyant material and the sinking of denser material.*

Measuring Tornado Intensity

Tornado intensity is measured on the Fujita scale, or simply F-scale, based on the amount of damage that a tornado can cause. The scale ranges from F0 to F5. The scale was modified recently to more accurately reflect specific wind speeds; this newer scale is known as the "Enhanced Fujita scale" and is labeled EF0 to EF5.

EF Scale	Estimated Wind Speed (kph)	Estimated Wind Speed (mph)
EF0	104–137	65–85
EF1	138–177	86–110
EF2	178–217	111–135
EF3	218–266	136–165
EF4	267–322	166–200
EF5	> 322	> 200

also subject to numerous tornados thanks to a constant influx of warm, moist air; the state experiences an annual average of about 66 tornados. Florida is also commonly subject to **waterspouts**, which often form when a tornado's cyclic winds travel over water (*Figure 9.30*). Waterspouts can also form in association with **convection** beneath large cumulus clouds; these are the most common kind, with over 400 typically seen annually in Florida.

The Southeast does not have a specific tornado season, though they tend to occur more frequently in February to April. Among large recent tornado events was the "2008 Super Tuesday tornado outbreak" (February 5–6, 2008). In total 87 tornados were confirmed, many in Tennessee and Kentucky, and 5 of them rated EF4; 57 people were killed across four states, and damage was estimated at half a billion dollars. An even larger event—one of the largest ever recorded—was the "2011 Super Outbreak" (April 25–28, 2011). It involved 355 confirmed tornados, 11 of which were EF4 and 4 of which received the maximum rating, EF5. Across six states, 324 people died, and the event caused $11 billion in damage. The outbreak most impacted Alabama and Mississippi, but also affected Arkansas, Georgia, Tennessee, and Virginia.

Although specific tornado paths are not predictable, the conditions that produce them are used to alert people so that they can seek shelter. The National Weather Service issues a *watch*, if the conditions are right for a type of storm event, or a *warning*, if the conditions are occurring or imminent for the storm event. The National Weather Service is part of NOAA, which maintains a US

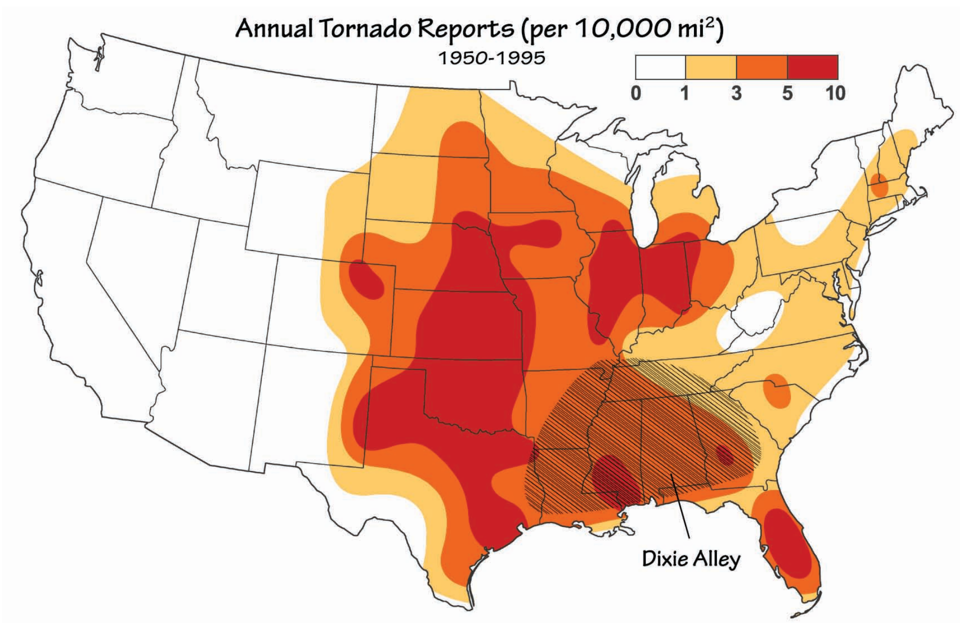


Figure 9.29: Annual tornado reports per 29,500 square kilometers (10,000 square miles) in the continental US, between 1950 and 1995. (See TFG website for full-color version.)

Figure 9.30: A tornadic waterspout east of downtown Miami, Florida.

heat • *a form of energy transferred from one body to another as a result of a difference in temperature or a change in phase.*

tropical depression • *an organized, rotating system of clouds and thunderstorms.*

map of all current watches and warnings. Since atmospheric conditions can change very quickly, an important factor in preventing loss of human life is getting the public to act upon the severe weather alerts. One recent attempt to improve public response to warnings is through a tornado alert index that helps people evaluate the risk of a local tornado. The Tor:Con index used by the Weather Channel provides a number from 1 to 10 that represents the probability of a tornado occurring. Meteorologists evaluate the atmospheric conditions associated with a storm and assign a score. For example, a 4 on the Tor:Con index would indicate a 40%, or moderate, chance of a tornado forming in a particular area.

Hurricanes

Hurricanes occur when a warm, moist, low-pressure air mass forms over the Atlantic Ocean south and east of Florida. These storms gather strength as warm surface ocean water evaporates in the summer, yielding humid, low-pressure air that rises; the moisture condenses into water droplets that form clouds, releasing latent **heat**, and thereby providing energy for even greater evaporation of warm ocean water. This positive feedback cycle continues until the low-pressure center moves over land. These storms are considered **tropical depressions** when wind speeds are below 63 kilometers per hour (39 miles per hour). As the storm grows, it develops a more organized structure, with warm air rising in the center and somewhat discrete bands of rain being formed. It becomes known as a *tropical storm* when its wind speeds reach the 63–117 kilometers per hour (39–73 miles per hour) range, and it is called a hurricane once winds have reached 119 kilometers per hour (74 miles per hour). The western Atlantic, Caribbean, and Gulf of Mexico area is one of the world's most active for hurricanes, though they also occur in areas of the western Pacific, where they are known as typhoons, and in the South Pacific to Indian Ocean, where they are called cyclones.

In an average year, about a dozen hurricanes travel through the western Atlantic and sometimes the Gulf of Mexico. Of these, roughly two a year strike the Atlantic coast. About 40% of all hurricanes to strike the US hit Florida—114 hurricanes in total have hit the state since 1851, 37 of them major hurricanes (Category 3 or above). The peak month is September, followed by August and October. More rarely, hurricanes may hit the coast in June, July, or November. The 2005 hurricane season was the most active in recorded history, with a record number of 15 hurricanes, 7 of which strengthened into major hurricanes (*Figure 9.31*). The costliest hurricane to date was Katrina in August 2005, with almost 2000 lives lost and over $100 billion in damage. The costliest hurricane in the Southeast was Andrew in 1992, with over $45 billion in damage (*Figure 9.32*). Although the Category 5 hurricane caused only 65 fatalities, it obliterated thousands of homes and buildings across Miami and Homestead, Florida.

Once hurricanes reach land, they lose energy rapidly, though they typically continue to deliver substantial precipitation and somewhat high winds for hundreds of kilometers (miles) onshore. Hurricanes that make landfall along the Atlantic coast tend to track northward following the eastern seaboard, while those that track over the Florida Panhandle, Mississippi, and Alabama generally veer north to northeast, heading across Georgia, North and South Carolina, and Tennessee.

Measuring Hurricane Intensity

Hurricanes are ranked in the Saffir-Simpson scale from category 1 to 5, with 5 being the highest, based on wind speed. Category 5 hurricanes occur on average only about once every three years in the Atlantic and Gulf of Mexico.

Saffur-Simpson Hurricane Scale	Wind Speed (kph)	Wind Speed (mph)
Category 1	119–153	74–95
Category 2	154–177	96–110
Category 3	178–208	111–129
Category 4	209–251	130–156
Category 5	≥ 252	≥ 157

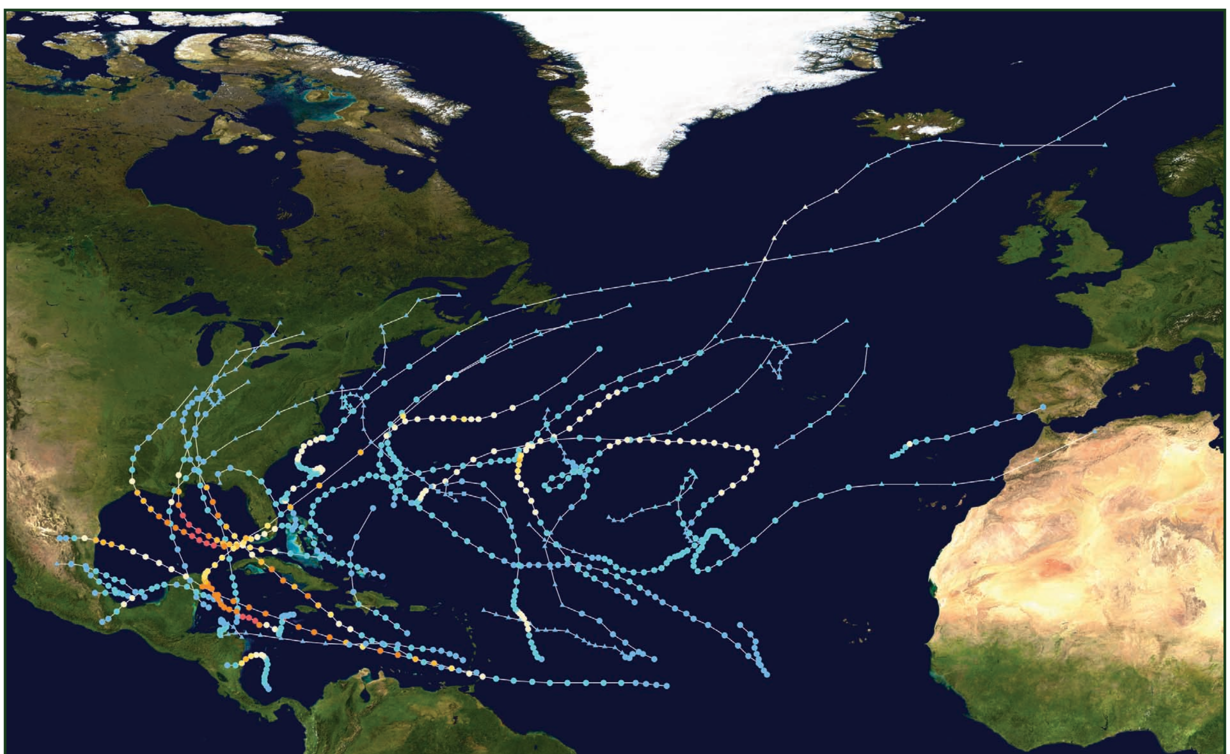


Figure 9.31: Tracks of all Atlantic hurricanes during the 2005 season. Warmer colors indicate higher maximum sustained wind speeds.(See TFG website for full-color version.)

Major Hurricanes Affecting the Southeastern States			
Date	**Name and Landfall Location(s)**	**Category at Landfall**	**Deaths**
August–September 1935	Labor Day Hurricane; FL	5	600
August 1969	Hurricane Camille; MS	5	259
August 1992	Hurricane Andrew; FL, LA	5	65
September 1919	Florida Keys Hurricane; FL	4	772
September 1926	Great Miami Hurricane; FL, AL, MS	4	539
September 1928	Okeechobee Hurricane; FL, SC	4	4079
October 1954	Hurricane Hazel; NC, SC	4	1191
August 1979	Hurricane Frederic; AL, MS	4	12
September 1989	Hurricane Hugo; SC	4	107
August 2004	Hurricane Charley; FL	4	35
June 1966	Hurricane Alma; FL	3	91
August–September 1996	Hurricane Fran; NC	3	27
September 2004	Hurricane Ivan; AL	3	124
July 2005	Hurricane Dennis; FL	3	89
August 2005	Hurricane Katrina; FL, LA	3	~2000

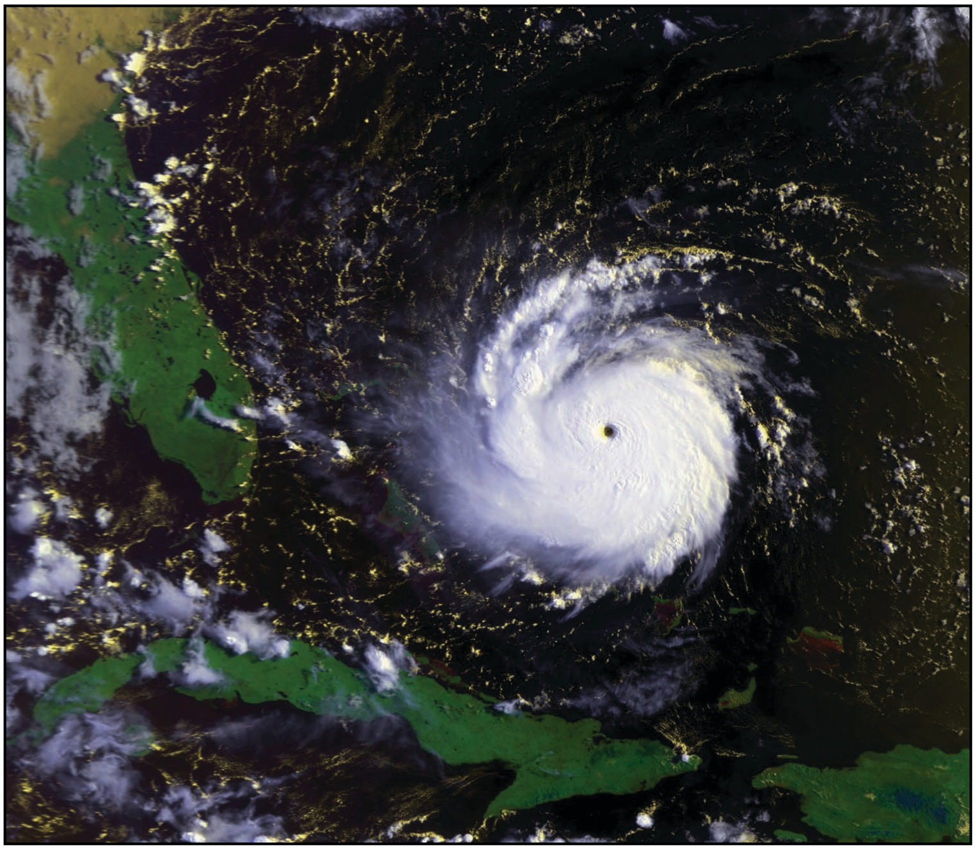


Figure 9.32: Satellite image of Hurricane Andrew as it approached the Florida coastline.

heat wave • *a period of excessively hot weather that may also accompany high humidity.*

Extreme Temperature and Drought

Extreme temperatures can create dangerous conditions for people and may lead to property damage. **Heat waves** are periods of excessively hot weather that may also accompany high humidity. Temperatures of just 3°C (6°F) to 6°C (11°F) above normal are enough to reclassify a warm period as a heat wave. Under these conditions, the mechanism of sweating does little to cool people down because the humidity prevents sweat from evaporating and cooling off the skin. Heat waves have different impacts on rural and urban settings. In rural settings, agriculture and livestock can be greatly affected. Heat stress recommendations are issued to help farmers protect their animals, particularly pigs and poultry, which, unlike cattle, do not have sweat glands.

The impacts of heat waves on urban settings include a combination of the natural conditions of excessive heat and the social conditions of living in a densely populated space. Cities contain a considerable amount of pavement, which absorbs and gives off more heat than vegetation-covered land does. Air conditioning units that cool down the inside of buildings produce heat that is released outside. Pollution from cars and industry also serve to elevate the

Drought

heat island effect • a phenomenon in which cities experience higher temperatures than do surrounding rural communities.

outdoor temperatures in cities. This phenomenon, in which cities experience higher temperatures than surrounding rural communities do, is known as the **heat island effect**. Other social conditions can increase the hazards associated with heat waves in urban areas. People who are in poor health, live in apartment buildings with no air conditioning, or are unable to leave their houses are at greatest risk of death during heat waves. In July 2011, parts of the Southeast experienced the nation's hottest summer heat wave in 75 years, with temperatures reaching upward of 55°C (131°F) during a period of four months (*Figure 9.33*). Although Texas, Oklahoma, and Arkansas took the brunt of the extreme heat, the Carolinas, Georgia, and Mississippi also experienced severe temperatures. The heat wave contributed to severe drought, amplified heat-based health emergencies, and caused a heavy spike in electricity usage (related to increased air conditioning use) that generated a record-breaking demand on the power grid and led to increased energy prices.

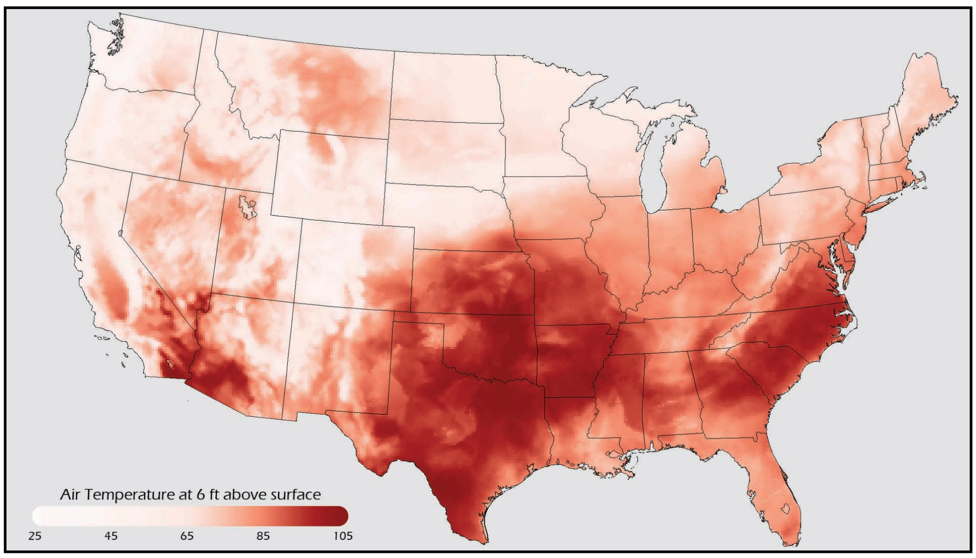


Figure 9.33: Air temperature in the continental US during July 2011. (See TFG website for full-color version.)

While high temperatures can be directly dangerous, a larger scale hazard arises when these temperatures are coupled with lack of precipitation in an extended drought period. Several significant droughts have occurred in the Southeastern states; the most severe droughts in Kentucky and Virginia occurred from 1930 to 1932, and intense drought struck much of the Southeast, especially Georgia and South Carolina, during the heat wave of 2011. In 2012, more than 25% of the state of Georgia was in a period of exceptional drought, the most intense level possible. Additionally, in October 2015, some parts of Mississippi experienced "extreme drought," the fourth of five drought levels recognized by NOAA's US Drought Monitor.

Climate Change

It is important to understand that most of the extreme climate change in Earth's history occurred before humans existed. That being said, the rapid release of carbon dioxide into the atmosphere from human activity is currently causing a **global warming** event. The seemingly slight increase in the average annual temperatures in the Southeast over the past 25 years has been accompanied by more frequent heat waves, shorter winters, and an increased likelihood of drought and wildfires.

Although wildfires can occur during any season, summer fires are the most common, since increased dryness contributes to fire risk. The Bugaboo Scrub Fire, which raged from April to June 2007, was the largest fire in the history of Florida and Georgia; it consumed 243,000 hectares (600,000 acres) of land and 1738 lives were lost (*Figure 9.34*). In 2014, one of the worst wildfire years on record, 2436 fires burned across Florida, destroying 41,115 hectares (101,599 acres) of land, while 1249 fires burned 63,289 hectares (156,391 acres) in Tennessee.

Water supply is also a critical issue for the Southeastern states. Large parts of the area obtain agricultural and drinking water from **aquifers**, underground layers of water-bearing **permeable** rock. The Floridan Aquifer, one of the world's most productive aquifers, underlies all of Florida as well as parts of South Carolina, Georgia, and Alabama. As drought has intensified and temperature has risen, the amount of water drawn from the aquifer (especially for agricultural irrigation) has increased, while the rate at which the aquifer refills has decreased. In addition, the aquifer is at risk from saltwater intrusion as sea level rises due to warming temperatures.

Figure 9.34: The Bugaboo Scrub Fire burns out of control near Lake City, Florida, in May 2007.

global warming • *the current increase in the average temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere.*

aquifer • *a water-bearing formation of gravel, permeable rock, or sand that is capable of providing water, in usable quantities, to springs or wells.*

permeability • *a capacity for fluids and gas to move through fractures within a rock, or the spaces between its grains.*

Increasing temperatures also allow certain pests, such as ticks and mosquitoes, to live longer, thereby increasing the risk of contracting the diseases they carry. In addition, invasive organisms that damage ecosystems, such as the hydrilla plant in Florida and along the Gulf Coast, have a better chance to multiply and outcompete native organisms because increased temperatures stress local ecosystems and create an environment more favorable to invasive species.

Another concern regarding hazards exacerbated by climate change in the Southeast is whether or not there has been or will be an increase in the number or severity of storms, such as hurricanes and tornados. According to NASA, the present data is inconclusive in terms of whether hurricanes are already more severe, but there is a greater than 66% chance that global warming will cause more intense hurricanes in the 21st century. Since climate is a measure of weather averaged over decades, it might take many years to determine that a change has occurred with respect to these types of storms. Scientists are certain that the conditions necessary to form such storms are becoming more favorable due to global warming.

The Union of Concerned Scientists has created an infographic that demonstrates the relative strength of the evidence that various hazards are increasing as a result of climate change (*Figure 9.35*).

See Chapter 8: Climate for more on the effects of climate change in the Southeast.

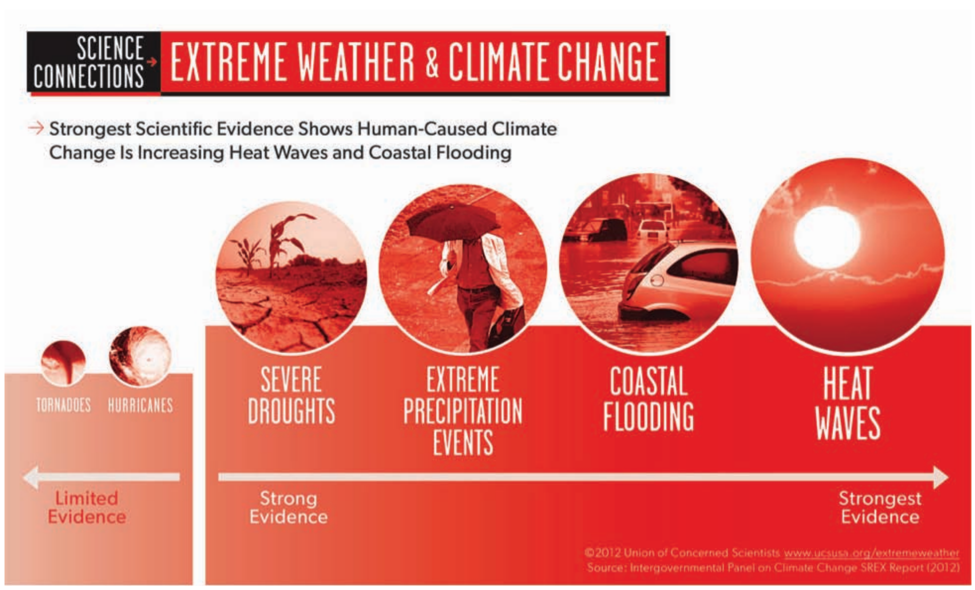


Figure 9.35: The strength of evidence supporting an increase in different types of extreme weather events caused by climate change.

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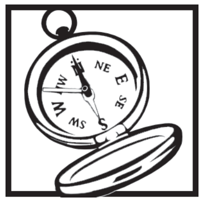

Chapter 10:
Real and Virtual Fieldwork:

"Why Does This Place Look the Way it Does?"

All the major topics in *The Teacher-Friendly Guides™* were built upon observations of the natural world, and these observations are the clues that scientists use to reconstruct the history of the Earth. Shelly fossils along the Himalayas tell of ancient sea floors that have been uplifted into mountains. Ripple marks that have since turned to stone tell of ancient shorelines. And scratches along the bedrock in Central Park tell of massive glaciers that—some 20,000 years ago—created a skyline much different than the one of steel and glass found in New York today. A number of forces and processes have made seas, forests, deserts, and the life those ecosystems hosted appear and disappear from the landscape over the course of geologic time. Many of these changes left behind hints that we can interpret today when we tell the story of a place. That massive glaciers once advanced as far south as New York is not a conclusion derived from mathematical modeling in a lab; it is instead evidenced by not only those scratches, but also by a host of observed glacial deposits that litter not only New York, but much of northern North America.

> *The story of a place is written in its landscape, rocks, fossils, and biota; fieldwork investigations help scientists—and students and teachers—tell that story.*

Introducing students to the practice of fieldwork can be a tremendous experience. Its central role in the education of geoscientists makes fieldwork a "signature pedagogy" in the preparation of professionals within the field, and fieldwork warrants a larger place in the K-12 curriculum. For these reasons, real and virtual fieldwork practices are well suited for addressing both *The Next Generation Science Standards* and *The Common Core Learning Standards.* Fieldwork as a topic is also fundamentally different from the other chapter topics in this guide. Therefore, this chapter is somewhat different in structure and is significantly longer than the other chapters in the Guide. The chapter begins by laying out some of the rationale for engaging in real and virtual fieldwork, and it then addresses some of the nuts-and-bolts issues for planning, carrying out, and documenting fieldwork with your students.

Exploring local natural history through inquiry-based approaches emphasizes critical thinking. And by conducting such investigations, students have taken a tremendous leap: they are not merely learning about science; they are doing science! But getting students into the field can be difficult. An alternative is for the educator to visit the field on his or her own time, returning to the classroom with a series of images and specimens that permit a Virtual Field Experience

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(VFE). Virtual fieldwork offers the opportunity to explore an area without leaving the classroom, and it allows multiple "visits" to a site. VFEs can also enhance and extend the experience when actual fieldwork is possible. The Earth is a system, after all, and any one site—virtual or real—can display a host of natural phenomena, from simple erosion and deposition to the principles of superposition and faunal succession to the formation of ripple marks or mud cracks. By adding to a VFE year after year, you can also document changes within the environment, such as changes to a stream's course, the succession of an ecosystem, or the nature of human disturbance. Ideally, virtual fieldwork in the classroom captures the active experience of a scientist examining an area: It provides opportunities to actively explore, discover, ask questions, and make observations that help to answer those questions, ultimately allowing students to develop educated responses to the question *"Why does this place look the way it does?"*

Commonalities of Virtual and Actual Fieldwork

This chapter addresses both actual and virtual fieldwork and the many connections between them. The process of making VFEs, at least in the ways we lay out here, involves doing actual fieldwork. Much of the work of making a VFE involves simply following good fieldwork practices in combination with a heightened attention to sharing the experience with students or other learners. While VFEs can be used in place of actual fieldwork, they can also be used to both prepare for and reflect upon actual fieldwork. Engaging students as partners in the creation of VFEs is an opportunity for teaching through inquiry while also building a resource that is useful to people outside of the school, as well as to future students. What follows addresses all of these possibilities.

NASA scientists routinely conduct actual fieldwork remotely.

We also draw attention to the distinction between field*work* and field *trips*. We strive to engage learners in *figuring things out*, while field trips—whether actual or virtual—are too often characterized by trip leaders *pointing things out*. Building in the opportunity for genuine discovery is challenging but promises to yield longer-term engagement and understanding.

Just Go (and Don't Stop)

The minimum requirement for conducting fieldwork is your own sweet self. This chapter discusses a wide range of tools and approaches, but doing fieldwork of any (safe) sort that doesn't damage the site is a key objective. The tools and approaches discussed in this chapter will extend your senses and help you to capture the experience in ways that will make it easier to share with students. Work within your comfort zone (but perhaps at its edge) and at a pace appropriate to what life allows, and gradually build your virtual representation of the local environment over the course of years, increasing student participation in the process as time goes by. Use the local landscape to nurture skills within your students that will allow them to read any type of landscape. Through this process, your students can teach members of your community about the story of your site while also creating and extending resources that can teach other learners around the country about where you live. Building a deep understanding of place through VFE development and then comparing your local environment with VFEs created by other teachers and students is an excellent way to use the local environment to understand the global environment.

Whether the fieldwork is real or virtual, it can either involve a single visit or be extended over many, many visits. Scientists may reach points where they have figured out particular pieces of the puzzle when understanding the nature of a site, but they never fully understand all aspects of a place’s story. Fieldwork, therefore, is something that is never "finished." Whether it is the second or seven-hundredth visit to a site, there is always more to discover. This is part of what makes science fascinating! It connects to the idea that while fieldwork may focus primarily upon a single topic, researchers (whether K-12 students, educators, or professional scientists) who develop a deep understanding of the story of a place must understand the roles of geology, ecology, climatology, anthropology, and more. Of course, this type of understanding will not come from a single class period of fieldwork, or even a single course infused with fieldwork, but the appreciation of this systems idea can be planted and nurtured.

Start local

In choosing a field site, whether it is local or distant or for actual or virtual fieldwork, it should be interesting from an Earth systems science perspective. Fortunately, if you know how to look, *every* site is interesting from an Earth system science perspective. Over the grand course of Earth history, the story of any location is a fascinating one that involves myriad changes. The work of telling the story of any environment is a form of rich inquiry. While it would also be fascinating to find a place that hasn’t changed, no such place exists on the surface of Planet Earth!

While VFEs provide the opportunity to study distant or otherwise difficult to access locations, we suggest starting close to home or school, at a location that students are already familiar with or have access to. What is outside your classroom door has more immediate relevance to the lives of your students than anywhere else on Earth. Nearly every unit in an Earth or environmental science course, and most of the units in a biology course, play out in some meaningful way in the local environment, and the local environment can extend the boundaries of the classroom tremendously with little or no cost. Things are only understood in comparison to something else, so comparing sites to one another can deepen one's understanding of both or even of all sites—but it is still best to start with the local.

Students can use real or virtual field sites to study how all the major topics in their Earth or environmental science curriculum are manifest in the "real world." In an ideal situation, the classroom is immediately adjacent to a safe, accessible field site, and there is flexibility within the school schedule that allows for in-depth study of the site in ways that cut across disciplinary boundaries. Unfortunately, it's not always practical to repeatedly visit an actual field site with 30 students throughout the year or semester. Through virtual fieldwork, students can come to see how the rock types and flora and fauna outside their classroom tell part of the story of that place.

In order to create VFEs, authors must closely study their field sites with an eye toward doing fieldwork with students. VFEs are a stepping-stone to bringing students into the field, even if the field is "only" the schoolyard. VFEs can be used to prepare students for the field and/or to process the fieldwork after visiting the actual site. Ideally, students will participate in the creation and extension of VFEs, but we recognize that getting to this point may take years.

Connecting to Earth Science Bigger Ideas, the Next Generation Science Standards, and the Common Core

Fieldwork investigations have the potential to be extended indefinitely in time and can involve the integration of a wide range of science and non-science disciplines. *"Why does this place look the way it does?"* is a bottomless question, meaning that it can be productively investigated for a very, very long time. Field scientists, be they professionals or fifth graders, will never fully answer this driving question absolutely or at every scale.

The act of VFE creation is a valuable type of professional development (PD) that creates useful evidence of having done the PD. Through the creation and continued use of virtual fieldwork, a teacher can become a true expert on his or her local environment—perhaps the preeminent expert. The process of VFE creation and use can also create evidence of inquiry teaching aligned to relevant standards. The VFE you create or augment can serve as a key piece of a professional portfolio.

The ultimate goal of our instruction is to build understanding of the Earth system and the ways in which science is used to build that understanding. We bring focus through the use of a small set of bigger ideas and overarching questions. These are discussed in detail in the Big Ideas Chapter and are also summarized below.

Overarching questions:

- How do we know what we know?
- How does what we know inform our decision making?

Earth system science bigger ideas:

- The Earth is a system of systems.
- The flow of energy drives the cycling of matter.

- Life, including human life, influences and is influenced by the environment.

- Physical and chemical principles are unchanging and drive both gradual and rapid changes in the Earth system.

- To understand (deep) time and the scale of space, models and maps are necessary.

Fieldwork should provide the opportunity to explore, describe, and build understanding of these questions and ideas. These ideas and questions map onto the *Next Generation Science Standards'* Disciplinary Core Ideas, Crosscutting Concepts, and Science and Engineering Practices. The Crosscutting Concepts and Scientific and Engineering Practices are shown in *Table 10.1*. As you read through the rest of this chapter, and as you and your students carry out fieldwork, revisit these lists of concepts and practices frequently in order to draw attention to how they connect to the work of reading the landscape.

Table 10.1: NGSS's Scientific and Engineering Practices and Crosscutting Concepts. As you and your students engage in fieldwork, consider how the practices and concepts are being used to make sense of the environment. See the Big Ideas Chapter for a more in-depth discussion.

Scientific and Engineering Practices	Crosscutting Concepts
1. Asking questions and defining problems	1. Patterns
2. Developing and using models	2. Cause and effect
3. Planning and carrying out observations	3. Scale, proportion, and quantity
4. Analyzing and interpreting data	4. Systems and system models
5. Using mathematics and computational thinking	5. Energy and matter
6. Constructing explanations and designing solutions	6. Structure and function
7. Engaging in argument from evidence	7. Stability and change
8. Obtaining, evaluating, and communicating information	8. Interdependence of science, engineering, and technology
	9. Influence of engineering, technology, and science on society and the natural world

Fieldwork Challenges and Benefits

Of course, VFEs also allow for some kind of "fieldwork" experience when actual fieldwork is difficult or impossible to carry out. The reasons that actual fieldwork is difficult are fairly obvious:

- **Fieldwork is logistically challenging.** It's hard to fit into a typical class period, or even a double lab period. To go off site requires permission slips, busing, and figuring out how to deal with behavior outside the normal classroom setting.

Challenges

- **It costs money.** Field trip budgets have been slashed, and weren’t even very common at the secondary level before budget cuts.

- **Many teachers have only limited experience doing field science themselves.** Earth science has more teachers teaching out of field than any other science discipline, and fieldwork is not a component of many Earth, biology, or environmental science teacher certification programs. It is intimidating to lead fieldwork if you haven’t been through it yourself.

- **Fieldwork poses safety and behavior concerns different from those in the classroom.** Falling off a cliff has different consequences than falling off a chair.

- **Teaching in the field employs a different set of skills than teaching in the classroom.** The logistics of moving groups of students from place to place and focusing their attention on the goals of the fieldwork takes careful planning, especially if multiple classes are involved.

These issues shouldn't preclude fieldwork, but they undeniably complicate it. These challenges are not insignificant, but the rewards of doing fieldwork are worth the trouble. Field trips are among the most memorable and most valued school experiences.

Fieldwork 101: Gathering Information and Creating Your Own VFE

What follows are recommendations. These recommendations are intended to help prepare you for fieldwork, but they are just guidelines, not steadfast rules. Bringing the field to the classroom at any scale is better than not bringing the field to the classroom at all. The careful attention to detail described here will prove extremely helpful, but avoid being discouraged if your first trip to the field isn't as productive as you had initially imagined. Scientists of all disciplines continually refine their methods and procedures, leading to more productive and "better" results over time. With time and more fieldwork, your confidence will grow. Get into the field, be safe, and do your best to capture the experience in a way that allows you to best reproduce it for your students!

Fieldwork 10

Fieldwork 101

Before visiting the site: understand the natural history of the region

In order to make sense of a local site, it's helpful to understand the geologic history of the larger region before your visit. Did inland seas once flood the area? Have mountain-building events shaped the landscape and its rocks? Was it glaciated? Since the reasons that a place looks the way it does are dependent upon more than the geology, you want to pay attention to this concept as well. That being said, since the geology is the base upon which the landscape is built, starting there makes good sense. *The Teacher-Friendly Guides™* are an excellent source for discovering the history of a region, as well as that history's effect on the rocks, fossils, and other features of the area.

Questions to Keep in Mind

When visiting or examining any area, the ultimate question to answer is: *Why does this place look the way it does?* But to help understand such an overarching concern, it is important to have certain other questions in mind. These questions will guide exploration, and they will help ensure that important information is recorded during your visit:

- What kind(s) of rock(s) are found in the area? How do you know?
- In what environment did these rocks probably form?
- What is the arrangement of the rocks?
- Are fossils preserved in the rocks? If so, what can they tell you about past environments?
- What has happened to this area to make it look the way it does today? (That is, what has happened to the area since the rocks formed?) Why do you think so? (What is the evidence for your claim?)

We have put together a set of questions that build upon the fundamentals listed above and that can be asked of any site. This is a key idea—that there are questions that can be asked productively about any environment. Recognizing that idea is a key step toward being able to take the lessons of one field trip and applying them to the "reading"of any landscape. These questions are included in the graphic organizer in *Figure 10.1*, and as a checklist in the section entitled Back in the Classroom.

10 Fieldwork

Fieldwork 101

Figure 10.1: This pair of graphic organizers shows various paths of inquiry that stem from the question: Why does this place look the way it does? *The top graphic focuses upon the geosciences, and the bottom focuses upon the environmental sciences. The questions within the diagrams are also included as printable checklists in the section "Back in the Classroom."*

Safety and Logistics in the Field

At the Site

Considerations are different for an adult or a group of adults in the field than they are for taking students into the field, but certain measures related to safety are universal. At any field site, safety is the first priority. No photograph, measurement, or fossil is worth the risk of personal injury or death. To ensure safe and productive fieldwork, keep the following thoughts in mind:

- Always carry a small, standard first-aid kit.
- Wearing the proper clothing is very important. Long pants are recommended, as are sturdy boots, which will help prevent twisted ankles as you scurry over uneven or loose surfaces.
- While walking through a valley or next to any outcrop, always be on the lookout for rock falls. Remember, slopes with no vegetation tend to produce more falls.
- If more than one individual is climbing an outcrop, do not climb single file. Rocks dislodged from one climber can quickly tumble down the outcrop and hit the next climber.
- When using your rock hammer, protective eyewear should always be worn. If your hammer possesses a sharp pick opposite the flat surface, always use the flat surface when striking. And if you are working with others, notify all in the vicinity before striking any surface with your hammer.
- Never use one hammer to strike another. Metal chips can be broken off and thrown at high speeds.

Sunscreen, insect repellent, flashlights, food, and water should be considered in relation to environmental conditions and length of the field excursion. Please note that this chapter is written with shorter excursions in mind where substantial supplies will not generally be required. The next section offers more detail on the materials to take with you into the field.

Give appropriate consideration to group management. We suggest taking individual classes into the field for short trips before attempting either longer fieldwork excursions or trips with multiple classes. Managing larger groups or longer trips requires attention to logistics that will not be addressed in depth here. Whether the group is large or small, consider the benefits of a buddy system and measures to keep track of where everyone is—both children and adults. If groups are spread out on the trail, the lead group should stop at trail crossings to make sure everyone follows the intended trail. Younger students should not be left unsupervised for *any* length of time. Schedules and rendezvous points are important for longer trips and larger groups. All teachers and chaperones should have one another's cell phone numbers.

10 Fieldwork

Needs

Things You Might Use in the Field

The Essentials and Near Essentials

As noted above, the essential materials for going in the field (besides yourselves) are clothing (especially footwear) that is suited to the weather and trail conditions and a first-aid kit appropriate to the situation. You will likely also want tools or devices to extend your senses, to preserve your observations, to collect materials (where safe and legal), to take photographs, and to store data, all of which will allow for continued observation and analysis after you return from the field. If your fieldwork is on the school grounds, or adjacent to it, you perhaps won't need anything different than what is needed on a typical class day, at least for the initial visit.

To extend your senses, start with simple things like magnifying loupes and rulers and potentially move on to include more sophisticated tools like probeware (to measure pH, temperature, and dissolved oxygen) or field microscopes. Since tools are used for both extending your senses and for capturing and preserving your observations, the most obvious tools for preserving one's observations are notebooks, pencils, cameras, GPS units, smartphones, and tablets.

As varied as field science is, a few items should be in every scientist's gear whether you are investigating rocks, observing streams, or documenting ecology. Even though processes and concepts are universal, each place is also unique, a product of its position on the Earth, its geological and ecological history, and the local human impacts. Making sense of why a place looks the way it does must take that context into account. Further, good science depends upon repeatability of observations: if another scientist (or your next class!) wants to analyze or build upon your observations, he or she must be able to know precisely where your study took place and how you made your observations. It is thus critical to locate the position of your studies on a map as precisely as possible. With modern GPS technology, it has never been easier to record a location to within a few meters, though you can certainly follow good science practices even if you don't have this capability. *Table 10.2* lists equipment and materials that are useful in the field.

Maps and Notebooks

Large-scale maps provide a way to see your field site in the context of other features in the area. At a closer scale they also provide a way to show the position of several sites relative to each other. At still higher resolution, maps provide the medium to store and display spatial information from one site. You will therefore probably want maps at all of these scales.

Large- and medium-scale maps for providing context can be found online. Google Maps and Google Earth are two of the best known interactive sources. If students need help understanding maps and scale, a helpful exercise is to create a "Powers of Ten" map of your schoolyard, starting with an overhead shot of the school yard that students recognize, then zooming out—making each of the new images increase in dimension by ten times—until one can see the site from the perspective of the whole Earth. A video tutorial, inspired

Needs

Table 10.2: Materials to take in the field. (Items in bold are highly recommended.)

<table>
<tr><th>For Safety and Comfort</th><th>For Extending the Senses</th><th>For Preserving and Extending Observations</th></tr>
<tr><td rowspan="3">☐ Yourself
☐ Appropriate footwear
☐ First aid supplies
☐ Water
☐ Sunscreen
☐ Insect repellent
☐ Food
☐ Safety goggles
☐ Flashlight

Common sense should be your guide when determining what is needed for a particular visit to the field. Trips that last a class period and are adjacent to the school may require nothing beyond materials for a typical class—a notebook and a pencil.</td><td>☐ Ruler or scale card
☐ Measuring tape or meter stick
☐ Magnifying loupe or hand lens (about 10× magnification)
☐ Water test kit
☐ Compass
☐ Clinometer
☐ Field microscope
☐ Field guides</td><td>☐ Notebook
☐ Pencil
☐ Materials for collecting
o Baggies
o Specimen labels
o Sharpies
☐ Rock hammer
☐ Camera</td></tr>
<tr><th colspan="2">For Both Extending the Senses and Preserving Observations</th></tr>
<tr><td colspan="2">☐ Maps
☐ Camera (possibly with video)
☐ Probeware and interface (like the Vernier LabQuest)
☐ Digital field microscope
☐ GPS unit, smartphone, or tablet
☐ Apps used in the field might include:
o GPS
o Google Earth or other virtual globe
o Skitch (or other image-annotating app) for adding notes to photos. Skitch also includes a map annotation function.
o Photosynth or other panorama app
o Video (the YouTube Capture app allows for basic video editing on your smartphone or tablet)
o Other specialized photography apps
o Audio recorder
o Notes
o Photo management software, such as Web Albums</td></tr>
</table>

by the classic film, is available at http://www.virtualfieldwork.org. It is simple to add your field site to the same Google Earth file containing the Powers of Ten centered on your school. This can help students better understand the location of the field site in relation to the school.

Field scientists typically show information about their field site: the location of observations (such as photographs and specimen collection) and also the scientific data (such as rock type, position of faults, areas of bedrock exposure, water quality information, and much more). For these purposes you may want to have a paper copy of a map you can bring into the field upon which you can make notes. Commonly topographic maps are used as base maps, in part because the contours can help you locate yourself on the map (if it's not completely flat) and partly because the topography itself is often relevant to Earth and the environmental data being collected. If your field area is larger than about 100 meters (330 feet) on a side, you can create a topographic map tailored to your needs using online software (http://www.gpsvisualizer.com). USGS topographic maps of the entire US are available as free downloads at http://www.usgs.gov/pubprod/. You may wish to download the local map and take an excerpt of the area surrounding your site.

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Needs

Positions of samples, photographs, and observations can be located using GPS. In this case, you can make notes about your GPS locations, and plot the locations on a computer later, or make use of an app like Skitch that allows you to annotate digital maps in the field. Photos taken with smartphones, tablets, and GPS-enabled cameras will include location data with pictures. Those familiar with Geographic Information Systems (GIS) can make elaborate maps using your own sets of coordinates and data. While GPS and GIS technology are now standard in most types of fieldwork, they are not essential for doing good fieldwork. Standard, intuitive tools for measuring are, however, quite helpful. A compass (either traditional or digital) can be helpful in orienting your field site in space, and a ruler and protractor can be helpful when drawing the field site in correct proportions (e.g., the position of samples along a transect or the angle of bedding or faults). Bring a clipboard so that you have a flat surface to write upon in the field—pencils and a good eraser are the best writing implements for drawing and annotating your map.

It is possible in principle to capture all your data electronically, but most field scientists still use a notebook even if they have access to the latest technology. Certain information can be captured very simply in the field with a pencil and paper while it may prove challenging with digital technology, such as when making annotated sketches of the field site and taking written notes. Normally pencil is used, in part because it doesn't smear if it gets wet, but also because it's erasable; while not essential, field scientists who know they may have to work in wet conditions will purchase notebooks with waterproof paper (Rite-in-the-Rain notebooks). An audio recorder (smartphone or standalone digital recorder) is handy when writing a lot of text is impractical, though it does create transcription work at the end of the day. Remember that it is considered a form of "best practice" to make sure that each entry includes the date, time, and locality.

Documentation and Specimen Collection

Photographs

Once at a field site it is easy to immediately begin taking photographs without recording notes to accompany them—a problem experienced by professional and amateur scientists alike. But the lack of proper documentation is perhaps the most common mistake made in the field, especially with digital photography, where it is easy to take tens or even hundreds of photographs at a single site. Also, before you begin photographing it is advisable to first explore the entire location and develop a plan for how you will communicate the site to your students back in the classroom. This plan will guide your photography, and the recorded notes will ensure that every image makes sense long after you've visited the site. Proper documentation includes the following steps:

- Note the location and orientation of the photographs you take. Recording this information on a map is very helpful.

- In each photograph, it is important to have a sense of scale. For smaller structures (like ripple marks or fossils) or close-ups of an outcrop or rock, it is important to show scale by using a common object, such as a penny, rock hammer, an unsharpened pencil, or (ideally) a clearly marked ruler. For larger structures, a really great scale is a person, so feel free to step into the picture! The importance of a scale cannot be overstated, as the proper identification of geologic features in photographs often depends on knowing the feature's size.

- In addition to showing scale within photographs, be sure to pay attention to different scales across the set of photographs you take. That is, include photographs across a wide range of scales, from the smallest fossil or mineral crystal to panoramic shots of the landscape. Maps and virtual globe software, such as Google Earth, can extend scales from the local landscape to a global perspective.

Drawings

Although photographs are key, simple sketches or drawings are also useful for documenting a field site. In fact, subtle changes in rock layers, for example, may not be visible in photographs, so to capture such features, drawing may be required. Drawing also forces you (or your students) to observe closely. It will be helpful to use either a Rite in the Rain notebook or a large, clear plastic bag to hold your notebook in case of rain. When drawing, keep in mind that you should document the same type of information that is documented in photographs (location, orientation, and scale). Drawing also requires close study in a way snapping a photograph does not. Louis Agassiz once said that "…a pencil is one of the best of eyes." While drawing, you have to think about the relationship of the elements you are representing, their scale, and their arrangement.

Annotating Photographs

The use of smartphones and tablets in the field allows for a hybrid of photographs and drawings. Many apps allow for captioning photos in the field, and some allow you to draw and write text on photos as you take them. Skitch is one such app, and it also allows for the taking of notes on the maps themselves. Photos taken on smartphones and tablets are also (typically) geo-referenced. This means that they can easily and quickly be included in a Google Earth or other GIS program in the precise location where the image was taken. If you are unable to annotate photographs in the field, or you wish to add more detail than is practical on your electronic device while you are at the field site, the "old fashioned" technique is to take a picture, then make a simple notebook sketch containing labels of key features. Later you can annotate a digital or printed version of the photograph using your field notes. If the conditions are poor for note taking either digitally or manually, it may be more practical to record audio notes that you can later match to your picture.

Using Field Guides

Select field guides appropriate to the focus of your work and consider whether or not you wish to bring others. The appropriate field guide might be something as simple as a single sheet with line drawings of the fossils common at your field site, a few pages containing a dichotomous key of common rock types, or a collection of field guides on fossils, birds, mammals, butterflies, rocks, flowering plants, and more. While scientists will come to know by sight the kinds of specimens commonly found at their site, they do not typically set out to memorize them, and uncommon things are sometimes found that send even experts back to their field guides.

Collecting Specimens

Rocks and fossils often provide significant clues for interpreting past environments. Layers of basalt indicate past volcanism, for example, whereas shales bearing trilobite and other fossils indicate deposition in a shallow sea. Collecting specimens from a site provides a wonderful opportunity to take a piece of the field into the classroom, allowing you to engage students in hands-on learning. Collecting specimens also permits further study away from a site where time and field conditions can impose certain limitations. You can and are encouraged to identify rocks, minerals, fossil types, and flora and fauna in the field. So, what do you need to know about collecting specimens?

- **You first need to confirm that collecting specimens at the site you are visiting is legal**. Typically, collecting is not allowed in parks, so be sure to check.

- Just as you made decisions about photography based on how you plan to communicate the site to students, collect specimens that will help tell the story of the site back in the classroom. If rock types change from area to area, either vertically or horizontally, then specimens of each type are ideal.

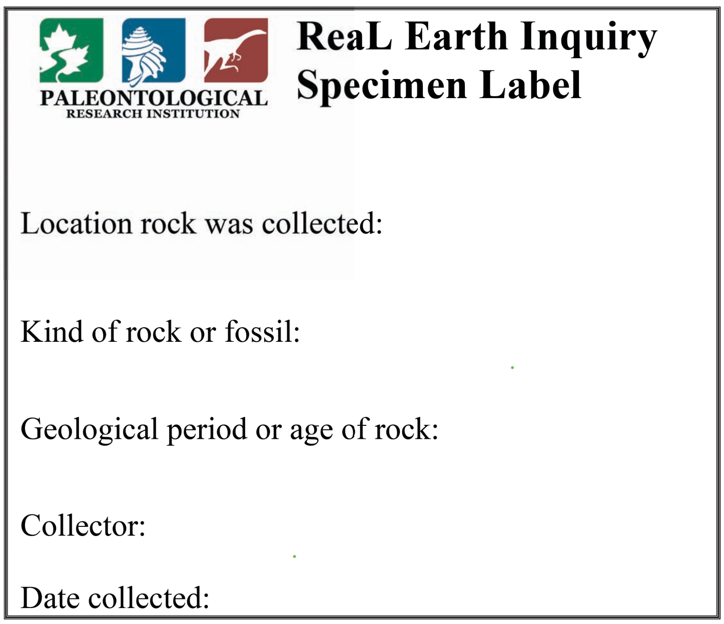
- Before collecting a specimen, take a photograph of it in situ, both close up as well as from a distance. Don't forget to include an object for scale in the photograph!

- Document the location from which the specimen is collected, preferably on a map of the area. Labeling the specimen with a number that corresponds to a number on your map is an effective technique.

- Specimens should be broken directly from the outcrop so the exact source is known. Eroded rocks scattered about on the floor of the site may have originated from multiple locations.

- The weathered surface of rocks often carries a different appearance than a "fresh" break. Ideally, collected specimens possess one weathered surface but are otherwise not weathered. Rocks broken directly from outcrops will ensure fresh surfaces.

- As specimens are collected, place each in a separate resealable bag, noting on the bag with permanent marker each specimen's location as indicated on your map. Include a specimen label within the bag, including the information shown in *Figure 10.2*.


PALEONTOLOGICAL RESEARCH INSTITUTION

ReaL Earth Inquiry Specimen Label

Location rock was collected:

Kind of rock or fossil:

Geological period or age of rock:

Collector:

Date collected:

Figure 10.2: This specimen label, printed six to a page, is available for download at http://virtualfieldwork.org/Assessments_and_Student_Materials.html.

Back in the Classroom: Virtual Field Experiences (VFEs)

Following your trip to a field site, perhaps the most critical step after returning to your lab or classroom is to examine all of your photographs, illustrations, specimens, and notes associated with each. Sometimes even the most diligent geologist forgets to record notes that, in hindsight, are critical. It is therefore recommended that one makes sure that his or her notes are legible and complete. Recopy your notes. Such an activity will not only ensure legibility for the future, but it will help indicate any gaps in your note taking. If gaps exist, then it is easiest to fill them in when your memory of the site is fresh.

Once your materials from the site visit are in order, it is time to develop an activity that will allow your students to experience the site much like you did—but in the classroom. VFEs allow you to compile this information in a way that is easy to share with others who wish to learn about the site. Ideally, VFEs provide opportunities for open-ended exploration, just as actual fieldwork does. Scientists in the field are not limited to a single possible way to operate, nor do they have a guide explaining what they see at every turn. In the field, one might pick up a rock and take a closer look, or pull out a magnifying glass and look at a cliff face. Exploration drives inquiry in the field, and inquiry and exploration are key goals of VFEs.

The concept of VFEs can take on multiple forms. For example, kits containing maps, printed photographs, and specimens (with notes on the map indicating where the specimens were collected or where the photographs were taken) can be produced. Or, your digital photographs can be embedded within a PowerPoint or Prezi presentation, a website, or a Google Earth tour with placemarks containing photos, video, or other data in the exact locations where the specimens were collected. Maps can also be overlain. Historic maps can be included, and Google Earth has historical imagery included for much of the world. Many VFEs incorporate more than one technological platform.

Keep in mind that these electronic presentations may take on a very linear, directed feel. In that respect, be careful that your VFE does not turn into a Virtual Field Trip. Virtual Field Trips have become increasingly common at many levels of education, but these experiences are typically guided tours rather than opportunities for inquiry. An online search will yield many examples of these tours, as will a search of the Digital Library of Earth System Education (DLESE). Such resources clearly have value, but they are passive experiences for students. VFEs, in contrast, should stress the importance of inquiry; learning for understanding involves students figuring things out. The act of making new, or extending existing, VFEs may be the simplest way to bring inquiry to the use of VFEs.

In considering VFEs as a recurring practice, initial experiences are perhaps more guided than the later experiences; allow a gradual transfer of responsibility from teacher to student. But VFEs ideally offer the same opportunities for exploration as those provided at an actual field site, with occasional moments of discovery that lead to new questions about the site. By asking such questions and then seeking answers, students are doing science. And it is perfectly reasonable to virtually visit a site several times for further data collection, or even to study different concepts at the same site. Scientists, of course, do exactly the same thing.

Prezi and PowerPoint VFE Templates

This section discusses templates intended to simplify VFE production in addition to providing general information on VFE development and use. There are templates in both Prezi and PowerPoint formats, each with a version of the graphic organizer shown in *Figure 10.1* as its centerpiece. Questions in the graphic organizers and in the rest of the templates are written generically, so they may be applied to any site. The templates serve as starting tools that are useful for creating an "entry level" VFE. They are available at http://virtualfieldwork.org/Template.html. The template includes graphic organizers for both Earth and environmental science, with the environmental science organizer embedded within the geoscience organizer.

How are teachers using virtual fieldwork?

VFEs might be used as a single, in-class exercise, or they can be explored across an entire year. We hope that teachers who use and develop VFEs will eventually use them across the entire curriculum, but it makes sense to start smaller. There is no single correct approach to using VFEs in the classroom. Here are some examples of ways teachers are using virtual fieldwork:

- Students in a rural community are using Google Earth to create Powers of Ten tours centered on their homes (based on the Eames' classic film). This helps students to internalize the abstraction that is central to making maps and to build deeper understandings of scale.
- Students are making geologic maps of the local bedrock.
- Students are creating an interpretive guide for a county forest.
- Students are exploring lakes, dams, streams, outcrops, quarries, waterfalls, and more.

For more VFEs, see our growing database at http://virtualfieldwork.org/.

What do I need to consider as I begin to build my VFE?

Considerations fall into four categories:

- **Logistical:** What do I have the attitude, time, resources, and skills to do? (Attitude is listed first as it is the most important factor.)
- **Pedagogical:** How do I bring the scientific content together with technologies in a way that best builds enduring understandings of bigger ideas and overarching questions, as well as of the smaller scale ideas and questions I deem important?
- **Technological:** What hardware and software do I need to assemble the materials for the VFE and to make it accessible to my students? This may include traditional scientific tools, like a rock hammer or a compass, as well as the computer technologies discussed in this chapter and on our website.
- **Content:** What scientific knowledge, ideas, processes, and practices do I want my students to understand and be able to do at the end of the experience?

Of course, these categories overlap and interplay substantially—teachers of Earth science use Google Earth in different ways than other Google Earth users do.

10 Fieldwork

VFEs

Most of the remainder of this chapter is a set of checklists to help you address these different considerations when outlining your VFE design. Take it with you into the field as you collect pictures and other kinds of data for your VFE; use it to identify issues you think are most important for the development of your VFE. Most of the items in the checklists are there to start you thinking about how to address a particular issue. Content is listed last for the sake of readability, as the checklists for the content section are longer than they are for the other categories.

The framework for understanding how to effectively blend <u>t</u>echnology, <u>p</u>edagogy, <u>a</u>nd <u>c</u>ontent <u>k</u>nowledge is known by its acronym TPACK.

Table 10.3: A checklist of cross category issues. Many of the questions in the checklist relate to more than one of the categories identified above. Because of this overlap, only the cross-category issues and content sections are of significant length.

Have I considered this?	Question:	Logistical	Pedagogical	Technical	Content
	Do I have appropriate safety and first aid equipment and materials?	√		√	
	What content do I want to address?	√	√	√	√
	Do I have connections in mind to at least a couple of the bigger ideas and overarching questions? • The Earth is a system of systems. • The flow of energy drives the cycling of matter. • Life, including human life, influences and is influenced by the environment. • Physical and chemical principles are unchanging and drive both gradual and rapid changes in the Earth system. • To understand (deep) time and the scale of space, models and maps are necessary. • How do we know what we know? • How does what we know inform our decision-making?		√		√
	How much time do I realistically have to spend on VFE creation?	√			
	How much class time do I want to dedicate to VFEs?	√	√	√	√
	Am I okay with the trade-off between some expected frustration and the pedagogical payback?	√	√	√	√
	Can I productively engage students in VFE development? *Or is that something to aspire to for next year?*	√	√	√	√
	How does the technology I have serve the goals I wish to meet?	√		√	
	Do I have enough batteries for my powered equipment?	√		√	
	Is the site accessible to me? *This includes legal, safety and proximity considerations.*	√	√		
	Are my students familiar with the site? If not, is it accessible to *all* of my students? *If the answer to both questions is no, select another site.*	√	√		
	Are the required pedagogical, technological, and content skills and knowledge needed to create the VFE within my reach? *Ideally, select challenges that are just within (or just beyond) your reach so that you grow professionally.*	√	√	√	√
	Do I have the hardware (including field equipment) and software needed for VFE creation? *The bare essentials are an Internet-connected computer, a digital camera, and either PowerPoint or Google Earth.*	√	√	√	

Logistical

We hope that VFE development is used to expand teachers' skills and knowledge. Performing fieldwork for the first time can be overwhelming, but remember that science is a process, and not even professional scientists capture all that they need in one visit. With practice, and the proper attitude, you will become more and more comfortable when visiting the field.

Pedagogical

While most pedagogical questions also address other categories as noted above, there are issues that deserve explicit attention here.

- Does the data you are collecting go toward answering why this place looks the way it does? *Or is there a good reason to introduce distracting information?*

- If the site is especially striking or unusual, have you considered how to get yourself and your students beyond the "novelty space" of the location? Crudely summarized, novelty space is the idea that you can't figure out what's going on at a field site if you're either awed by its beauty or freaked out by its perceived dangers. This is one of several reasons for choosing a site that is already familiar to the students.

Technological

Most technological issues are also logistical; these are addressed in the table above.

Content

Why does this place look the way it does? The driving question of our work can serve as an entry into any major topic in Earth or environmental science curricula. It also brings relevance to the science since we want to start with sites near the school that are already somewhat familiar to the students. We want students to look at the familiar with new eyes, and to become skilled at reading their local landscape. Ultimately, we want the skills built by reading the local landscape (being able to tell the story of why a place looks the way it does) to be transferable to *any* landscape.

What scientific content do you want your students to better understand through their work in the VFE? How does this fit into the larger goals of the course? Can you draw, and help your students to draw, connections to bigger ideas and overarching questions? What topics in Earth science can be addressed by doing fieldwork?

Understandings will be made much deeper in schools where teachers in more than one subject or grade level engage their students in studying the local environment.

Below are questions taken from the geoscience and environmental science graphic organizers. Most teachers will likely use one sheet or the other, but not both. Your VFE likely won't address all of the questions (on either sheet), but you should be able to strategically select what you minimally wish to address.

10 Fieldwork

VFEs

For the Geosciences:

For all of the following questions:
- How do you know? (What evidence is there?)
- What does it tell you about past environments?
- What does it imply about the future?

☐ **Describe the shape of the land.**
- Are there mountains, valleys, or hills?
- What are the valley shapes?
- What can cause valleys to form?
- What can cause mountains or hills to form?
- Are the mountains or hills young or old?
- What roles does tectonics play in shaping the site?

☐ **What effects has water had on the landscape?**
- Is water depositing material, eroding material, or both?
- Is the action of water primarily chemical, primarily physical, or both chemical and physical?

☐ **What effect has the climate had on the landscape?**
- Was the past climate different?
- What factors may have been affected or caused by climate?
- How has fire played a role in shaping the environment?

☐ **Describe the ecosystem.**
- See the ecosystem graphic organizer and checklist.

☐ **What does the arrangement of the rocks and soils indicate about past conditions?**
- Do the rocks seem to form a sequence?
- Where would you find the oldest rocks? The youngest rocks?
- Does the rock record include evidence of ancient disturbances? If yes, describe.
- Are there different kinds of rocks at different outcrops?

☐ **What types of rock and soils are there and what do they indicate about past conditions?**

Sediments and Sedimentary Rocks
- Is the sample clastic or organic /chemical?
- If clastic, what is the grain size?
- If organic, what minerals is it made out of?
- Are there fossils?

Metamorphic
- Is the rock foliated or non-foliated?
- What was the parent rock?

Igneous
- Did the rock form above or below ground?
- Is it felsic or mafic?

☐ **What effects has life, including human life, had on the landscape?**
- How have plants shaped the landscape?
- How have animals generally, and humans in particular, changed the landscape?
- On what scale?

For the Environmental Sciences:

For all of the following questions:

- How do you know? (What evidence is there?)
- What does it tell you about past environments?
- What does it imply about the future?

☐ **Describe how life shapes the land.**

- What are the pioneer plants?
- How do pioneer plants impact soil formation?
- How are animals shaping the land?
- Are there invasive species? If yes, what are they, and how are they changing the ecosystem?
- Have disturbances played a role in the introduction of invasives? If yes, describe.
- How are new invasives likely to change the ecosystem over the next century?

☐ **Describe the role of water in the ecosystem.**

- In what ways does water serve or disturb habitats?
- How does life move, use, and store water?

☐ **How has climate shaped the ecosystem?**

- How is the climate reflected by living things at the site?
- Describe any microclimates and how they affect life.
- Describe how sun and shadow affect life.
- What roles do fire, hurricanes, or other climate-related disturbances play in shaping this landscape?

☐ **Describe the role rocks and soil play in the ecosystem.**

- How does life change the rocks and soil at the site?
- How is life dependent upon the rocks and soil at the site?
- Does the rock record include evidence of ancient disturbances? If yes, describe.
- See also the geoscience questions.

☐ **Describe the types and arrangements of plants and animals and what they indicate about present and past environments.**

- Why do living things in the environment look the way they do?
- What life forms were the earliest to arrive?
- Describe how different life forms are distributed throughout the field site.
- What is the impact of invasive species and other disturbances?
- See also the **Describe how life shapes the land** section.

Plants

- How have plants shaped the landscape?
- How has the landscape affected the plants?

Animals

- How do animals contribute to plant distribution?
- How has the landscape affected the animals?

Other biota

☐ **What effects have humans had on the landscape?**

- What resources do humans use from here?
- How have humans changed the landscape?
- On what scale?

Closing Thoughts

This chapter was written to help get you started in the creation of VFEs and, in a broader sense, to help you learn more about fieldwork. But how do you know when to stop? It may be more productive to think of VFEs or activities involving actual fieldwork as undertakings that are becoming ready for use rather than as finished products. Here is a nice quote from Wendell Berry's essay "Faustian Economics" that relates to this concept:

> *It is the artists, not the scientists, who have dealt unremittingly with the problem of limits. A painting, however large, must finally be bounded by a frame or a wall. A composer or playwright must reckon, at a minimum, with the capacity of an audience to sit still and pay attention. A story, once begun, must end somewhere within the limits of the writer's and the reader's memory. And of course the arts characteristically impose limits that are artificial: the five acts of a play, or the fourteen lines of a sonnet. Within these limits artists achieve elaborations of pattern, of sustaining relationships of parts with one another and with the whole, that may be astonishingly complex. And probably most of us can name a painting, a piece of music, a poem or play or story that still grows in meaning and remains fresh after many years of familiarity.*

Resources

Field Geology Teaching Practices

Extraordinary Science Field Trips, Summer 2013, *National Science Teachers Association Reports*, 25(1): 1–2, http://www.nsta.org/docs/NSTAReports201307.pdf.

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Issigonis, M. 2006. Field trips as an aid to teaching Earth science courses. *The Earth Scientist*, 22(3): 14–16.

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My Geologic Address: Locating Oneself in Geologic Time and Process, by K. Ault, SERC InTeGrate workshop "Teaching the Methods of Geoscience" activities, http://serc.carleton.edu/integrate/workshops/methods2012/activities/ault.html.

Orion, N., & A. Hofstein. 1994. Factors that influence learning during a scientific field trip in a natural environment. *Journal of Research in Science Teaching*, 31: 1097–1119.

Russell, H. R. 1998. *Ten-Minute Field Trips: A Teacher's Guide to Using the School Grounds for Environmental Studies, 3rd edition*, National Science Teachers Association, Alexandria, VA, 163 pp. (Focused on elementary and junior high; chapter on Earth science pp.113–137.)

Shulman, L. S. 2005. Signature pedagogies in the professions. *Daedalus*, 134(3): 52–59.

Teaching in the Field, National Association of Geoscience Teachers, http://nagt.org/nagt/teaching_resources/field/index.html. (Set of resources for teaching field geology.)

Whitmeyer, S. J., E. J. Pyle, & D. W. Mogk, eds. 2009. Field geology education: historical perspectives and modern approaches. *Geological Society of America Special Papers* 461, http://specialpapers.gsapubs.org/content/461.toc. (29 articles focused on undergraduate education.)

Guides to Fieldwork

(Mostly focused on post-secondary education, but useful as references.)

Coe, A., T. Argles, D. Rothery, & R. Spicer. 2010. *Geological Field Techniques*. Wiley-Blackwell, Chichester, UK, 336 pp. (This is a current standard.)

Compton, R. R. 1962. *Manual of Field Geology*. John Wiley & Sons, New York, 378 pp. (An old classic.)

Compton, R. R. 1985. *Geology in the Field*. Wiley, New York, 398 pp. (An updated version of Compton, 1962.)

How to Read a Geologic Map, Wisconsin Geological and Natural History Survey, http://wgnhs.uwex.edu/wisconsin-geology/bedrock-geology/read-geologic map/.

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Maley, T. S. 2005. *Field Geology Illustrated, 2nd edition* Mineral Land Publications, Boise, ID, 704 pp.

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Appendix: The Teacher-Friendly Guides™, Virtual Fieldwork, and the NGSS's Three-Dimensional Science

The Next Generation Science Standards contain a set of learning goals that define and describe the ideas and practices that we need in order to think scientifically. The NGSS are not a curriculum. They tell teachers not how to teach, but rather, are tools to show what to teach. They also help families know what children are expected to learn, and help schools and teachers know what to assess. So, how do you teach in ways that align with NGSS, if NGSS itself doesn't tell you? The strategies, tools and resources associated with the ReaL Earth Inquiry project, like this *Teacher-Friendly Guide™*, are intended to offer a partial answer to that question.

"ReaL Earth Inquiry" is the project name of the NSF grant (0733303) to the Paleontological Research Institution to develop teacher resources such as Teacher-Friendly Guides™ to regional Earth science and Virtual Fieldwork Experiences. "ReaL" refers to Regional and Local.

The vision of NGSS differs in a number of important ways from current common practice in schools and classrooms across the country. Teaching about local and regional Earth and environmental science can and has worked well for many teachers under more traditional standards, but by attending to the three dimensions of the NGSS (see below), we believe it can work even better. Deep understandings of why your local environment looks the way it does requires understanding the local environment from multiple disciplinary perspectives, and understanding the connections amongst these different disciplinary ideas. That is, to understand your local environment, a systems perspective is needed. Scientifically accurate meaningful understanding can and does come out of single lessons, single units, and single courses, but these understandings become richer, deeper, and more durable if they are connected across courses. The NGSS vision includes recognition that building a deep understanding of big ideas is both very important and a process that takes years of coordinated effort. Fortunately, the many processes that shape the local environment are part and parcel of existing curricula, and especially for Earth science, biology, and environmental science courses, nearly every unit has central aspects that play out on a human scale just outside the school door. A coordinated approach to the study of the local environment across units within a single course and across grade levels

Acronyms frequently used in *The Next Genertion Science Standards* (NGSS):

PE: Performance Expectation
DCI: Disciplinary Core Idea
CC: Crosscutting Concept
SEP: Scientific and Engineering Practice
PS: Physical Sciences
LS: Life Sciences
ESS: Earth & Space Sciences
ETS: Engineering, Technology, and the Applications of Science

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and courses can be a fairly subtle change in each teacher's daily routines, but it has the potential for big returns in terms of the depth of student understanding. This deeper understanding pertains not only to the local environment and the way course topics are represented within it, but also to systems more generally, to the nature and importance of scale, and to much, much more.

NGSS builds upon the earlier work in the National Science Education Standards (NSES), but brings more of a systems approach not only to its representation of science, but to the standards themselves. NSES defined science not just as a body of ideas, but an evolving body of ideas extended by inquiry. NGSS continues this work by clarifying inquiry and the sciences as a set of relationships amongst three dimensions: Disciplinary Core Ideas (DCIs), Scientific and Engineering Practices, and Crosscutting Concepts. Each of the three dimensions is judged to be of roughly equal importance and they are seen as interdependent. To truly, deeply, understand science and how scientific understandings develop, learners must not only understand each dimension, but how the dimensions are related to one another—the whole is greater than the sum of the parts. By coming to understand these interconnections, teachers and students will also come to better understand the nature of both scientific inquiry and of complex systems.

A Perspective on Science Education Priorities

The bulk of the NGSS is a series of Standards, each a page or two in length, with "Performance Expectations" (PEs) at the top of the first page, followed "Foundation Boxes" and "Connection Boxes" supporting the PEs. It’s tempting to jump into the discussion of NGSS by starting there. It’s also tempting to start with the Disciplinary Core Ideas (DCIs), especially for those who specialize in a particular scientific discipline. But readers shouldn’t do either of those things. Appendix K of NGSS notes, "The goal is not to teach the PEs, but rather to prepare students to be able to perform them by the end of the grade band course sequence." It's important to understand the basic three-dimensional structure of the NGSS before looking at the PEs or DCIs. We will give them both their due, but we won't start with either of them.

If you have a degree in a particular science, and this is the science that makes up the bulk of your teaching load, it's natural to go straight for your area of expertise in the NGSS, to see how that's addressed. But don't do that, or, if you already have, try to imagine that you haven't. Before considering the concepts and practices essential to being literate in your discipline, consider what you think everyone needs to know about science disciplines *outside your area of specialization*, and consider the ideas that are broadly applicable across all the sciences. That is, think about the fundamentals of science.

Imagine having magical powers that allowed you to make every American understand six or eight profound scientific ideas—ideas that, if everyone understood them, would help people make the world a better place because they would make better decisions. Imagine again that this power could also be used to give everyone a small set of well-developed scientific skills. What should these ideas and skills be? Ponder what these ideas and skills are before reading further, perhaps going so far as to put them down on paper. Ask your colleagues, and your former students the same question. What are the most important ideas and skills for everyone to understand or be able to do related to science?

The profound scientific ideas you thought of are likely to be something like NGSS's Crosscutting Concepts, and the scientific skills are likely to be something like the Scientific and Engineering Practices (*Table A.1*). In reviewing the NGSS, teachers at the secondary and college levels who specialize in a particular subject are often naturally drawn first to the Disciplinary Core Ideas for their discipline, and when they find a favorite topic that is not addressed to what they consider an appropriate depth, they are upset that NGSS is not providing the content necessary to prepare their students for the future. But, decades of educational practice teaching science courses with thousand-page textbooks and scores of key ideas has not yielded a scientifically literate populace. It is essential to focus on smaller sets of truly big ideas (see also the *Big Ideas* chapter) and work across grade-levels to build understandings over time. This may mean, however, that your favorite topics are no longer explicitly listed in the learning goals.

Table A.1 contains abbreviated versions of the Concepts, Practices, and Ideas. You can find longer descriptions within the NGSS, and we'll look at one as an illustrative example. Consider the full description of Crosscutting Concept #3:

> *Scale, proportion, and quantity.* In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

It seems likely that most Americans do not have a good and durable understanding of this concept, yet it has relevance to many aspects of their daily lives. The same could be said of most, if not all, of the remaining concepts on the list.

The Crosscutting Concepts are described in some detail in Appendix G of NGSS, and the Scientific and Engineering Practices are described in Appendix F.

Such understandings are almost certainly more important than knowing particular facts about geologic history or the nature of disease (two topics not given deep attention in the NGSS). Indeed, it's only possible to understand geologic history or the nature of disease if you also understand these concepts!

While your favorite topics may not be explicitly mentioned in NGSS, that doesn't necessarily preclude them from being taught. There's a tremendous amount of content in these *Teacher-Friendly Guides™* that are not mentioned in NGSS, yet we believe that all of the contents of the Guides *support* teaching that is aligned with the NGSS. Different topics, such as glaciers or mineral resources, can serve as our pedagogical partners in building understandings of the Crosscutting Concepts, Scientific and Engineering Practices, and the Disciplinary Core Ideas that make up the NGSS. In other words, we can and should teach these topics, but understanding the particular topic isn't the primary goal. The primary goal is to use the teaching of these topics as a means to build an understanding of those bigger ideas.

It isn't clear if K–12 science curricula designed to bring the NGSS's vision to fruition will be more or less rigorous than today's common K–12 curricula, but rigor shouldn't be the goal of education. Education should develop citizens who can reason critically and use evidence to inform their actions. This isn't to say that schooling shouldn't be challenging, but rather that its challenges should be in the service of meeting other goals. Building deep and interconnected understandings of the three dimensions of NGSS will not be a simple task, but it has the potential to better prepare for students for citizenships, college, and careers.

Connecting "Why does this place look the way it does?" and Virtual Fieldwork to NGSS

This *Teacher-Friendly Guide*™ is one part of a large project designed to help educators teach about Regional and Local (ReaL) Earth system science in an inquiry-based way. This ReaL Earth Inquiry Project, and all of its related resources, support educators and students in the investigation of the project's driving question: "*Why does this place look the way it does?*" The "place" of the question is anywhere you happen to be, but we hope and expect users of these materials will start by studying areas outside their backdoor or their classroom door. The *Fieldwork* chapter (Chapter 11) addresses both actual and Virtual Fieldwork, and we believe the coupling of virtual and actual fieldwork is an excellent way to teach and learn, and it's an approach that is fully three dimensional, in the NGSS's sense of that term.

Read through the Practices outlined in *Table A.1* with an eye toward engaging in and documenting fieldwork. See the graphic organizer and the question list in Chapter 11 and consider how these questions can be asked of any site, and how they can serve to inspire new questions that are site-specific. Then, consider the making of Virtual Fieldwork Experiences (VFEs) to document the site, allowing for continued investigation after leaving the field, and sharing findings with others in the community and beyond. This approach provides opportunities to engage *all* of the practices. To build rich explanations of the range of processes at play in a field site requires application of *all* of the Crosscutting Concepts. There are also opportunities for using field sites to build understandings of *all* of the DCIs, though selected ones from the Life and Earth & Space Sciences have the most direct correspondence. The use of virtual and actual fieldwork is scalable to fit the educational need, so a particular lesson or activity would be

Appendix

Scientific and Engineering Practices	Crosscutting Concepts
1. Asking Questions and Defining Problems 2. Developing and Using Models 3. Planning and Carrying Out Investigations 4. Analyzing and Interpreting Data 5. Using Mathematics and Computational Thinking 6. Constructing Explanations and Designing Solutions 7. Engaging in Argument from Evidence 8. Obtaining, Evaluating, and Communicating Information	1. Patterns 2. Cause and Effect 3. Scale, Proportion, and Quantity 4. Systems and System Models 5. Energy and Matter 6. Structure and Function 7. Stability and Change 8. Interdependence of Science, Engineering, and Technology 9. Influence of Engineering, Technology, and Science on Society and the Natural World

Disciplinary Core Ideas			
Physical Sciences	*Life Sciences*	*Earth and Space Sciences*	*Engineering, Technology, and the Applications of Science*
PS 1: Matter and its interactions **PS 2:** Motion and stability: Forces and interactions **PS 3:** Energy **PS 4:** Waves and their applications in technologies for information transfer	**LS 1**: From molecules to organisms: Structures and processes **LS 2**: Ecosystems: Interactions, energy, and dynamics **LS 3**: Heredity: Inheritance and variation of traits **LS 4**: Biological evolution: Unity and diversity	**ESS 1:** Earth's place in the universe **ESS 2:** Earth's systems **ESS 3:** Earth and human activity	**ETS 1:** Engineering design **ETS 2:** Links among engineering, technology, science, and society

Table A.1: Summary of NGSS's Three Dimensions. For more detailed descriptions, see the relevant appendices in The Next Generation Science Standards.

expected to target just one or two, but a program of fieldwork across a course would allow for the addressing of many of the Concepts, Practices, and Ideas.

Look again to the graphic organizers from Chapter 11: Fieldwork. It is easy to see how, especially in Earth science, biology, or environmental science courses, most of the units in these courses play out in some meaningful way outside the classroom door. As the DCIs are akin to umbrellas relative to a course's units, these too largely play out in meaningful ways outside the classroom door. The

Appendix

NGSS recognizes that in order to understand big ideas, years of coordinated study are required. The coordinated study of the local and regional environment provides an excellent opportunity for this. A field site can be studied using increasingly sophisticated approaches across the K–12 experience, and for the students, this does not entail repetition, but rather the opportunity to study a site from different disciplinary vantage points across all or part of the K–12 continuum. If such an approach is adopted broadly, kids who move during the course of their schooling can bring in new eyes, and information, to compare and contrast the environment in their new school with the environment where they used to live.

How to Read the NGSS

Each standard in the NGSS includes multiple interconnected parts. They have an architecture that can be seen in *Figure A.1*. This diagram is taken directly from the NGSS website's page, "How to Read the Next Generation Science Standards." This page includes a short written overview and an accompanying video as well as links to more detailed information. The standards are designed to be read online, with features like pop-ups, choices for highlighting different parts of the text (the different dimensions) in different colors, and links to related content elsewhere within the NGSS. If you're not familiar with how they work, you should follow the link above and then explore around the NGSS a bit before reading further.

Know that the appearance of the Standards can be a bit intimidating, with all the abbreviations, acronyms, codes, and different colors, but after a bit of time working with the text, its logic does become understandable.

Example of ReaL Connections to Performance Expectations

Earth and Space Science Disciplinary Core Idea #2 is "Earth's Systems," and it has five supporting concepts:

- ESS2.A: Earth Materials and Systems
- ESS2.B: Plate Tectonics and Large-Scale System Interactions
- ESS2.C: The Roles of Water in Earth's Surface Processes
- ESS2.D: Weather and Climate
- ESS2.E: Biogeology

In the middle school grade band of NGSS, there are six performance expectations associated with ESS2. All six are listed below, but not in their complete form. "Clarification Statements" and "Assessment Boundaries" are not included in the full list, but we'll look at one of the Performance Expectations in greater detail. See the full list (and the full standard) at http://nextgenscience.org/msess2-earth-systems.

Appendix

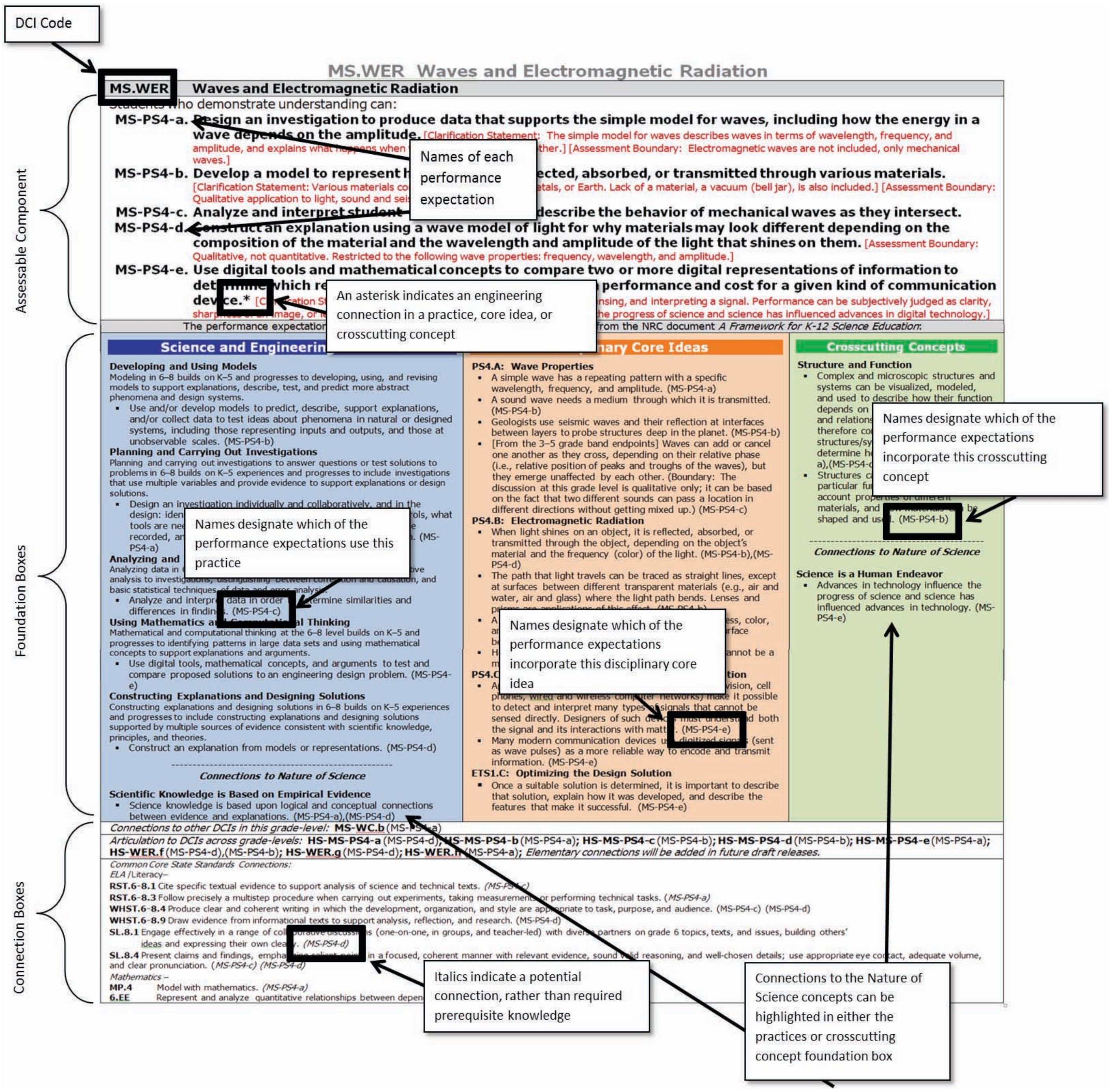


Figure A.1: The architecture of a standard. The NGSS is designed with the web in mind and features of its online architecture make it easier to understand than this diagram might indicate.

Appendix

MS-ESS2 Earth's Systems (Middle School-Earth System Science 2)
Students who demonstrate understanding can:

MS-ESS2-1. ***Develop a model to describe*** ***<u>the cycling of</u>*** **Earth's materials and the flow of energy that drives this process.**

MS-ESS2-2. ***Construct an explanation based on evidence for how*** **geoscience processes have changed Earth's surface** ***<u>at varying time and spatial scales</u>.***

MS-ESS2-3. ***Analyze and interpret data*** ***<u>on the distribution</u>*** **of fossils and rocks, continental shapes, and seafloor structures** ***<u>to provide evidence</u>*** **of the past plate motions.**

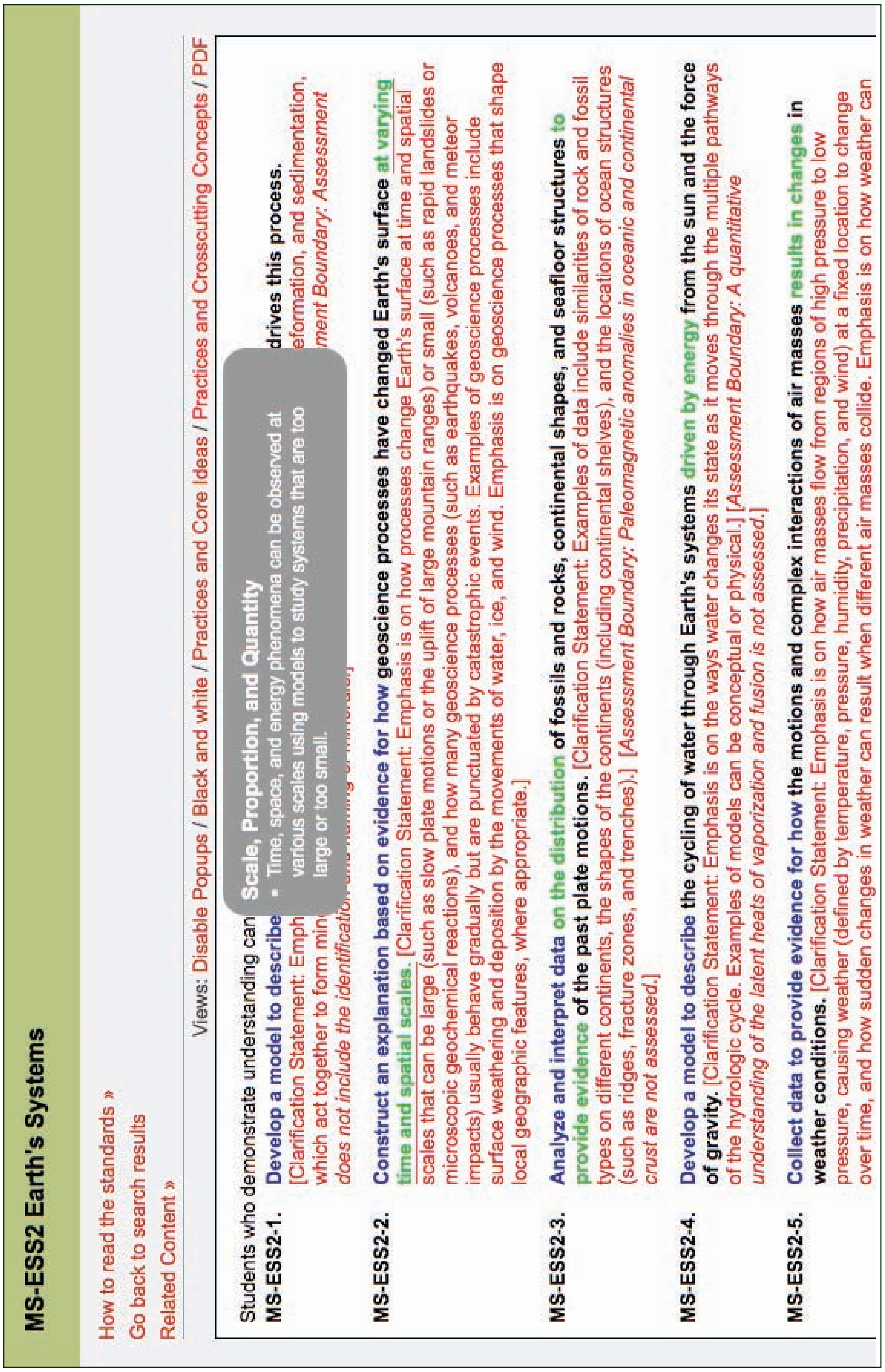
MS-ESS2-4. ***Develop a model to describe*** **the cycling of water through Earth's systems** ***<u>driven by energy</u>*** **from the sun and the force of gravity.**

MS-ESS2-5. ***Collect data to provide evidence for how*** **the motions and complex interactions of air masses** ***<u>results in changes</u>*** **in weather conditions.**

MS-ESS2-6. ***Develop and use a*** ***<u>model to describe how</u>*** **unequal heating and rotation of the Earth cause patterns of** ***<u>atmospheric and oceanic circulation that determine</u>*** **regional climates.**

Each of the six above Performance Expectations (PEs) incorporates aspects of each of the three dimensions. The color-coding helps to reveal some of that. "Science and Engineering Practices" are shown in blue (***italics*** here) and Crosscutting Concepts are shown in green (***<u>underlined italics</u>*** here). Disciplinary Core Ideas are in black. This is one of the color-coding options in the online presentation. Pop-ups (which can be disabled) appear when the different colored parts of the PE are scrolled over with the mouse. *Figure A.2* is a screen grab of the first three PEs for ESS2, with a pop-up showing the Crosscutting Concepts related to "MS-ESS2-2."

All of these Performance Expectations directly aligns with "*Why does this place look the way it does?*" We'll take a closer look at MS-ESS2-2, which addresses how geoscience processes have shaped the Earth's surface at varying time and spatial scales. This Guide coupled with the development of a VFE of a site local to your school, provides rich opportunities for addressing both this particular PE, along with all of the others within this standard. The Clarification Statements often provide helpful examples, and Assessment Boundaries indicate what will not be addressed in the assessments now under development. Importantly, this is not an indication that these topics are out of bounds. These standards represent minimum expectations—exceeding these expectations is often appropriate.


MS-ESS2 Earth's Systems

How to read the standards »
Go back to search results
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Views: Disable Popups / Black and white / Practices and Core Ideas / Practices and Crosscutting Concepts / PDF

Students who demonstrate understanding can

Scale, Proportion, and Quantity
- Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.

MS-ESS2-1. Develop a model to describe … drives this process. [Clarification Statement: Emph… …eformation, and sedimentation, which act together to form min… …ment Boundary: Assessment *does not include the identificatio…*

MS-ESS2-2. **Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.** [Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]

MS-ESS2-3. **Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions.** [Clarification Statement: Examples of data include similarities of rock and fossil types on different continents, the shapes of the continents (including continental shelves), and the locations of ocean structures (such as ridges, fracture zones, and trenches).] [*Assessment Boundary: Paleomagnetic anomalies in oceanic and continental crust are not assessed.*]

MS-ESS2-4. **Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.** [Clarification Statement: Emphasis is on the ways water changes its state as it moves through the multiple pathways of the hydrologic cycle. Examples of models can be conceptual or physical.] [*Assessment Boundary: A quantitative understanding of the latent heats of vaporization and fusion is not assessed.*]

MS-ESS2-5. **Collect data to provide evidence for how the motions and complex interactions of air masses results in changes in weather conditions.** [Clarification Statement: Emphasis is on how air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time, and how sudden changes in weather can result when different air masses collide. Emphasis is on how weather can

Figure A.2: A screen-grab of part of the middle school standard on Earth Systems: MS-ESS2. Shown here are the first three PEs, with the first partially obscured by a pop-up related to the CC in the second.

Appendix

Figure A.2 only shows a piece of the standard—only the first few Performance Expectations. Like the example in the previous section, this PE also includes Foundation Boxes, which highlight what pieces of each of the three dimensions is addressed in the standard and Connection Boxes, which highlight connections to other disciplines and grade levels. Drawing these connections is important in helping fortify understandings of both the particular content and how that content is contextualized in broader human and natural systems.

Appendix

Resources

(Following are some of the most commonly used and cited publications on science education standards and bench-marks.)

American Association for Advance of Science. 1993. *Benchmarks for Science Literacy*. Oxford University Press, http://www/[rpkect2-61.org/publications/bsl/online/index.php.

Bransford, J. D., A. L. Brown, & R. R. Cocking, eds. 2000. *How People Learn: Brain, Mind, Experience, and School, expanded edition*. National Academies Press, Washington, DC, http://www.nap.edu/openbook.php?record_id=9853.

Common Core State Standards Initiative, http://www.corestandards.org. (While not focused on science education directly, standards on math and non-fiction reading impact are importantly related.)

National Center for Science Education. 2013. *Evolution and Climate Change in the NGSS*, http://ncse.com/news/2013/04/evolution-climate-change-ngss-0014800.

National Research Council. 1996. *National Science Education Standards*. National Academies Press, Washington, DC, http://www.nap.edu/openbook.php?record_id=4962. (NRC is a body of the National Academy of Sciences.)

National Research Council. 2011. *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics*. National Academies Press, Washington, DC, http://www.nap.edu/openbook.php?record_id=13158.

National Research Council. 2012. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. National Academies Press, Washington, DC, http://www.nap.edu/openbook.php?record_id=13165.

National Research Council. 2013. *Next Generation Science Standards: For States, By States*. National Academies Press, Washington, DC, http://www.nextgenscience.org.

NGSS@NSTA website, National Science Teacher Association, http://ngss.nsta.org/.

Wysession, M. 2013. The Next Generation Science Standards and the Earth and Space Sciences. *The Science Teacher*, April/May issue, http://nstahosted.org/pdfs/ngss/resources/201304_NGSS-Wysession.pdf. (Duggan-Haas, author of this Appendix, worked with Wysession on NRC's Conceptual Framework for New Science Education Standards.)

a Glossary

	Note: Words in **bold font** are also defined in this glossary.
Acadian Orogeny	a **Devonian** mountain-building event involving the collision of the eastern coast of North America and the **accreted terrane** of **Avalon**. The event caused **metaphorphism**, folding, and **faulting** in an area from New York to Newfoundland; sediments **eroded** from the mountains accumulated in thick strata, the Catskill Delta, in the **Appalachian Basin** of New York and Pennsylvania. See also: orogeny
accretion, accrete	the process by which a body of rock increases in size due to the addition of further **sedimentary** particles or of large chunks of land, such as **terranes**.
active plate boundary, active plate margin	the boundary between two **plates** of the Earth's **crust** that are colliding, pulling apart, or moving past each other. See also: plate tectonics
aeolian	pertaining to, caused by, or carried by the **wind**. Aeolian sediments are often polished, giving them a "frosty" appearance. The name comes from Aeolus, the Greek god of wind.
aerosol	tiny solid or liquid particles in the air. Examples include dust, smoke, mist, and human-made substances such as particles emitted from factories and cars.
agate	a crystalline **silicate** rock with a colorful banded pattern. It is a variety of **chalcedony** (**quartz**). Agates usually occur as **nodules** in **volcanic** rock.
aggregate	crushed stone or naturally occurring un**lithified** sand and gravel, used for construction, agriculture, and industry. Aggregate properties depends on the properties of the component rock. Rock quarried for crushed stone includes, for example, **granite** and **limestone**.
Alfisols	a **soil order**; these are highly fertile and productive agricultural **soils** in which clays often accumulate below the surface. They are found in humid and subhumid **climates**.
Alleghanian Orogeny	a **Carboniferous** to **Permian** mountain-building event involving the collision of the eastern coast of North America and northwestern coast of Africa (then part of **Gondwana**). The event caused a combination of **metamorphism**, folding, and **faulting** in an area from Alabama to Newfoundland. The **orogeny** resulted in the Appalachian and Allegheny mountains, which are heavily **eroded** remnants of the original mountains formed by the event.
alluvium, alluvial	a layer of river-deposited sediment.
aluminum	a metallic chemical element (Al), and the most abundant metal in the Earth's crust. Aluminium has a low **density** and an excellent ability to resist corrosion. Structural components made from the metal and its alloys are commonly used in the aerospace industry, transportation, and household goods.
amber	a yellow or yellowish-brown hard translucent **fossil** resin that sometimes preserves small soft-bodied organisms inside.

Glossary a

ammonoid, ammonite	a group of **extinct cephalopods** belonging to the Phylum Mollusca, and possessing a spiraling, tightly-coiled shell characterized by ridges, or septa.
amphibole	a group of dark-colored **silicate minerals**, or either **igneous** or **metamorphic** origin.
Andisols	a **soil order**; these are highly productive **soils** often formed from **volcanic** materials. They possess very high water- and nutrient-holding capabilities, and are commonly found in cool areas with moderate to high levels of precipitation.
anorthosite	a **plutonic igneous rock** made mostly of plagioclase **feldspar**. Most anorthosite rocks were formed in the **Proterozoic** eon (**Precambrian**).
anthracite	a dense, shiny **coal** that has a high carbon content and little volatile matter. Anthracite is as much as 95% carbon. Found in deformed rocks, anthracite is the cleanest burning of the three types of coal, because it contains the highest amount of pure carbon.
anthropogenic	caused or created by human activity.
anticline	a layer of rock folded (bent) along an axis, concave side down (i.e., in an upside down "U" or "V" shape). Thus rocks at the center of the anticline, along the fold (crest), are lifted up relative to the rest of the layer.
Appalachian Basin	an **inland basin**, formed by the **Taconic** and **Acadian** mountain-building events. The **crust** was **downwarped** as a result of the colliding **plates**, and the basin was later filled with an **inland sea**.
aquifer	a water-bearing formation of **gravel**, **permeable** rock, or **sand** that is capable of providing water, in usable quantities, to springs or wells.
archaeocete	a member of a group of primitive whales that lived during the **Eocene** and **Oligocene** epochs. The earliest members of the group are from the Indo-Pakistan region and were only partially aquatic.
archaeocyathid	a vase-shaped organism with a **carbonate** skeleton, generally believed to be a **sponge**. Archaeocyathids were the first important animal **reef** builders, originating in the early **Cambrian**. They were very diverse, but went **extinct** by the end of the Cambrian. Archeocyathids are often easiest to recognize in **limestones**, by their distinctive cross-sections.
Archean	a **geologic time** interval that extends from 4 billion to 2.5 billion years ago. It is part of the **Precambrian**.
Aridisols	a **soil order**; these are formed in very dry (arid) **climates**. The lack of moisture restricts **weathering** and leaching, resulting in both the accumulation of **salts** and limited subsurface development. They are commonly found in deserts.
artesian	a channel that releases pressure from an aquifer, allowing the aquifer's internal pressure to push the water up to the surface without the aid of a pump.
arthropod	an invertebrate animal, belonging to the Phylum Arthropoda, and posessing an external skeleton (exoskeleton), body segments, and jointed appendages. Arthropods include crustaceans, arachnids, and insects, and there are over a million described arthropod species living today. **Trilobites** are a major group of extinct arthropods.

a–b Glossary

asbestos	a fibrous **silicate mineral** that is resistant to heat, flames, and chemical action. As a very slow conductor of heat, asbestos was once commonly used as a fireproofing material and electrical insulation. Concerns over its health effects on the lungs have led to its removal from most common uses.
asphalt	a black, sticky, semi-solid, and viscous form of **petroleum**.
asthenosphere	a thin, semifluid layer of the Earth, below the outer rigid **lithosphere**, forming much of the upper **mantle**. The **heat** and pressure created by the overlying lithosphere make the solid rock of the asthenosphere bend and move like metal when heated. The layer is thought to flow vertically and horizontally with circular **convection** currents, enabling sections of lithosphere to subside, rise, and undergo lateral movement.
atmosphere	a layer of gases surrounding a planet. Earth's atmosphere protects living organisms from damage by solar ultraviolet radiation, and it is mostly composed of nitrogen. Oxygen is used by most organisms for respiration. Carbon dioxide is used by plants, algae, and **cyanobacteria** for photosynthesis.
Avalon	an early **Paleozoic microcontinent** offshore of what is now the eastern coast of North America. Avalon collided with and became the eastern edge of North America during the **Acadian Orogeny**.
badlands	a type of **eroded topography** that forms in semi-arid areas experiencing occasional periods of heavy rainfall. Sloping ground composed of **sandstones** and calcareous sediments underlain by **clay** or other soft materials is eroded over time into an intricate series of gullies and ravines. Different layers of rock **weather** at different rates, resulting in a variety of sculpted spurs and buttresses, as well as tall pillars of softer rock with a hard **capstone**.
Baltica	a late-**Proterozoic**, early-**Paleozoic** continent that included ancient Europe (northern Europe without Ireland and Scotland). Baltica began moving toward North America in the Ordovician, starting the **Taconic Orogeny**. North America fully collided with Baltica in the **Devonian**, resulting in the **Acadian Orogeny** on the eastern edge of the continent.
banded iron formation	rocks with regular, alternating, thin layers of **iron oxides** (e.g., **hematite** and **magnetite**) and either **shale** or **silicate** minerals (e.g., **chert**, **jasper**, and **agate**). They are a primary source of iron **ore**.
barite	a usually white, clear, or yellow mineral found in **limestone**, **clay**-rich rocks, and **sandstones**. Barite ($BaSO_4$) occurs as flattened blades or in a circular pattern of crystals that looks like a flower and, when colored red by iron stains, is called a "desert rose." Before federal laws were passed in 1906 to prevent the practice, finely ground barite was often added to flour and other foods to increase the weight.
barrier island	a long, thin island next to and parallel to a coastline.

basalt	an **extrusive igneous rock**, and the most common rock type on the surface of the Earth. It forms the upper surface of all oceanic **plates**, and is the principal rock of ocean/seafloor ridges, oceanic islands, and high-volume continental eruptions. Basalt is fine-grained and mostly dark-colored, although it often **weathers** to reds and browns because of its high **iron** content. Basaltic **magmas** are produced by partial melting of the upper **mantle**. Materials melt when we increase their temperature, but a second way to melt a solid is to decrease the pressure. In the interior of the Earth this second mechanism—decompression—is far more important. When pressure on the mantle is released as it is forced up through the crust, it becomes basaltic magma.
basement rocks	the foundation that underlies the surface geology of an area, generally composed of **igneous** or **metamorphic** crystalline rock. In certain areas, basement rock is exposed at the surface because of **uplift** or **erosion**.
bauxite	a whitish, grayish, brown, yellow, or reddish-brown rock composed of hydrous **aluminum oxides** and aluminum hydroxides; the principal commercial source of aluminum.
bentonite	a **clay**, formed from decomposed volcanic ash, with a high content of the **mineral** montmorillonite.
beryl	a white, blue, yellow, green, or pink **mineral**, found in coarse **granites** and **igneous rocks**. It is a source of beryllium and used as a **gemstone**; the green variety is called emerald, the blue is known as aquamarine.
biodiversity	the number of kinds of organisms at any given time and place. Global changes in biodiversity through **geologic time** tells paleontologists that something is happening to the rate of **extinction** or the rate of origin of new species. Regional changes are influenced by migration, or the number of species supported by available food and space resources.
biofuel	carbon-based **fuel** produced from renewable sources of **biomass** such as plants and garbage. Energy is obtained through combustion, so **greenhouse gases** are still produced. Because plants get their carbon from the air, burning them for **energy** and re-releasing it into the air has less effect on **climate** than **fossil fuels**, whose carbon is otherwise sequestered away from the **atmosphere**.
bioherm	a pile of **lithified** calcareous skeletal material formed on the sea floor from some variety of marine organisms, often including calcareous marine algae and marine invertebrates such as corals. **Reefs** are a form of bioherm in which organisms built the three-dimensional structure, while banks are bioherms in which skeletal material accumulated through transport.
biomass	organic material from one or more organisms.
biostratigraphy	the branch of geology that uses **fossils** to determine the relative age of **sedimentary** layers.
biota	the organisms living in a given region, including plants, animals, fungi, **protists**, and bacteria.
bioturbation	the displacement of sediment and **soil** by animals or plants.
bitumen	any of various flammable mixtures of hydrocarbons and other substances, occurring naturally or obtained by distillation from coal or **petroleum**, that are a component of asphalt and tar and are used for surfacing roads and for waterproofing.

Glossary

bituminous coal	a relatively soft **coal** containing a tar-like substance called **bitumen**, which is usually formed as a result of high pressure on **lignite**.
bivalve	a marine or freshwater invertebrate animal belonging to the Class Bivalvia (or Pelecypoda) in the Phylum Mollusca. Bivalves are generally called "clams," but they also include scallops, mussels, cockles, and oysters. Bivalves are characterized by right and left calcareous shells (valves) joined by a hinge. Most are **filter feeders**, collecting food particles from the water with their gills. During the **Paleozoic**, bivalves lived mostly on the surface of the ocean floor. In the **Mesozoic**, bivalves became extremely diverse and some evolved the ability to burrow into ocean floor sediments.
blastoid	an **extinct** form of stemmed **echinoderm**, similar to a **crinoid**. Blastoids possessed a nut-shaped body covered with interlocking plates, which was covered with fine hairlike structures for use in **filter feeding**. The body was held above the sea floor by a stalk of stacked disc-shaped plates.
body fossils	**fossils** that consist of an actual part of an organism, such as a bone, shell, or leaf.
bolide	an extraterrestrial object of any composition that forms a large crater upon impact with the Earth. In astronomy, bolides are bright **meteors** (also known as fireballs) that explode as they pass through the Earth's **atmosphere**.
boreal	a cold temperate region relating to or characteristic of the sub-Arctic **climatic** zone, often dominated by **conifers**, birch, and poplar.
brachiopod	a marine invertebrate animal belonging to the Phylum Brachiopoda, and characterized by upper and lower calcareous shell valves joined by a hinge, and a crown of tentacles (lophophore) used for **filter feeding** and respiration. Brachiopods are the most common **fossil** in **Paleozoic sedimentary rocks**. Brachiopods look somewhat similar to the clams that you find at the beach today. Brachiopods and **bivalves** both have a pair of hinged shells (valves) to protect themselves while feeding. However, the soft parts of modern brachiopods tell us that they are completely unrelated to bivalves. Brachiopods have a special structure formed by tissue with thousands of tiny hair-like tentacles stretched along a coiled piece of internal shell material. These tentacles catch and move small particles toward the mouth. This body plan is very different from that of bivalves, which have a larger, fleshy body and collect particles with their gills. To tell the difference between a brachiopod and a bivalve, look for symmetry on the surface of the shell. Bivalve valves are of equal size and mirror image shapes. Brachiopods' bottom valves, however, are slightly bigger and often have a different shape.
breccia	a **pyroclastic** rock composed of **volcanic** fragments from an explosive eruption.
brine	See **hydrothermal solution**
British Thermal Unit (BTU or Btu)	the most commonly used unit for **heat energy**. One Btu is approximately the amount of heat required to raise one pound of water by one degree Fahrenheit. A Btu is also about the amount of energy released by burning a single wooden match.

bryozoan	a marine or freshwater, colonial invertebrate animal belonging to the Phylum Bryozoa, and characterized by an encrusting or branching calcareous skeleton from which multiple individuals (zooids) extend from small pores to **filter feed** using crowns of tentacles (lophophores). Bryozoans have a long and exemplary **fossil** record. One of the more common **Paleozoic** varieties looks like fine-mesh cloth with numerous tiny holes in which the individual animals in the colony lived. Although they function somewhat like coral, and are often found in similar environments, bryozoans are more closely related to **brachiopods**.
calcite	a **carbonate mineral**, consisting of **calcium carbonate** ($CaCO_3$). Calcite is a common constituent of **sedimentary rocks**, particularly **limestone**.
calcium carbonate	a chemical compound with the formula $CaCO_3$, commonly found in rocks in the mineral forms **calcite** and aragonite, as well as the shells and skeletons of marine organisms.
caldera	a collapsed, cauldron-like **volcanic** crater formed by the collapse of land following a volcanic eruption.
calving	the process by which ice breaks off from the end of a **glacier** (sometimes into a lake or ocean, sometimes over the edge of a cliff).
calyx	the head of a crinoid.
Cambrian	a **geologic time** period lasting from 541 to 485 million years ago. During the Cambrian, multicellular marine organisms became increasingly diverse, as did their mineralized **fossils**. The Cambrian is part of the **Paleozoic** era.
Canadian Shield	the stable core of the North American continental landmass, containing some of the oldest rocks on Earth. The shield has experienced very little tectonic activity (**faulting** or folding) for millions of years. As the stable cores of all continents, shields are often covered by layers of younger material.
capstone, caprock	a harder, more resistant rock type that overlies a softer, less resistant rock. The harder rock typically helps to control the rate of **erosion**.
carbonate rocks	rocks formed by accumulation of **calcium carbonate**, often made of the skeletons of aquatic organisms such as corals, clams, **snails**, **bryozoans**, and **brachiopods**. These organisms thrive in warm, clear shallow waters common to tropical areas, therefore modern carbonate rocks are observed forming in places such as the Florida Keys and the Bahamas. They are also one of the dominant rock forms of the bottom of the ocean, where sediments form from the skeletons of planktonic organisms such as **foraminifera**. Carbonate rocks include **limestone**, **dolostone**, and **dolomite**.

C Glossary

Carboniferous	a **geologic time** period that extends from 359 to 299 million years ago. It is divided into two subperiods, the **Mississippian** and the **Pennsylvanian**. By the Carboniferous, terrestrial life had become well established. The name Carboniferous means "coal-bearing," and it is during this time that many of today's coal beds were formed. The Carboniferous is part of the **Paleozoic**.
cataclastic	pertaining to rocks made up of cemented fragments that originated from the mechanical breakdown of rock associated with **plate tectonics**. Cataclastic rocks form in regions that have undergone intense **metamorphism** and are associated with features such as folds and **faults**. They typically contain bent, broken, and granular **minerals**.
cementation	the precipitation of **minerals**, such as **silica** and **calcite**, that bind together particles of rock, bones, etc., to form a solid mass of **sedimentary rock**.
Cenozoic	the **geologic time** period spanning from 66 million years ago to the present. The Cenozoic is also known as the age of mammals, since extinction of the large reptiles at the end of the **Mesozoic** allowed mammals to diversify. The Cenozoic includes the **Paleogene**, **Neogene**, and **Quaternary** periods.
cephalopod	a marine invertebrate animal belonging to the Class Cephalopoda in the Phylum Mollusca, and characterized by a prominent head, arms and tentacles with suckers, and jet propulsion locomotion. Cephalopods are swimming predators with beak-shaped mouthparts. The shells of cephalopods range from long straight cones to spirals, but some have internal shells or no significant shell at all, such as the octopus.The group includes belemnites, **ammonoids**, nautilus, squid, and octopuses. A **mass extinction** between the **Cretaceous** and **Paleogene** eliminated many varieties of cephalopods.
chalcedony	a crystalline **silicate mineral** that is a microcrystaline variety of quartz.
chalcopyrite	a yellow **mineral** consisting of a **copper**-**iron** sulfide ($CuFeS_2$). Chalcopyrite is the most common and important source of copper, and can also be called copper **pyrite**.
chalk	a soft, fine-grained, easily pulverized, white-to-grayish variety of **limestone**, composed of the shells of minute planktonic single-celled algae.
chemical fossils	chemicals produced by an organism that leave behind an identifiable trace in the geologic record. Chemical **fossils** provide some of the oldest evidence for life on Earth.
chemical reaction	a process that involves changes in the structure and **energy** content of atoms, molecules, or ions but not their nuclei.

Glossary

chert	a **sedimentary rock** composed of microcrystaline **quartz**. It is often found as **nodules** or **concretions** in **limestone** and other marine sedimentary rocks. As these rocks form, water moving through them transports small amounts of **silicon** dioxide that accumulate into clumps of microscopic crystals. The resulting rocks are extremely strong and have no planes of weakness. For thousands of years, humans exploited these qualities, breaking chert nodules into blades and other tools.
chordate	an animal that possesses the following five traits during at least one stage of its development: a notochord (the flexible rod that, in vertebrates, becomes the backbone), a hollow dorsal nerve cord, pharyngeal gill slits, an endostyle (precursor to the thyroid gland), and a post-anal tail.
Cincinnati Arch	an **uplifted** region that existed between the **Illinois Basin**, the **Michigan Basin**, and the **Appalachian Basin** during the late **Ordovician** and **Devonian**. It stretched from southeastern Ontario all the way to northern Alabama.
cinder	a type of **pyroclastic** particle in the form of gas-rich **lava** droplets that cool as they fall.
clay	the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet. Chemically, clays are hydrous **aluminum silicates**.
cleavage	a physical property of **minerals**. Cleavage occurs when a mineral breaks in a characteristic way along a specific plane of weakness. **Mica** and **graphite** have very strong cleavage, allowing them to easily break into thin sheets.
climate	a description of the average temperature, range of temperature, humidity, precipitation, and other **atmospheric**/hydrospheric conditions a region experiences over a period of many years (usually more than 30). These factors interact with and are influenced by other parts of the Earth **system**, including geology, geography, insolation, currents, and living things. The climate of a region represents the average **weather** over a long period of time.
climate change	See **global warming**
coal	a combustible, compact black or dark-brown carbonaceous rock formed by the compaction of layers of partially decomposed vegetation. The greatest abundance of coal by far is located in strata of **Carboniferous** age.
coalification	the process by which **coal** is formed from plant materials through **compression** and **heating** over long periods of time.
coccolithophore	a marine phytoplankton with a skeleton made up of microscopic calcareous disks or rings, and forming much of the content of **chalk** rocks.
cold front	the boundary between the warm air and the cold air moving into a region. At this boundary, **denser**, colder air moves in, making the less dense, warm air rise. This displaced warm air cools as it rises because air pressure decreases with increasing height in the **atmosphere**. As the air cools, it becomes saturated with water vapor, and condensation begins to occur, eventually leading to dramatic rainstorms.

Glossary

color (mineral)	a physical property of **minerals**. Color is determined by the presence and intensity of certain elements within the mineral.
color (soil)	a physical property of **soils**. Soil color is influenced by **mineral** content, the amount of organic material, and the amount of water it routinely holds. These colors are identified by a standard soil color chart called the Munsell chart.
columnar joint	five- or six-sided columns that form as cooling **lava** contracts and cracks. Columnar joints are often found in **basalt** flows, but can also form in ashflow **tuffs** as well as shallow **intrusions**. The columns are generally vertical, but may also be slightly curved.
commodity	a good for which there is demand, but which is treated as equivalent across all markets, no matter who produces it.
compression, compressional force	forces acting on an object from all or most directions, resulting in compression (flattening or squeezing). Compressional forces occur by pushing objects together.
concretion	a hard, compact mass, usually of spherical or oval shape, found in **sedimentary rock** or **soil**. Concretions form when **minerals** precipitate around a particulate nucleus within the sediment.
conglomerate	a **sedimentary rock** composed of multiple large and rounded fragments that have been **cemented** together in a fine-grained **matrix**. The fragments that make up a conglomerate must be larger than grains of **sand**.
conifer	a woody plant (**tree**) of the division Coniferophyta. Conifers bear cones that contain their seeds.
Conservation of Energy	a principle stating that **energy** is neither created nor destroyed, but can be altered from one form to another.
contact metamorphism	the process by which a **metamorphic rock** is formed through direct contact with **magma**. Changes that occur due to contact metamorphism are greatest at the point of contact. The farther away the rock is from the point of contact, the less pronounced the change.
convection	the rise of buoyant material and the sinking of denser material. In the **mantle**, variations in **density** are commonly caused by the melting of **subducting** materials.
convergent boundary	an **active plate boundary** where two tectonic **plates** are colliding with one another. **Subduction** occurs when an oceanic plate collides with a continental plate or another oceanic plate. If two continental plates collide, mountain building occurs. See also: **plate tectonics**
copper	a ductile, malleable, reddish-brown metallic element (Cu). Copper is used extensively as wiring in the electrical industry as well as in alloys such as brass and bronze.
coquina	a porous, sometimes crumbly **limestone**, composed of fragments of shells and coral, and used as a building material.

cordaite	a member of a group called the Cordaitales, which were closely related to early members of the **conifers**. The best known taxon is the eponymous **Pennsylvanian** genus *Cordaites*. The group was prominent in swampy habitats during the **Carboniferous**, but went **extinct** by the end of the **Triassic**.
corundum	an **aluminum oxide mineral** (Al_2O_3) that is, after **diamond**, the hardest known natural substance. Corundum is best known for its **gem** varieties, ruby (red), and sapphire (blue).
craton	the old, underlying portion of a continent that is geologically stable relative to surrounding areas. The portion of a craton exposed at the surface is termed a shield, while that overlain by younger layers is often referred to as a platform. A craton can be thought of as the heart of a continent—it is typically the oldest, thickest, and most stable part of the bedrock. It is also usually far from the margins of tectonic **plates**, where new rock is formed and old destroyed. This rock has usually been **metamorphosed** at some point during its history, making it resistant to **erosion**.
creep	the slow movement or deformation of a material under the influence of pressure or stress (such as gravity); the slow progression of rock and **soil** down a slope due to the interacting factors of gravity, vegetation, water absorption, and steepness.
Cretaceous	a **geologic time** period spanning from 144 to 66 million years ago. It is the youngest period of the **Mesozoic**. The end of the Cretaceous bore witness to the **mass extinction** event that resulted in the demise of the **dinosaurs**. "Cretaceous" is derived from the Latin word *creta* meaning "chalk." The white (**chalk**) cliffs of Dover on the southeastern coast of England are a famous example of Cretaceous chalk deposits.
crinoid	a marine invertebrate animal belonging to the Class Crinoidea of the Phylum Echinodermata, and characterized by a head (**calyx**) with a mouth on the top surface surrounded by feeding arms. Several groups of stemmed **echinoderms** appeared in the early **Paleozoic**, including crinoids, **blastoids**, and **cystoids**. Crinoids have five-fold symmetry and feathery arms (sometimes held off the sea floor on a stem) that collect organic particles from the water. The stems, the most often preserved part, are made of a series of stacked discs. Upon death, these stems often fall apart and the individual discs are preserved separately in the rock. The crinoid's feathery arms make it look something like a flower on a stem. Thus, crinoids are commonly called "sea lilies," although they are animals, not plants.
cross-bedding	layering within a bed in a series of rock strata that does not run parallel to the plane of stratification. Cross-beds form as flowing water or **wind** pushes sediment downcurrent, creating thin beds that slope gently in the direction of the flow as migrating ripples. The downstream slope of the ripple may be preserved as a thin layer dipping in the direction of the current, across the natural flat-lying repose of the beds. Another migrating ripple will form an additional layer on top of the previous one.

Glossary

crust	the uppermost, rigid outer layer of the Earth. Two types of crust make up the **lithosphere**, which is broken into tectonic **plates**. Oceanic crust is **denser** but significantly thinner than continental crust, while continental crust is much thicker but less dense (and therefore buoyant). When continental crust collides with oceanic crust, the denser oceanic crust will be dragged (**subducted**) under the buoyant continental crust. Although mountains are created by these oceanic/continental crust collisions due to the **compression** of the two plates, much taller ranges are produced by continental/continental collisions. When two buoyant continental crusts collide, there is nowhere for the crust to go but up! The modern Himalayas, at the collision site of the Asian and Indian plates, are a good example of very tall mountains formed by a collision between two continental crusts.
Cryogenian	a **geologic time** period lasting from 850 to 635 million years ago, during the **Precambrian**. During this period, the Earth was subject to a 200-million-year-long **ice age**.
crystal form	a physical property of **minerals**, describing the shape of the mineral's crystal structure (not to be confused with **cleavage**). A mineral might be cubic, rhomboidal, hexagonal, or polyhedral.
cyanobacteria	a group of bacteria, also called "blue-green algae," that obtain their **energy** through photosynthesis.
cycad	a palm-like, terrestrial seed plant (**tree**) belonging to the Class Cycadopsida, and characterized by a woody trunk, a crown of stiff evergreen leaves, seeds without protective coatings, and no flowers. Cycads were very common in the **Mesozoic**, but are much reduced in diversity today, restricted to the tropical and subtropical regions of the planet.
cyclothem	alternating sequences of marine and non-marine **sedimentary rocks**, usually including **coal**, and characterized by their light and dark colors.
cystoid	**extinct**, stalked **echinoderms** related to **crinoids**, but with an ovoid body and triangular pore openings.
debris flow	a dangerous mixture of water, mud, rocks, **trees**, and other debris that can move quickly down valleys. Such flows can result from sudden rainstorms or snowmelt that create flash floods. Areas that have experienced a recent wildfire are particularly vulnerable to debris flows, since there is no vegetation to hold the **soil**.
degrade (energy)	the transformation of **energy** into a form in which it is less available for doing work, such as **heat**.
delta, deltaic	a typically wedge-shaped deposit formed as sediment is eroded from mountains and transported by streams across lower elevations. The Mississippi Delta is a modern delta containing sediment being transferred from the Mississippi River into the Gulf of Mexico.
dendritic drainage	a drainage pattern where many smaller streams join and contribute to ever larger streams. The pattern looks somewhat like a **tree**, in which smaller branches connect to progressively larger branches.
density	a physical property of **minerals**, describing the mineral's mass per volume.

derecho	a set of powerful straight-line **winds** that exceed 94 kilometers per hour (58 miles per hour) and can often approach 160 kilometers per hour (100 miles per hour). These powerful windstorms can travel over 400 kilometers (250 miles) and cause substantial wind damage, knocking down trees and causing widespread power outages. The lightning associated with these intense storms can cause both forest fires and house fires. *Derecho* is the Spanish word for "straight ahead."
derrick	a lifting device in the form of a framework steel tower that is built over a deep drill hole, typically an oil well. An oil derrick is composed of machinery for hoisting and lowering tools required during the drilling process, and readying the well for extraction of **petroleum**.
Devonian	a **geologic time** period spanning from 419 to 359 million years ago. The Devonian is also called the "age of fishes" due to the diversity of fish that radiated during this time. On land, seed-bearing plants appeared and terrestrial **arthropods** became established. The Devonian is part of the **Paleozoic**.
diabase	a dark-gray to black, medium-grained, **intrusive igneous rock** consisting mainly of labradorite and **pyroxene**. The crystal size of diabase is medium, between that of a **basalt** (finely crystalline) and a **gabbro** (coarsely crystalline).
diamond	a **mineral** form of carbon, with the highest **hardness** of any material. Most natural diamonds are formed at high temperature and pressure deep in the Earth's **mantle**.
dike	a sheet of **intrusive igneous** or **sedimentary rock** that fills a crack cutting across a pre-existing rock body.
dimension stone	the commercial term applied to quarried blocks of rock cut to specific dimensions and used for buildings, monuments, facing, and curbing.
dinosaur	a member of a group of terrestrial reptiles with a common ancestor and thus certain anatomical similarities, including long ankle bones and erect limbs. All of the large reptile groups, including the dinosaurs, disappeared at or before the **mass extinction** at the end of the **Cretaceous**.
divergent plate boundary	an **active plate boundary** where two tectonic **plates** are pulling apart from one another, causing the **mantle** to well up at a **rift**. Mid-ocean ridges are the most common divergent boundary and are characterized by the eruption of bulbous pillow-shaped **basalt lavas** and **hydrothermal** fluids.
dolomite	a **carbonate mineral**, consisting of calcium magnesium carbonate ($CaMg(CO_3)_2$). Dolomite is an important reservoir rock for **petroleum**, and also commonly hosts large **ore** deposits.
dolostone	a rock (also known as dolomitic **limestone** and once called magnesian limestone) primarily composed of **dolomite**, a **carbonate mineral**. It is normally formed when magnesium bonds with **calcium carbonate** in limestone, forming dolomite.
double refraction	the result of light passing through a material that splits it into two polarized sets of rays, doubling images viewed through that material. For example, a single line on a sheet of paper will appear as two parallel lines when viewed through a clear **calcite** crystal.
downwarp	a segment of the Earth's **crust** that is broadly bent downward.

Glossary

dynamic metamorphism	See **regional metamorphism**
earthquake	a sudden release of energy in the Earth's **crust** that creates **seismic waves**. Earthquakes are common at **active plate boundaries**.
echinoderm	a member of the Phylum Echinodermata, which includes starfish, sea urchins, and **crinoids**. Echinoderms have radial symmetry (which is usually five-fold), and a remarkable ability to regenerate lost body parts.
edestid	a member of a group of primitive **sharks** from the **Carboniferous** period known for their "tooth-whorls," unusual serrated teeth that grew in curved brackets and were used like the teeth in pinking shears.
effervesce	to foam or fizz while releasing gas. **Carbonate minerals** will effervesce when exposed to hydrochloric acid.
efficiency	the use of a relatively small amount of **energy** for a given task, purpose, or service; achieving a specific output with less energy input.
embayment	a bay, such as where the sea overflows a depression of land near the mouth of a river, or where there is a recess in a coastline.
energy	the **power** derived from the use of physical or chemical resources. Everything we do depends upon energy—without it there would be no civilization, no sunlight, no food, and no life. Energy moves people and goods, produces electricity, heats our homes and businesses, and is used in manufacturing and other industrial processes.
energy carrier	a source of **energy**, such as electricity, that has been subject to human-induced energy transfers or transformations.
Entisols	a **soil order**; these are **soils** of relatively recent origin with little or no **horizon** development. They are commonly found in areas where **erosion** or deposition rates outstrip rates of soil development, such as **floodplains**, mountains, and **badland** areas.
Eocene	a **geologic time** period extending from 56 to 33 million years ago. The Eocene is an epoch of the **Paleogene** period.
erosion	the transport of **weathered** materials. Rocks are worn down and broken apart into finer grains by **wind**, rivers, wave action, freezing and thawing, and chemical breakdown. Over millions of years, weathering and erosion can reduce a mighty mountain range to low rolling hills. Some rocks wear down relatively quickly, while others can withstand the power of erosion for much longer. Softer, weaker rocks, such as **shale** and poorly **cemented sandstone** and **limestone**, are much more easily worn than hard, crystalline **igneous** and **metamorphic rocks**, or well-cemented sandstone and limestone. Harder rocks are often left standing as ridges because the surrounding softer, less resistant rocks were more quickly worn away.

erratic, glacial erratic	a piece of rock that differs from the type of rock native to the area in which it rests, carried there by **glaciers** often over long distances. Erratics are often distinctive because they are a different type of rock than the bedrock in the area to which they have been transported. For example, boulders and pebbles of **igneous** and **metamorphic rocks** are often found in areas where the bedrock is **sedimentary**; it is sometimes possible to locate the origin of an erratic if its composition and textures are highly distinctive.
estuary	a place where freshwater and saltwater mix, created when sea level rises to flood a river valley.
eukaryotes	organisms with complex cells containing a nucleus and organelles. **Protists** and all multicellular organisms are eukaryotes.
evaporite	a **sedimentary rock** created by the precipitation of **minerals** directly from seawater, including **gypsum**, **calcite**, **dolomite**, and **halite**.
exfoliation	a type of physical **weathering**. When overlying layers are weathered away, the reduction of downward pressure allows the underlying rock to expand toward the surface. This expansion causes **joints**, or cracks, to form parallel to the surface, producing slabs that resemble the curved layers of an onion.
exhumation	the **erosional** uncovering or exposing of a geological feature that had been previously covered by deposited sediments.
exsolve	to come out of solution and, in the case of a gas, form bubbles.
extinction	the end of species or other taxonomic groups, marked by death of the last living individual. Paleontologists estimate that over 99% of all species that have ever existed are now extinct. The species of modern animals that we study in biology today represent less than 1% of what has lived throughout **geologic time**.
extrusion, extrusive rock	an **igneous rock** formed by the cooling of **lava** after **magma** escapes onto the surface of the Earth through **volcanic** craters and cracks in the Earth's **crust**.
fault	a fracture in the Earth's **crust** in which the rock on one side of the fracture moves measurably in relation to the rock on the other side.
feldspar	an extremely common group of rock-forming **minerals** found in **igneous**, **metamorphic**, and **sedimentary rocks**. There are two groups of feldspar: alkali feldspar (which ranges from potassium-rich to sodium-rich) and plagioclase feldspar (which ranges from sodium-rich to calcium-rich). Potassium feldspars of the alkali group are commonly seen as pink crystals in igneous and metamorphic rocks, or pink grains in sedimentary rocks. Plagioclase feldspars are more abundant than the alkali feldspars, ranging in color from light to dark. Feldspars are commercially used in ceramics and scouring powders.
felsic	**igneous rocks** with high **silica** content and low **iron** and magnesium content. They are light in color and are typically found in continental **crust**.

Glossary

filter feeder	an animal that feeds by passing water through a filtering structure that traps food. The water may then be expelled and the food digested. This strategy is employed by a wide range of animals today, from clams and krill to flamingos and whales.
flint	a hard, high-quality form of **chert** that occurs mainly as **nodules** and masses in **sedimentary rock**. Due to its strength and the fact that it splits into thin, sharp flakes, flint was often used to make tools during the Stone Age. Flint will also create sparks when struck against steel, and has been used to ignite gunpowder in more modern times.
floodplain	the land around a river that is prone to flooding. This area can be grassy, but the sediments under the surface are usually deposits from previous floods.
fluorite, fluorspar	the **mineral** form of calcium fluoride (CaF_2). Fluorite is used in a variety of commercial applications, including as lenses for microscopes, the production of some glass, and the chemical industry. Fluorite lent its name to the phenomenon of fluorescence, which occurs in some fluorites due to impurities in the crystal.
fluvial	See **outwash plain**
flux (mineral extraction)	a **mineral** added to the metals in a furnace to promote fusing or to prevent the formation of **oxides**.
foliation	the arrangement of the constituents of a rock in leaflike layers, as in **schists**. During **metamorphism**, the weight of overlying rock can cause **minerals** to realign perpendicularly to the direction of pressure, layering them in a sheet-like pattern.
foraminifera	a class of aquatic **protists** that possess a calcareous or **siliceous** exoskeleton. Foraminifera have an extensive **fossil** record.
foreland bulge	an area of **uplift** on the far side of an **inland basin**. Mountain building associated with **plate convergence** generally results in **downwarping**, that is, a basin associated with the load of mountains. Away from the area of maximum **subsidence**, the basin gradually shallows, followed by an area of uplift (the foreland bulge).
fossil	preserved evidence of ancient life, including, for example, preserved skeletal or tissue material, molds or casts, and traces of behavior. Fossilization may alter biological material in a variety of ways, including **permineralization**, **replacement**, and **compression**. Remains are often classified as fossils when they are older than 10,000 years, the traditional start of the **Holocene** (Recent) epoch. However, this date is only a practical guideline—scientists studying successions of plant or animal remains would not recognize any sudden change in the material at 10,000 years, and would typically refer to all material buried in sediments as fossil material. The word fossil is derived from the Latin word *fossilis*, meaning "dug up."

fossil fuels	**fuel** for human use that is made from the remains of ancient **biomass**, referring to any hydrocarbon fuel source formed by natural processes from anaerobically decomposed organisms, primarily **coal**, **petroleum**, **natural gas** (methane), and **peat**. Fossil fuels are non-renewable, meaning that because they take thousands to millions of years to form, the rate of use is far greater than the rate of formation, and eventually we will run out.
fracture (mineral)	a physical property of **minerals**, formed when a mineral crystal breaks; also a crack in rocks, sometimes known as a **joint**. This process is separate from **cleavage**, which occurs when a mineral breaks in a characteristic way along a specific plane of weakness.
frost wedging	physical **weathering** that occurs when water freezes and expands in cracks.
fuel	a material substance possessing internal potential **energy** that can be transferred to the surroundings for specific uses—included are **petroleum**, **coal**, and **natural gas** (the **fossil fuels**), and other materials, such as uranium, hydrogen, and **biofuels**.
gabbro	a coarse-grained, **mafic**, and **intrusive igneous rock**. Most oceanic **crust** contains gabbro.
galena	an abundant **sulfide mineral** with cubic crystals. It is the most important ore of **lead**, as well as an important source of **silver**.
gastropod	a marine, freshwater, or terrestrial invertebrate animal belonging to the Class Gastropoda of the Phylum Mollusca, and characterized by a single, coiled, calcareous shell, a muscular foot for gliding, and internal asymmetry caused by an embryonic process (torsion). Gastropods include snails and slugs.
Gellisols	a **soil order**; these are weakly **weathered soils** formed in areas that contain **permafrost** within the soil profile.
gem, gemstone	a **mineral** that has aesthetic value and is often cut and polished for use as an ornament.
geologic time scale	a standard timeline used to describe the age of rocks and **fossils**, and the events that formed them. It spans Earth's entire history, and is often subdivided into four major time intervals: the **Precambrian**, **Paleozoic**, **Mesozoic**, and **Cenozoic**.
ginkgo	a terrestrial **tree** belonging to the plant division Ginkgophyta, and characterized by broad fan-shaped leaves, large seeds without protective coatings, and no flowers. Ginkgos were very common and diverse in the **Mesozoic**, but today only one species exists, *Ginkgo biloba*.
glacier	a body of dense ice on land that does not melt away annually and has sufficient mass to move under its own weight. Glaciers form when snow accumulates faster than it melts over many years. As long as melt does not exceed accumulation, the ice and snow pile up and become a self-sustaining system. As glaciers slowly flow, they abrade and **erode** the landscape around them to create grooves, scratches, **moraines**, and other distinguishing features. Glaciers form only on land, and are much thicker than ice that forms on the surface of water. 99% of Earth's glacial ice exists as vast polar **ice sheets**, but glaciers are also found high in the mountains of every continent except Australia.

Glossary

glassy rock	a **volcanic** rock that cooled almost instantaneously, resulting in a rock with tiny crystals or no crystals at all. **Obsidian**, **basalt** glass, and **pumice** are examples of glassy rocks.
global warming	the current increase in the average temperature worldwide, caused by the buildup of **greenhouse gases** in the **atmosphere**. With the coming of the Industrial Age and exponential increases in human population, large amounts of gases have been released into the atmosphere (especially carbon dioxide) that give rise to global warming. The term "climate change" is preferred because warming contributes to other climatic changes such as precipitation and storm strength.
gneiss	a **metamorphic rock** that may form from **granite** or layered **sedimentary rock** such as **sandstone** or siltstone. Parallel bands of light and dark **minerals** give gneiss its banded texture.
gold	a soft, yellow, corrosion-resistant element (Au), which is the most malleable and ductile metal on Earth. Gold has an average abundance in the crust of only 0.004 parts per million. It can be profitably mined only where **hydrothermal solutions** have concentrated it.
Gondwana, Gondwanaland	the supercontinent of the Southern Hemisphere, composed of Africa, Australia, India, and South America. It combined with the North American continent to form **Pangaea** during the late **Paleozoic**.
gossan	the near-surface, **oxidized** portion of a **sulfide**-rich **ore** body.
granite	a common and widely occurring type of **igneous rock**. Granite usually has a medium- to coarse-grained texture, and is at least 20% **quartz** by volume.
graphite	a **mineral** and the most stable form of carbon. Graphite means "writing stone," a reference to its use as pencil lead. Graphite occurs in metamorphic rocks, igneous rocks, and meteorites.
graptolite	an **extinct** colonial invertebrate animal belonging to the Class Graptolithina of the Phylum Hemichordata, and characterized by individuals housed within a tubular or cup-like structure. The soft parts of a graptolite's body have never been clearly identified.
gravel	unconsolidated, semi-rounded rock fragments larger than 2 millimeters (0.08 inches) and smaller than 75 millimeters (3 inches).
greenhouse gas	a gas in the **atmosphere** that absorbs and emits **heat**. The primary greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.
Grenville Orogeny	a mountain-building event that took place over the interval of approximately 1.3 to 1 billion years ago, along the southeastern and eastern edges of North America from Mexico to Canada. The Grenville Orogeny played a role in the formation of the supercontinent **Rodinia**. See also: **orogeny**
gypsum	a soft, **sulfate mineral** that is widely mined for its use as fertilizer and as a constituent of plaster. Alabaster, a fine-grained light colored variety of gypsum, has been used for sculpture making by many cultures since ancient times.

halite	See **salt**
hardness	a physical property of **minerals**, specifying how hard the mineral is, and its resistance to scratching. Hardness helps us understand why some rocks are more or less resistant to **weathering** and **erosion**. See also: **Moh's Scale of Hardness**
heat	a form of **energy** transferred from one body to another as a result of a difference in temperature or a change in phase. Heat is transmitted through solids and fluids by conduction, through fluids by **convection**, and through empty space by radiation.
heat island effect	a phenomenon in which cities experience higher temperatures than do surrounding rural communities.
heat wave	a period of excessively hot **weather** that may also accompany high humidity. Temperatures of just 3°C (6°F) to 6°C (11°F) above normal are enough to reclassify a warm period as a heat wave. Under high humidity, the mechanism of sweating does little to cool people down because the humidity prevents sweat from evaporating and cooling off the skin.
hectare	a metric unit of area defined as 10,000 square meters.
hematite	a **mineral** form of **iron oxide** (Fe_2O_3). The name hematite has its origins in the Greek word *haimatos*, meaning "blood." It is very common in **Precambrian** banded iron formations. Iron from hematite is used in the manufacture of steel. The vivid red pigments that iron lends to the mineral also makes it valuable as a commercial pigment.
Histosols	a **soil order**; these are organic-rich soils found along lake coastal areas where poor drainage creates conditions of slow decomposition and **peat** (or muck) accumulates.
Holocene	the most recent portion of the **Quaternary**, beginning about 11,700 years ago and continuing to the present. It is the most recent (and current) **interglacial**, an interval of glacial retreat. The Holocene also encompasses the global growth and impact of the human species.
horizon (soil)	a layer in the **soil**, usually parallel to the surface, which has physical characteristics (usually **color** and texture) that are different from the layers above and below it. Each type of soil usually contains three or four horizons.
hornblende	a dark **silicate mineral** that can occur in a variety of forms. Hornblende is a common constituent of many **igneous** and **metamorphic rocks**.
horsetail	see **sphenopsid**

h–i Glossary

hot spot	a **volcanic** region thought to be fed by underlying **mantle** that is anomalously hot compared with the mantle elsewhere. Hot spots form from plumes of hot material rising through the mantle. Magma from the hot spot pushes its way up through the **crust**, creating an **igneous intrusion** and sometimes a volcano. Although the hot spot remains fixed, the **plates** of the **lithosphere** continue to move above it. As a plate continues to move over the hot spot, the original volcano shifts off of the hot spot and a new intrusion or volcano is formed. This gradually produces a chain of **volcanic islands** such as the Hawaiian Islands. **Erosion** of volcanoes may eventually wear down the crust to reveal the igneous intrusions that formed the volcano's magma chamber.
humus	the organic component of soil; a major part of the **soil horizon** containing organic matter.
Huronian glaciation	a **glaciation** beginning about 2.4 billion years ago, that covered the entire surface of the Earth in ice for as long as 300 million years.
hurricane	a rapidly rotating storm system with heavy **winds**, a low-pressure center, and a spiral arrangement of thunderstorms. These storms tend to form over large, warm bodies of water. Once winds have reached 119 kilometers per hour (74 miles per hour), such a storm is classified as a hurricane. Hurricanes usually develop an eye, which is visible as a small, round, cloud-free area at the center of the storm. The eye is an area of relative calm and low **atmospheric** pressure. The strongest thunderstorms and winds circulate just outside the eye, in the eyewall.
hydrothermal solution	hot, **mineral**-rich water moving through rocks.These solutions are often enriched in **salts** (such as sodium chloride, potassium chloride, and calcium chloride) and thus are called "brines." The brine is as salty or even saltier than seawater. Salty water can contain minute amounts of dissolved minerals such as **gold**, **lead**, **copper**, and **zinc**. The presence of salt in the water suppresses the precipitation of the metallic minerals from the brine because the chlorides in the salt preferentially bond with metals. Additionally, because the brine is hot, minerals are more easily dissolved, just as hot tea dissolves sugar more easily than cold tea.
Iapetus Ocean	the proto-Atlantic Ocean, located against the eastern coast of North America's ancestral landmass before **Pangaea** formed. In Greek mythology, Iapetus was the father of Atlantis.
ice age	a period of global cooling of the Earth's surface and **atmosphere**, resulting in the presence or expansion of **ice sheets** and alpine **glaciers**. Throughout the Earth's history, it has been periodically plunged into ice ages, dependent upon the **climate** and position of the continents. Over the past 2.6 million years, North America has experienced about 50 glacial advances and retreats. The most recent ice age ended about 12,000 years ago.
ice cap	an **ice field** that lies over the tops of mountains.
ice field	an extensive area of interconnected **glaciers** spanning less than 50,000 square kilometers (19,305 square miles). Ice fields are usually constrained by an area's **topography**. Ice fields that lie over the tops of mountains are called **ice caps**.

ice lobe	a broad, rounded section of a continental **glacier** that flows out near the glacier's terminus, often through a broad trough.
ice sheet	a mass of **glacial** ice that covers part of a continent and has an area greater than 50,000 square kilometers (19,000 square miles).
iceberg	a large chunk of ice, generally ranging in height from 1 to 75 meters (3 to 246 feet) above sea level, that has broken off of an **ice sheet** or **glacier** and floats freely in open water.
igneous rocks	rocks derived from the cooling of **magma** underground or molten **lava** on the Earth's surface. Igneous rocks differ not only in their cooling rates and subsequent crystal sizes, but also in their chemical compositions. Rocks found in continental **crust**, such as **granite**, have high **silica** content and low iron and magnesium content. They are light in color and are called **felsic**. Rocks found in oceanic crust, like **basalt**, are low in silica and high in iron and magnesium. They are dark in color and are called **mafic**. Although the composition of magma can be the same as lava, the texture of the rocks will be quite different due to different rates of cooling. It is because of this difference in genesis that geologists are able to make the distinction between **extrusive** and **intrusive** igneous rocks when encountered at an outcrop at the Earth's surface.
Illinois Basin	an **inland basin** centered in the state of Illinois, which formed when **Baltica** approached North America in the **Ordovician**. More than four billion barrels of **petroleum** have been extracted from the Illinois Basin.
ilmenite	an **ore** of **titanium**, produced for use as a white pigment in paint.
Inceptisols	a **soil order**; these are **soils** that exhibit only moderate **weathering** and development. They are often found on steep (relatively young) **topography** and overlying **erosion**-resistant bedrock.
index fossil	a **fossil** used to determine the relative age of **sedimentary** deposits. An ideal index fossil lived during a short period of time, was geographically and environmentally widespread, and is easy to identify. Some of the most useful index fossils are hard-shelled organisms that were once part of the marine plankton.
inland basin	a depression located inland from the mountains, and formed by the buckling (**downwarping**) of the Earth's **crust**. Basins naturally preserve thick sediment layers because they accumulate eroded sediment and commonly continue to subside under the weight of the sediment.
inland sea	a shallow sea covering the central area of a continent during periods of high sea level. An inland sea is located on continental **crust**, while other seas are located on oceanic crust. An inland sea may or may not be connected to the ocean. For example, Hudson Bay is on the North American **plate** and connects to the Atlantic and Arctic oceans, while the Caspian Sea is on the European plate but does not drain into any ocean at all.
intensity (earthquake)	a subjective measurement that classifies the amount of shaking and damage done by an **earthquake** in a particular area.
interglacial	a period of **geologic time** between two successive **glacial** stages.

i–k Glossary

intertidal	areas that are above water during low tide and below water during high tide.
intrusion, intrusive rock	a **plutonic igneous rock** formed when **magma** from within the Earth's **crust** escapes into overlying strata. As the magma rises, pushing through overlying layers of rock, it begins to cool. The cooling magma can crystallize and harden to become intrusive igneous rock, locked within layers of older rock.
iron	a metallic chemical element (Fe). Iron is most often found in combination with other elements, such as oxygen and **sulfur**, to form **ores** like **hematite**, **magnetite**, siderite, and **pyrite**. The ready availability of iron at Earth's surface made it one of the earliest mined **mineral** resources in the US.
isotope	a form of an element that contains a specific number of neutrons. For example, the isotope of carbon with six neutrons is known as carbon-12 (^{12}C) and the isotope of carbon with eight neutrons is carbon-14 (^{14}C).
jade	a word applied to two green **minerals** that look similar and have similar properties: jadeite (a kind of **pyroxene**) and nephrite (a kind of **amphibole**). Both minerals are formed during **metamorphism** and are found primarily near **subduction** zones, which explains why jade is abundant in a variety of locations along **active plate boundaries**.
jasper	a speckled or patterned **silicate** stone that appears in a wide range of **colors**. It is a variety of **chalcedony**. Jasper forms when silica precipitates in a fine particulate material such as soft sediment or **volcanic ash**. The particulates give the stone its color and patterns.
joint	a surface or plane of **fracture** within a rock.
joule (J)	the **energy** expended (or work done) to apply a force of one newton over a distance of one meter.
Jurassic	the **geologic time** period lasting from 201 to 145 million years ago. During the Jurassic, **dinosaurs** dominated the landscape and the first birds appeared. The Jurassic is the middle period of the **Mesozoic**.
kaolinite	a **silicate clay mineral**, also known as "china clay." Kaolinite is the main ingredient in fine china dishes such as Wedgwood.
karst topography	a kind of landscape defined by bedrock that has been **weathered** by dissolution in water, forming features like sinkholes, caves, and cliffs. Karst **topography** primarily forms in **limestone** bedrock.
kinetic energy	the **energy** of a body in motion (e.g., via friction).

Köppen system	a commonly used system of **climate** categorization developed by Russian climatologist Wladimir Köppen. It is based on the kinds of vegetation that areas sustain, and defines 12 climate types: rainforest, monsoon, tropical savanna, humid subtropical, humid continental, oceanic, Mediterranean, steppe, subarctic, tundra, polar **ice cap**, and desert. Updated by Rudolf Geiger, it has been refined to five groups each with two to four subgroups.
lacustrine	of or associated with lakes.
Lagerstätte (pl. Lagerstätten)	**fossil** deposit containing animals or plants that are preserved unusually well, sometimes even including the soft organic tissues. Lagerstätten form in chemical environments that slow decay of organic tissues or enhance preservation through mineralization. Also, quick burial of the organism leaves no opportunity for disturbance of the fossils. Lagerstätten are important for the information they provide about soft-bodied organisms that we otherwise would know nothing about.
landslide	the rapid slipping of a mass of earth or rock from a higher elevation to a lower level under the influence of gravity and water lubrication. Landslides include rock falls, avalanches, **debris flows**, mudflows, and the **slumping** of rock layers or sediment. See also: **mass wasting**
last glacial maximum	the most recent time the **ice sheets** reached their largest size and extended farthest toward the equator, about 26,000 to 19,000 years ago. Ice sheets over North America melted back until about 10,000 years ago—they have been relatively stable since that time.
lava	molten rock located on the Earth's surface. When **magma** rises to the surface, typically through a volcano or **rift**, it becomes lava. Lava cools much more quickly than magma because it is at the surface, exposed to the **atmosphere** or ocean water where temperatures are much cooler. Such rocks, with little time to crystallize, have small or no crystals.
Law of Superposition	the geologic principle that states that unless rock layers have been overturned or **intruded**, older rocks are found at the bottom and younger rocks are found at the top of a **sedimentary** sequence. See also: **stratigraphy**
lead	a metallic chemical element (Pb). Lead was one of the first metals mined in North America, where it was sought after especially for making shot. It is used in batteries, communication systems, and building construction.
levee	a deposit of sediment built up along and sloping away from the sides of a river's **floodplain**; also, an artificial embankment along a waterway to prevent flooding, especially from a river.
lignite	a soft, brownish-black **coal** in which the alteration of plant matter has proceeded farther than in **peat** but not as far as in **bituminous coal**.
lime	an inorganic white or grayish white compound made by roasting **limestone** (**calcium carbonate**, $CaCO_3$) until all the carbon dioxide (CO_2) is driven off. Originating from limestone, **dolomite**, or **marble**, lime is very important to agriculture, in which it is regularly applied to make **soils** "sweeter" (less acidic).

Glossary

limestone	a **sedimentary rock** composed of **calcium carbonate** ($CaCO_3$). Most limestones are formed by the deposition and consolidation of the skeletons of marine invertebrates; a few originate in chemical precipitation from solution. Limestone is ordinarily white but can be colored by impurities such as **iron oxide** (making it brown, yellow, or red), or organic carbon (making it blue, black, or gray). The rock's texture varies from coarse to fine.
liquefaction	a process by which water-saturated unconsolidated sediment temporarily loses strength and behaves as a fluid when vibrated.
lithification	the process of creating **sedimentary rock** through the compaction or **cementation** of soft sediment. The word comes from the Greek *lithos*, meaning "rock."
lithium	a metallic chemical element (Li) used in the manufacture of ceramics, glass, greases, and batteries.
lithosphere	the outermost layer of the Earth, comprising a rigid **crust** and upper **mantle** broken up into many **plates**. The plates of the lithosphere move with the underlying **asthenosphere**, on average about 5 centimeters (2 inches) per year and as much as 18 centimeters (7 inches) per year.
loam	a **soil** containing equal amounts of **clay**, **silt**, and **sand**.
lode	an ore deposit that fills a fissure or crack in a rock formation; alternately, an **ore** vein that is embedded between layers of rock.
loess	very fine-grained, wind-blown sediment, usually **rock flour** left behind by the grinding action of flowing **glaciers**.
luminescence	the emission of light.
luster	a physical property of **minerals**, describing the appearance of the mineral's surface in reflected light, and how brilliant or dull it is. Luster can range from metallic and reflective to opaque, vitreous like glass, translucent, or dull and earthy.
lycopod	an **extinct**, terrestrial **tree** belonging to the plant division Lycopodiophyta, and characterized by a tall, thick trunk covered with a pattern of diamond-shaped leaf scars, and a crown of branches with simple leaves. Lycopods, or "scale trees," grew up to 98 feet (30 meters) high in **Mississippian** and **Pennsylvanian** forests. The plant division Lycopodiophyta survives today but only as very small plants on the forest floor, sometimes called "ground pines."
mafic	**igneous rocks** that contain a group of dark-colored **minerals**, with relatively high concentrations of magnesium and **iron** compared to **felsic** igneous rocks.
magma	molten rock located below the surface of the Earth. Magma can cool beneath the surface to form **intrusive igneous rocks**. However, if magma rises to the surface without cooling enough to crystallize, it might break through the **crust** at the surface to form **lava**.

magnetic	affected by or capable of producing a magnetic field.
magnetite	a **mineral** form of **iron oxide** (Fe_3O_4). It is the most **magnetic** naturally occurring mineral. The molecules in magnetite align with the North and South poles when rocks containing magnetite ore are formed. By examining the alignment today, scientists can reconstruct how the rocks have moved since their formation, giving them clues about the previous arrangement of the continents. Magnetite lodestones were used as an early form of compass. Huge deposits of magnetite have been found in **Precambrian banded iron formations**.
magnitude (earthquake)	a logarithmic scale used to measure the seismic energy released by an **earthquake**. Magnitudes follow a numerical scale, with M1 earthquakes classified as micro, M2 earthquakes classed as minor, and earthquakes of M8 or greater being classified as great.
mammoth	an **extinct** terrestrial vertebrate animal belonging to the Order Proboscidea of the Class Mammalia. Mammoths are from the same line of proboscideans that gave rise to African and Asian elephants. They had tall bodies with a rather high, "domed" skull, and teeth with numerous parallel rows of ridges. Mammoths are among the most common **Pleistocene** vertebrate **fossils** in North America, Europe, and Asia.
mantle	the layer of the Earth between the **crust** and core. It consists of solid **silicate** rocks that, over long intervals of time, flow like a highly viscous liquid. Convection currents within the mantle drive the motion of **plate tectonics**.
marble	a **metamorphic rock** composed of recrystallized **carbonate minerals**, most commonly **calcite** or **dolomite**. Not everything commercially called a marble is "true marble," which lacks **fossils** and is recrystallized from **limestone** or **dolostone**.
marl	a fine-grained **sedimentary rock** consisting of **clay minerals**, **calcite** and/or aragonite, and **silt**.
mass extinction	the **extinction** of a large percentage of the Earth's species over a relatively short span of **geologic time**. Unfortunately, this is not just a phenomenon of the past: it is estimated that the extinction rate on Earth right now may be as much as 1000 times higher than normal, and that we are currently experiencing a mass extinction event.
mass wasting	a process in which **soil** and rock move down a slope in a large mass. This can occur both on land (such as a **landslide**) or underwater (such as a **turbidity current**).
mastodon	an **extinct** terrestrial vertebrate animal belonging to the Order Proboscidea of the Class Mammalia, and characterized by an elephant-like shape and size, and massive molar teeth with conical projections. Mastodons are among the most common **Pleistocene** vertebrate **fossils** in North America.
matrix	a fine-grained mass of material around and embedding larger grains or crystals. The term matrix can also describe sediment or rock in which a **fossil** is embedded.

Glossary

Mesozoic	a **geologic time** period that spans from 252 to 66 million years ago. This period is also called the "age of reptiles" since **dinosaurs** and other reptiles dominated both marine and terrestrial ecosystems. During this time, the last of the Earth's major supercontinents, **Pangaea**, formed and later broke up, producing the Earth's current geography. The Mesozoic contains the **Triassic**, **Jurassic**, and **Cretaceous** periods.
metamorphism, metamorphic rocks	rocks formed by the recrystallization and realignment of **minerals** in pre-existing **sedimentary**, **igneous**, and **metamorphic rocks** when exposed to high enough temperature and/or pressure. This can be a result of **plate** movements, very deep burial, or contact with molten rock or superheated water. This process destroys many features in the rock that would have revealed its previous history, transforming it into an entirely new form. Tectonic forces can cause minerals to realign perpendicularly to the direction of pressure, layering them in a pattern called **foliation**, as exemplified in **gneiss** and **schist**. **Recrystallization**, as seen in **marble** and **quartzite**, results as rock is heated to high temperatures, and individual grains reform as interlocking crystals, making the resulting metamorphic rock harder than its parent rock.
meteorite	a stony or metallic mass of matter that has fallen to the Earth's surface from outer space.
mica	a large group of sheet-like **silicate minerals**.
Michigan Basin	an **inland basin** centered on Michigan's Lower Peninsula, which formed when **Baltica** approached North America in the **Ordovician**. The rocks of the Michigan Basin are a commercial source of **petroleum**.
microcontinent	a piece of continental **crust**, usually **rifted** away from a larger continent. Microcontinents and other smaller fragments of continental crust (**terranes**) each had their own, often complex, geologic history before they were tacked onto the margin of another continent.
Milankovitch Cycles	cyclical changes in the amount of **heat** received from the sun, associated with how the Earth's orbit, tilt, and wobble alter its position with respect to the sun. These changes affect the global **climate**, most notably alterations of **glacial** and **interglacial** intervals.
mineral	a naturally occurring, inorganic solid with a specific chemical composition and a well-developed crystalline structure. Minerals are identified based on their physical properties, including **hardness**, **luster**, **color**, **crystal form**, **cleavage**, **density**, and **streak**. There are over 4900 identified minerals. However, the number of common rock-forming minerals is much smaller. The most common minerals that form **igneous**, **metamorphic**, and **sedimentary rocks** include **quartz**, **feldspars**, **micas**, **pyroxenes**, and **amphiboles**.
mineralogy	the branch of geology that includes study of the chemical and physical properties and formation of **minerals**.
Miocene	a **geologic time** unit extending from 23 to 5 million years ago. During the Miocene, the Earth experienced a series of **ice ages**, and hominid species diversified. The Miocene is the first epoch of the **Neogene** period.

Mississippi Embayment	a **topographically** low-lying basin in the south-central United States, stretching from Illinois to Louisiana. The Mississippi Embayment originated as far back as the **Precambrian**, during the breakup of **Rodinia**. During this time, many smaller **rifts** in the **crust** formed adjacent to the major rift that split away North America—one of these smaller rifts is located beneath the modern day Mississippi Embayment. During the breakup of **Pangaea**, the area **subsided**, forming a trough that was flooded during the **Cretaceous**. When sea level fell, the Mississippi River was born. Thousands of meters of Cretaceous to Recent sediment were deposited in the river valley. Recurrent activity along **faults** associated with the deeply buried ancient rifts beneath the embayment caused the 1811–1812 New Madrid Earthquakes, one of the largest **earthquakes** ever recorded in North America.
Mississippian	a subperiod of the **Carboniferous**, spanning from 359 to 323 million years ago.
Mohs Scale of Hardness	the scale of relative **hardness** of **minerals**, developed by the Austrian mineralogist Frederich Mohs in 1824. The scale is very useful as a means for identifying minerals or quickly determining hardness. A piece of glass has a hardness of approximately 5 on the scale; our fingernails are just over 2; a knife blade is just over 5. Diamond ranks at 10 as the hardest mineral.
Mollisols	a **soil order**; these are agricultural **soils** made highly productive due to a very fertile, organic-rich surface layer.
monadnock	an isolated hill or small mountain on a plain, formed from rock more resistant to **erosion** than that of the rest of the surrounding landscape. These features are named after Mount Monadnock (New Hampshire), which is made of **schist** and **quartzite**.
moraine	an accumulation of unconsolidated **glacial** debris (**soil** and rock) that can occur in currently glaciated and formerly glaciated regions, such as those areas acted upon by a past **ice age**. The debris is scraped from the ground and pushed forward by the glacier, to be left behind when the ice melts. Thus, many moraines mark the terminus or edge of a glacier. Lateral moraines can also occur between and at the sides of glaciers or **ice lobes**.
mosasaur	an **extinct**, carnivorous, marine vertebrate reptile. Mosasaurs were characterized by a streamlined body for swimming, a powerful fluked tail, and reduced, paddle-like limbs. They were common in **Cretaceous** seas and were were powerful swimmers, reaching 12–18 meters (40–59 feet) in length.
mysticete	a member of the group of whales (cetaceans), such as finback and humpback whales, which have baleen for feeding upon some combination of plankton, krill, and small fish. The earliest mysticetes occur in the late **Eocene**.
natural gas	a hydrocarbon gas mixture composed primarily of methane (CH4), but also small quantites of hydrocarbons such as ethane and propane. See also: **fossil fuel**
natural hazards	events that result from natural processes and that have significant impacts on human beings.

n–o Glossary

Neogene	the **geologic time** period extending from 23 to 2.6 million years ago. During the Neogene, global **climate** cooled, the continents moved close to their current positions, mammals and birds continued to evolve, and the first hominins appeared. The Neogene is a portion of the **Cenozoic**.
Newark Supergroup	a sequence of nonmarine **sedimentary rocks** that accumulated in **rift basins** along what is now eastern North America (North Carolina to Newfoundland) in the late **Triassic** to early **Jurassic** periods. The rifts formed as **Pangaea** split apart. In some places the strata contain well-preserved fish **fossils** or **dinosaur** tracks.
nodule	a small, irregular or rounded **mineral** deposit that has a different composition from the **sedimentary rock** that encloses it. Nodules typically form when minerals precipitate from a supersaturated solution within or around features such as **biotic** remains.
nuclear	pertaining to a reaction, as in fission, fusion, or **radioactive** decay, that alters the energy, composition, or structure of an atomic nucleus.
obsidian	a glassy **volcanic** rock, formed when **felsic lava** cools rapidly. Although obsidian is dark in color, it is composed mainly of **silicon** dioxide (SiO_2), and its dark color is a result of impurities such as **iron** and magnesium. Obsidian is extremely brittle and breaks with very sharp edges. It was valuable to Stone Age cultures for its use as cutting implements or arrowheads.
odontocete	a member of the group of whales (cetaceans) such as sperm whales and killer whales, which have baleen for feeding upon some combination of fish, squid, and mammals. The earliest odontocetes occur in the **Oligocene**.
oil	See **petroleum**
Oligocene	a **geologic time** interval spanning from about 34 to 23 million years ago. It is an epoch of the **Paleogene**.
olivine	an **iron**-magnesium **silicate mineral** ($(Mg,Fe)_2SiO_4$) that is a common constituent of magnesium-rich, silica-poor **igneous rocks**.
oolite (adj. oolitic)	a **sedimentary rock**, especially **limestone**, consisting of tiny (< 2 millimeters [0.787 inches]), spherical grains made of concentric layers of **calcium carbonate** (ooids), sometimes preserved within a limy mud **matrix**. Ooids typically grow when calcium carbonate precipitates as the ooids roll around in *intertidal* supersaturated seawater.
ophiolite	a section of the Earth's oceanic **crust** and the underlying upper **mantle** that has been **uplifted** and exposed above sea level and often thrust onto continental crustal rocks. Ophiolites are often formed during **subduction**–as oceanic crust is subducted, some of the deep-sea sediments overlying the crust, the oceanic crust itself, and sometimes rock from the upper mantle, can be scraped off the descending plate and **accreted** to the continental crust.
Ordovician	a **geologic time** period spanning from 485 to 443 million years ago. During the Ordovician, invertebrates dominated the oceans and fish began to diversify. The Ordovician is part of the **Paleozoic**.

ore	a type of rock that contains **minerals** with valuable elements, including metals, that are economically viable to extract.
orogeny	a mountain-building event generally caused by colliding **plates** and **compression** of the edge of the continents. Orogeny is derived from the Greek word *oro*, meaning "mountain."
outwash plain	large **sandy** flats created by sediment-laden water deposited when a **glacier** melts. Outwash sediments are also called "fluvial material."
oxbow	a stream meander in the shape of a "U," named after the U-shaped collar of an ox yoke. An oxbow may curve sufficiently to bend back and connect with itself; in this case the stream will straighten and the curved bow may become isolated as an "oxbow lake."
oxidation, oxide	a **chemical reaction** involving the loss of at least one electron when two substances interact; most often used to describe the interaction between oxygen molecules and the substances they come into contact with. Oxidation causes effects such as rust and cut apples turning brown.
Oxisols	a **soil order**; these are very old, extremely leached and **weathered soils** with a subsurface accumulation of **iron** and **aluminum oxides**. Commonly found in humid, tropical environments.
Paleocene	a **geologic time** interval spanning from about 66 to 56 million years ago. It is an epoch of the **Paleogene** period.
paleoecology	the study of the relationships of **fossil** organisms to one another and their environment.
Paleogene	the **geologic time** interval extending from 66 to 23 million years ago. During the Paleogene, mammals and birds diversified into many of the niches that had previously been held by **dinosaurs**. The Paleogene is the first part of the **Cenozoic**.
Paleozoic	a **geologic time** period that extends from 541 to 252 million years ago. **Fossil** evidence shows that during this time period, life evolved in the oceans and gradually colonized the land. The Paleozoic includes the **Cambrian**, **Ordovician**, **Silurian**, **Devonian**, **Carboniferous**, and **Permian** periods.
Pangaea	a supercontinent, meaning "all Earth," which formed over 300 million years ago and lasted for almost 150 million years, during which all of the Earth's continents were joined in a giant supercontinent. Pangaea eventually **rifted** apart and separated into the continents in their current configuration.
parent material	the original geologic material from which **soil** formed. This can be bedrock, preexisting soils, or other transported sediment such as **till** or **loess**.
passive margin	a tectonically quiet continental edge, such as the eastern margin of North America, where **crustal** collision or **rifting** is not occurring.

Glossary

peat	an accumulation of partially decayed plant matter. Under proper **heat** and pressure, it will turn into **lignite coal** over geologic periods of time. As much as 9 meters (30 feet) of peat might need to accumulate to produce an economically profitable coal seam. By the time that a peat bed has been turned into a layer of **anthracite**, the layer is one-tenth its original thickness.
peds	clumps of **soil**, identified by their shape, which may take the form of balls, blocks, columns, and plates. These structures are easiest to see in recently plowed fields, where the soil is often granular and loose or lumpy.
pegmatite	a very coarse-grained **igneous rock** that formed below the surface, usually rich in **quartz**, **feldspars**, and **micas**. Pegmatite **magmas** are very rich in water, carbon dioxide, **silicon**, **aluminum**, and potassium, and form as the last fluids to crystallize from magma or the first **minerals** to melt at high temperatures during **metamorphism**.
Pennsylvanian	a subperiod of the **Carboniferous**, spanning from 323 to 299 million years ago.
perennial	continuous; year-round or occurring on a yearly basis.
peridotite	a coarse-grained **plutonic** rock containing **minerals**, such as **olivine**, which make up the Earth's **mantle**.
periglacial zone	a region directly next to an **ice sheet**, which, although it was never covered or **scoured** by ice, has its own distinctive landscape and features because it was next to the ice margin. The average annual air temperature in a periglacial area is between −12° and 3°C (10° and 37°F). Though the surface of the ground may melt in the summer, it refreezes in the winter.
permafrost	a layer of **soil** below the surface that remains frozen all year round. Its thickness can range from tens of centimeters (inches) to a few meters (yards). Permafrost is typically defined as any soil that has remained at a temperature below the freezing point of water for at least two years.
permeable, permeability	a capacity for fluids and gas (such as water, oil and natural gas) to move through fractures within a rock, or the spaces between its grains. Sandstone, limestone, and fractured rocks of any kind generally are permeable. Shale, on the other hand, is usually impermeable because the small, flat clay particles that make up the rock are tightly packed into a dense rock with very little space between particles. Poorly sorted sedimentary rocks can also be impermeable because smaller grains fill in the spaces between the bigger grains, restricting the movement of fluids.
Permian	the **geologic time** period lasting from 299 to 252 million years ago. During the Permian, the world's landmass was combined into the supercontinent **Pangaea**. The Permian is the last period of the **Paleozoic**. It ended with the largest **mass extinction** in Earth's history, which wiped out 70% of terrestrial animal species and 90% of all marine animal species.
permineralization	a **fossilization** method in which empty spaces (such as in a bone or shell) are filled by minerals.

petroleum	a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface and consisting primarily of hydrocarbons. Petroleum, also called oil, is a **fossil fuel**, formed when large masses of dead organisms (usually algae or plankton) are buried underneath sediments and subjected to intense **heat** and pressure. Today, petroleum is used to manufacture a wide variety of materials, and it is commonly refined into various types of fuels. It is estimated that 90 million barrels are consumed globally every day.
phosphate	an inorganic **salt** of phosphoric acid, and a nutrient vital to biological life.
phyllite	a **metamorphic rock** that is intermediate in grade between **slate** and **schist**.
physiography	a subfield of geography that studies the Earth's physical processes and patterns, including consideration of the shape (not just the height) of land forms, as well as the bedrock, soil, water, vegetation, and **climate** of an area, and how they interacted in the past to form the landscape we see today.
pillow basalt	**basaltic lava** that forms in a characteristic "pillow" shape due to its **extrusion** underwater.
placer deposit	a **mineral** deposit occurring in rivers and streams where less **dense** sediment has been carried downstream but denser minerals such as **gold** have been left behind.
placoderms	an **extinct** class of heavily armored fishes. Placoderms lived from the **Silurian** to the **Devonian**.
plate tectonics	the process by which the **plates** of the Earth's **crust** move and interact with one another at their boundaries. The Earth is dynamic, consisting of constantly moving plates that are made of rigid continental and oceanic **lithosphere** overlying a churning, plastically flowing **asthenosphere**. These plates are slowly pulling apart, colliding, or sliding past one another with great force, creating strings of **volcanic islands**, new ocean floor, **earthquakes**, and mountains.
plates	large, rigid pieces of the Earth's **crust** and upper **mantle**, which move and interact with one another at their boundaries. See also: **plate tectonics**
Pleistocene	a subset of the **Quaternary**, lasting from 2.5 million to about 11,700 years ago. During the Pleistocene, continental **ice sheets** advanced south and retreated north several dozen times.
plesiosaur	a member of a group of **extinct**, long-necked, **Mesozoic** marine reptiles.
Pliocene	a **geologic time** interval extending from roughly 5 to 2.5 million years ago. The Pliocene epoch is a subdivision of the **Neogene** period, and is the time period directly preceding the onset of **Pleistocene glaciations**.
pluton, plutonic rock	a body of **intrusive igneous rock** that formed under the Earth's surface through the slow crystallization of **magma**. The term comes from the name of Pluto, Roman god of the underworld.
porosity	the percentage of openings in a body of rock such as pores, **joints**, channels, and other cavities, in which gases or liquids may be trapped or migrate through.

p Glossary

potash	a name used for a variety of **salts** containing potassium, with mined potash being primarily potassium chloride (KCl). The majority of potash is used as fertilizer, but an increasing amount is being used in a variety of other ways: water softening, snow melting, a variety of industrial processes, as a medicine, and to produce potassium carbonate (K_2CO_3).
power (energy)	the rate at which **energy** is transferred, usually measured in **watts** or, less frequently, horsepower.
Precambrian	a **geologic time** interval that spans from the formation of Earth (4.6 billion years ago) to the beginning of the **Cambrian** (541 million years ago). Relatively little is known about this time period since very few **fossils** or unaltered rocks have survived. What few clues exist indicate that life first appeared on the planet as long as 3.9 billion years ago in the form of single-celled organisms. The Precambrian contains the Hadean, **Archean**, and **Proterozoic** eons.
primary energy source	a source of **energy** found in nature that has not been subject to any human-induced energy transfers or transformations (like conversion to electricity). Examples include **fossil fuels**, solar, **wind**, and hydropower.
progradation	outward building of strata toward the sea in the form of a beach, fan, or **delta**, caused by continuous deposition of sediment by rivers, or by the progressive accumulation of material thrown up by waves or other shoreline processes.
Proterozoic	a **geologic time** interval that extends from 2.5 billion to 541 million years ago. It is part of the **Precambrian**. During this eon, the Earth transitioned to an oxygenated **atmosphere** and **eukaryotic** cells, including fungi, plants, and animals, originated.
protists	a diverse group of single-celled **eukaryotes**.
protolith	the original parent rock from which a **metamorphosed** rock is formed.
pterosaurs	**extinct** flying reptiles with wingspans of up to 15 meters (49 feet). They lived during the same time as the **dinosaurs**.
pumice	a **pyroclastic** rock that forms as frothing and sputtering **magmatic** foam cools and solidifies. It is so **vesicular** that it can float. Pumice is a common product of explosive eruptions. Today it is used in a variety of mediums, including construction materials and abrasives.
pyrite	an iron sulfide **mineral** (FeS_2). Pyrite's superficial resemblance to **gold** has led to the common nickname "fool's gold."
pyroclastic rocks	rocks that form during explosive **volcanic** eruptions, and are composed from a variety of different volcanic ejecta. The term comes from Greek, and means "broken fire." Pyroclastic debris of all types is known as **tephra**.
pyroxene	dark-colored, rock-forming **silicate minerals** containing **iron** and magnesium, found in many **igneous** and **metamorphic rocks**. They are often present in **volcanic** rocks.

quartz	the second most abundant **mineral** in the Earth's continental **crust** (after the **feldspars**), made up of **silicon** and oxygen (SiO_2). It makes up more than 10% of the crust by mass. There are a wide variety of types of quartz: onyx, **agate**, and petrified wood are fibrous, microcrystalline varieties collectively known as **chalcedony**. Although agate is naturally banded with layers of different **colors** and porosity, commercial varieties of agate are often artificially colored. **Flint**, **chert**, and **jasper** are granular microcrystalline varieties of quartz, with the bright red color of jasper due to the inclusion of small amounts of iron within the mineral structure. The most common, coarsely crystalline varieties include massive quartz veins, the distinct, well-formed crystals of "rock crystal," and an array of colored quartz, including amethyst (purple), rose quartz (pink), smoky quartz (gray), citrine (orange), and milky quartz (white).
quartzite	a hard **metamorphic rock** that was originally **sandstone**. Quartzite usually forms from sandstone that was metamorphosed through tectonic **compression** within orogenic belts. Quartzite is quarried for use as a building and decorative stone.
Quaternary	a **geologic time** period that extends from 2.6 million years ago to the present. This period is largely defined by the periodic advance and retreat of continental **glaciers**. The Quaternary is part of the **Cenozoic**.
radioactivity	The emission of radiation (**energy**) by an unstable atom.
radiocarbon dating	a method of determining the age of a biological object by measuring the ratio of carbon **isotopes** ^{14}C and ^{12}C. Because the decay rate of ^{14}C is 5000 years, it is useful for numerical dating as far back as 50,000 years. Beyond this point, nearly all of the ^{14}C has decayed.
radon	a naturally occurring **radioactive**, colorless, odorless gas. It is one of the products of decay from the breakdown of radioactive elements in **soil**, rock, and water, released by **weathering**.
rare earth elements	a set of 17 heavy, **lustrous** elements with similar properties, some of which have technological applications. Although they are relatively common in the **crust**, these metals are not usually found concentrated in economically viable **ore** deposits.
recrystallization	the change in structure of **mineral** crystals that make up rocks, or the formation of new mineral crystals within the rock. Recrystallization commonly occurs during **metamorphism**. When rocks are metamorphosed, individual grains that make up the original rock are melted slightly and recrystallize. The pressure allows crystals to grow into a tighter, interlocking arrangement than in an unmetamorphosed rock.
recurrence interval	the time elapsed between major events, such as floods.

Glossary

reef	a feature lying beneath the surface of the water, which is a buildup of sediment or other material built by organisms, and which has positive **relief** from the sea floor. While some reefs result from abiotic processes such as deposition or wave action, the best-known reefs are built by corals and other marine organisms.
regional metamorphism	a **metamorphic rock** that has been altered due to deep burial and great pressure. This type of metamorphic rock tends to occur in long belts at the center of mountain ranges. Different types of metamorphic rock are created depending on the gradients of **heat** and pressure applied.
relief (topography)	the change in elevation over a distance.
renewable energy, renewable resource	**energy** obtained from sources that are virtually inexhaustible (defined in terms of comparison to the lifetime of the Sun) and replenish naturally over small time scales relative to human life spans.
replacement	a **fossilization** method by which the original material is chemically replaced by a more stable **mineral**.
residual weathering deposit	a **mineral** deposit formed through the concentration of a **weathering**-resistant mineral, in which the other minerals around it have been **eroded** away.
rhyolite, rhyolitic	a **felsic volcanic** rock high in abundance of **quartz** and **feldspar**.
rift	a break or crack in the **crust** that can be caused by tensional stress as a landmass breaks apart into separate **plates**.
rift basin	a **topographic** depression caused by **subsidence** within a **rift**; the basin, since it is at a relatively low evelation, usually contains freshwater bodies such as rivers and lakes.
ripple marks	surface features created when sediment deposits are agitated, typically by water currents or **wind**. The crests and troughs formed by this agitation are occasionally **lithified** and preserved, providing information about the flow of water or wind in the paleoenvironment.
rock flour	very fine sediments and **clay** resulting from the grinding action of **glaciers**.
Rodinia	a supercontinent that contained most or all of Earth's landmass, between 1.1 billion and 750 million years ago, during the **Precambrian**. Geologists are not sure of the exact size and shape of Rodinia. It was analagous to but not the same supercontinent as **Pangaea**, which formed was assembled several hundred million years later during the **Permian**.
rugose coral	an **extinct** group of corals that were prevalent from the **Ordovician** through the **Permian**. Solitary forms were most common; these were horn-shaped, leading to their common name, "horn corals."
rutile	a typically reddish brown **mineral** formed of TiO_2. It is an **ore** of **titanium**.
salt	a **mineral** composed primarily of sodium chloride (NaCl). In its natural form, it is called "rock salt" or "halite." Salt is essential for animal life, and is a necessary part of the diet. In addition, salt is used for de-icing roads in winter and is also an important part of the chemical industry.

salt dome	a largely subsurface geologic structure, consisting of a vertical cylinder of **salt** embedded in horizontal or inclined **sedimentary** strata. Salt buried under thousands of feet of overlying sediment often deforms plastically. Because it is less **dense** than the rocks above it, it flows upward toward areas of lower pressure, forming geological structures named for their shapes (e.g., domes, canopies, tables, and lenses).
salt lick	a naturally occurring **salt** deposit that animals regularly lick, providing the sodium, calcium, **iron**, phosphorus, and **zinc** required for bone, muscle, and other growth.
sand	rock material in the form of loose, rounded, or angular grains, and formed as a result of the **weathering** and decomposition of rocks. Particles of sand are between 0.05 and 2 millimeters (0.00016 and 0.0065 inches) in diameter.
sandstone	**sedimentary rock** formed by cementing together grains of **sand**.
schist	a medium-grade **metamorphic rock** with sheet-like crystals flattened in one plane. The flattened crystals are often muscovite or biotite **mica**, but they can also be **talc**, **graphite**, or **hornblende**.
scleractinian coral	a modern "stony" coral; a colonial or solitary marine invertebrate animal belonging to the Order Scleractinia in the Class Anthozoa of the Phylum Cnidaria, and characterized by an encrusting calcareous skeleton from which multiple individuals (polyps) extend from small pores to capture prey with small tentacles equipped with stinging cells (nematocysts). Although scleractinians look somewhat similar to extinct **rugose** and **tabulate corals**, each group possesses distinctive features in the shape of the skeletal cup holding the individual polyps. Modern scleractinians host commensal algae (zooxanthellae) whose photosynthetic activities supply the coral with energy.
scoria	a highly **vesicular** form of **basalt**. It tends to form as **cinders** in the early stages of a **volcanic** eruption, when gas bubbles are still caught up in the frothy, erupting **magma**. Once the gas has escaped, the remaining magma can flow out, creating basalt **lava** flows that spread out over the landscape.
scour, scouring	**erosion** resulting from **glacial** abrasion on the landscape.
sedimentary rocks	rocks formed through the accumulation and consolidation of grains of broken rock, crystals, skeletal fragments, and organic matter. Sediment that forms from **weathering** is transported by **wind** or water to a depositional environment such as a lakebed or ocean floor; here they build up, burying and compacting lower layers. As water permeates the sediment, dissolved **minerals** may precipitate out, filling the spaces between particles and **cementing** them together. Sedimentary rocks may also accrete from fragments of the shells or skeletal material of marine organisms such as clams and coral. Sedimentary rocks are classified by their sediment size or their mineral content. Each one reveals the story of the depositional environment where its sediments accumulated and the history of its **lithification**.
seismic waves	the shock waves or vibrations radiating in all directions from the center of an **earthquake** or other tectonic event.

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seismic zone	a regional zone that encompasses areas prone to seismic hazards, such as **earthquakes** or **landslides**.
serpentinite	a **metamorphic rock** formed when **peridotite** from a **subducting plate** reacts with water, producing a light, slippery, green rock.
sessile	unable to move, as in an organism that is permanently attached to its substrate.
shale	a dark, fine-grained, laminated **sedimentary rock** formed by the **compression** of successive layers of **silt**- and **clay**-rich sediment. Shale is weak and often breaks along thin layers. Shale that is especially rich in unoxidized carbon is dark grey or black. These organic-rich black shales are often source rocks for **petroleum** and **natural gas**.
shark	a large fish characterized by a cartilaginous skeleton and five to seven gill slits on the side of the head. Sharks first appeared 420 million years ago, and have since diversified to over 470 species.
shearing, shear	the process by which **compressive** stress causes the **fracturing** and **faulting** of brittle rocks.
silica, silicon, silicate	a chemical compound also known as silicon dioxide (SiO_2). Silica is most commonly found as **quartz**, and is also secreted as skeletal material in various organisms. It is one of the most abundant materials in the **crust**.
siliciclastic	pertaining to rocks that are mostly or entirely made of silicon-bearing clastic grains such as **quartz**, **feldspar**, and **clays** that were **weathered** from **silicate** rocks.
silt	granular sediment most commonly composed of **quartz** and **feldspar** crystals. Particles of silt have diameters of less than 0.074 millimeters.
Silurian	a **geologic time** period spanning from 443 to 419 million years ago. During the Silurian, jawed and bony fish diversified, and life first began to appear on land. The Silurian is part of the **Paleozoic**.
silver	a metallic chemical element (Ag). Silver is used in photographic film emulsions, utensils and other tableware, and electronic equipment.
sirenian	a sea cow, including dugongs and manatees. These aquatic herbivorous mammals live in various nearshore and freshwater habitats. Sirenians appeared during the **Eocene** epoch.
slate	a fine-grained, **foliated metamorphic rock** derived from a **shale** composed of **volcanic ash** or **clay**.
slump	a slow-moving **landslide** in which loosely consolidated rock or **soil** layers move a short distance down a slope. See also: **mass wasting**
snail	See **gastropod**

soapstone	a **metamorphic schist**ose rock composed mostly of **talc**. Soapstone has a flaky texture and a greasy or soapy feel, and is an effective medium for carving.
soil	the collection of natural materials that collect on Earth's surface above the bedrock. Soil consists of layers (**horizons**) of two key ingredients: plant litter, such as dead grasses, leaves, and fallen debris, and sediment derived from the **weathering** of rock. Each of these components can influence the texture and consistency of the soil, as well as the **minerals** available for consumption by plants. The word is derived from the Latin *solum*, which means "floor" or "ground."
soil orders	the twelve major units of **soil taxonomy**, which are defined by diagnostic horizons, composition, soil structures, and other characteristics. Soil orders depend mainly on **climate** and the organisms within the soil. These orders are further broken down into 64 suborders based on properties that influence soil development and plant growth, with the most important property being how wet the soil is throughout the year.
soil taxonomy	the system used to classify **soils** based on their properties.
solution mining	the extraction of soluble **minerals** from subsurface strata by the injection of fluids, and the controlled removal of mineral-laden solutions.
sphalerite	**zinc sulfide** (ZnS), the chief **ore mineral** of zinc.
sphenopsid	a terrestrial plant belonging to the Family Equisetaceae in the plant division Pteridophyta, and characterized by hollow, jointed stems with reduced, unbranched leaves at the nodes. Sphenopsids, or horsetails, reached over 33 feet (10 meters) high during the **Pennsylvanian**.
Spodosols	a **soil order**; these are acidic **soils** in which **aluminum** and **iron oxides** accumulate below the surface. They typically form under pine vegetation and sandy parent material.
spodumene	a translucent **pyroxene mineral** (lithium aluminum inosilicate) occurring in prismatic crystals, and a primary source of **lithium**. Some varieties of spodumene are also prized as **gems**.
sponge	a marine invertebrate belonging to the Phylum Porifera, and characterized by a soft shape with many pores and channels for water flow. Because they have no nervous, digestive, or circulatory systems, some consider them to be colonies of specialized single cells. Sponges come in a variety of shapes and body forms, and have been around at least since the **Cambrian**. Entire sponges are rarely preserved, but their tiny skeletal pieces (spicules) are common in **sedimentary rocks**. See also: **archaeocyathid**
stratigraphy, stratigraphic	the branch of geology specifically concerned with the arrangement and age of rock units. See also: **Law of Superposition**

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stratovolcano	a conical volcano made up of many **lava** flows as well as layers of **volcanic ash** and **breccia** from explosive eruptions. Stratovolcanoes are often characterized by their periodic violent eruptions, which occur due to their presence at **subduction** zones. While young stratovolcanoes tend to have steep cone shapes, the symmetrical conical shape is readily disfigured by massive eruptions. Many older stratovolcanoes contain collapsed craters called **calderas**.
streak	a physical property of **minerals**, obtained by dragging the mineral across a porcelain plate and effectively powdering it. During identification, the color of the powder eliminates the conflating variables of external **weathering**, **crystal form**, or impurities.
stromatoporoid	a type of calcareous **sponge** that acted as an important **reef**-builder throughout the **Paleozoic** and the late **Mesozoic**.
subduction	the process by which one **plate** moves under another, sinking into the **mantle**. This usually occurs at **convergent plate boundaries**. **Denser** plates are more likely to subduct under more buoyant plates, as when oceanic **crust** sinks beneath continental crust.
subsidence	the sinking of an area of the land surface.
subsoil	the layer of **soil** beneath the **topsoil**, composed of **sand**, **silt**, and/or **clay**. Subsoil lacks the organic matter and **humus** content of topsoil.
sulfur, sulfate	a bright yellow chemical element (S) that is essential to life. It acts as an **oxidizing** or reducing agent, and occurs commonly in raw form as well as in **minerals**.
sustainable	able to be maintained at a steady level without exhausting natural resources or causing severe ecological damage, as in a behavior or practice.
suture	the area where two continental **plates** have joined together through continental collision. See also: **convergent boundary**, **plate tectonics**
system	a set of connected things or parts forming a complex whole—in particular, a set of things working together as parts of a mechanism or an interconnecting network.
tabulate coral	an **extinct** form of colonial coral that often formed honeycomb-shaped colonies of hexagonal cells.
Taconic Orogeny	a late **Ordovician** mountain-building event involving the collision and **accretion** of a **volcanic island** arc along the eastern coast of North America, from New England to eastern Canada. Sediments **eroded** from the resulting mountains accumulated in thick strata, the Queenston Delta, in the **Appalachian Basin** from New York to Quebec. See also: **orogeny**
talc	hydrated magnesium silicate, formed during **hydrothermal** alteration accompanying **metamorphism**. Talc can be formed from **calcite**, **dolomite**, **silica**, and some **ultramafic** rocks.
tektite	**gravel**-sized glass formed when melted rock from the Earth's surface is ejected during **meteorite** impacts. Tektites differ chemically and texturally from **volcanic** glass.

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tephra	fragmented material produced by a **volcanic** eruption. Airborne tephra fragments are called **pyroclastic**.
terrace	a flat or gently sloped embankment or ridge occurring on a hillside, and often along the margin of (or slightly above) a body of water, representing a previous water level.
terrane	a piece of **crustal** material that has broken off from its parent continent and become attached to another **plate**. Due to their disparate origins, terranes have distinctly different geologic characteristics than the surrounding rocks. Florida is a good example of an exotic terrane, originating as part of the supercontinent **Gondwana**. Parts of the western coast of North America (including Alaska and the Northeastern US) are also terranes that have been **sutured** onto the coast.
Tertiary	an unoffical but still commonly used term for the time period spanning from 66 million to 2.5 million years ago, including the **Paleogene**, **Neogene**, and part of the **Pleistocene**. Although the Tertiary period was officially phased out in 2008 by the International Commission on Stratigraphy, it can still be found in scientific literature. (In contrast, the **Carboniferous** and **Pennsylvanian** & **Mississippian** periods all enjoy official status, with the latter pair being more commonly used in the US.)
thorium	a **radioactive** rare earth element, with potential applications in next-generation **nuclear** reactors that could be safer and more environmentally friendly than current uranium reactors.
till	unconsolidated sediment that is **eroded** from the bedrock, then carried and eventually deposited by **glaciers** as they recede. Till may include a mixture of **clay**, **sand**, **gravel**, and even boulders. The term originated with farmers living in glaciated areas who were constantly removing rocks from their fields while breaking the **soil** for planting, a process known as tilling.
titanium	a metallic chemical element (Ti). Titanium is important because of its lightweight nature, strength, and resistance to corrosion.
topographic inversion	a landscape with features that have reversed their elevation relative to other features, most often occurring when low areas become filled with **lava** or sediment that hardens into material more resistant to **erosion** than the material that surrounds it.
topography	the landscape of an area, including the presence or absence of hills and the slopes between high and low areas. These changes in elevation over a particular area are generally the result of a combination of deposition, **erosion**, **uplift**, and subsidence. These processes that can happen over an enormous range of timescales.
topsoil	the surface or upper layer of **soil**, as distinct from the subsoil, and usually containing organic matter.
tornado	a vertical funnel-shaped storm with a visible horizontal rotation. The word tornado has its roots in the Spanish word *tonar*, which means "to turn."
trace fossils	**fossils** that record the actions of organisms, such as footprints, trails, **trackways**, and burrows. Trace fossils cannot always be associated at least with a group of organisms or way of life. The first trace fossils appear a couple hundred million years before the first animal (**body**) fossils.

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trackway	a set of impressions in soft sediment, usually a set of footprints, left by an animal. Trackways preserved as **fossils** are known as **trace fossils**.
transform boundary	an **active plate boundary** in which the **lithospheric plates** move sideways past one another.
transgression	a relative rise in sea level in a particular area, through global sea level rise or **subsidence** of land.
tree	any woody **perennial** plant with a central trunk. Not all trees are closely related; different kinds of plants have evolved the tree form through geological time. The trees of the **Paleozoic** were more closely related to club mosses or ferns than they were to today's trees.
trellis drainage	a drainage pattern in which roughly parallel main streams are intersected by tributaries that are at nearly right angles. The name refers to the similarity of the pattern to a garden trellis, or the vines that grow along it.
Triassic	a **geologic time** period that spans from 252 to 201 million years ago. During this period, **dinosaurs**, **pterosaurs**, and the first mammals appear and begin to diversify. The Triassic begins directly after the **Permian**-Triassic mass extinction event, and is the first period of the **Mesozoic**.
trilobite	an extinct marine invertebrate animal belonging to the Class Trilobita of the Phylum Arthropoda, and characterized by a three-part body and a chitinous exoskeleton divided longitudinally into three lobes. Trilobites have been extinct since the end of the **Paleozoic**. Trilobites were primitive **arthropods** distantly related to horseshoe crabs. As bottom dwellers, they were present in a variety of environments. Like crabs and lobsters, trilobites molted their exoskeletons when they grew. Most fossils of trilobites are actually molts, broken as they were shed off the trilobite. Thus, it is common to find only parts of trilobites, such as the head, mid-section, or tail.
tropical depression	an organized, rotating system of clouds and thunderstorms. A tropical storm has wind speeds of less than 63 kilometers per hour (39 miles per hour). It has no eye, and lacks the shape and organization of a more powerful **hurricane**.
tsunami	a series of ocean waves that are generated by sudden displacement of water, usually caused by an **earthquake**, **landslide**, or **volcanic** explosions (but also from other sources such as meteor impacts, **nuclear** explosions, and **glacier calving**). Unlike a wind-generated sea wave, a tsunami wave has an extremely long wavelength. A very large wind wave could have a wavelength of 200 meters (650 feet), while a typical tsunami has a wavelength of 200 kilometers (120 miles). Tsunamis can travel at 800 kilometers per hour (500 miles per hour) in the open ocean. While at sea, a tsunami has a long wavelength, but a small wave height—ships in the open ocean may never notice the passing of a tsunami wave. As the wave approaches shore, however, the wavelength decreases and the wave height (amplitude) increases.

tuff	a **pyroclastic** rock made of consolidated **volcanic ash**. Tuff is the result of pyroclastic flows, in which the violent expansion of hot gas shreds the erupting **magma** into tiny particles that cool in the air to form dense clouds of volcanic ash. The tremendous explosions that are necessary to create ash-flow tuffs are caused by **rhyolitic** magma, which is **felsic**. High **silica** content makes the magma quite viscous, preventing gas bubbles from easily escaping, thus leading to pressure buildups that are released by explosive eruptions. The ash flows from these violent explosions tend to hug the ground, eventually solidifying into tuffs. Tuffs and other pyroclastic materials are **vesicular** (**porous**) due to gases expanding within the material as it cools.
turbidity current	a submarine sediment avalanche. These fast-moving currents of sediment are often caused by **earthquakes** or other geological disturbances that loosen sediment on a continental shelf. These massive sediment flows have extreme **erosive** potential, and often carve out underwater canyons. Turbidity currents deposit huge amounts of sediment during flow; such deposits are called turbidites. Because of the rate at which turbidity currents deposit **dense** sediments, they are often responsible for the effective preservation of many **fossil** organisms, which are swept up from shallow marine environments and buried in the deep sea.
Ultisols	a **soil order**; these are **soils** with subsurface **clay** accumulations that possess low native fertility and are often red hued (due to the presence of **iron oxides**). They are found in humid tropical and subtropical **climates**.
ultramafic rocks	**igneous rocks** with very low **silica** content (< 45%), which are composed of usually greater than 90% **mafic minerals**. The Earth's **mantle** is composed of ultramafic rocks, which are dark green to black in **color** due to their high magnesium and **iron** content.
unconformity	the relation between adjacent rock strata for which the time of deposition was separated by a period of nondeposition or **erosion**; a break in a **stratigraphic** sequence.
uplift	upward movement of the **crust** due to **compression**, **subduction**, or mountain building. Uplift can also occur as a rebounding effect after the removal of an **ice sheet** reduces the amount of weight pressing on the crust.
Vertisols	a **soil order**; these are **clayey soils** with a high moisture capacity. During dry periods, these soils shrink and develop wide cracks; during wet periods, they swell with moisture.
vesicular	porous or pitted with vesicles (cavities). Some **extrusive igneous rocks** have a vesicular texture.
volcanic ash	fine, unconsolidated **pyroclastic** grains under 2 millimeters (0.08 inches) in diameter. Consolidated ash becomes **tuff**.
volcanic islands	a string of islands created when molten rock rises upward through oceanic **crust**. Volcanic islands are common in several contexts, including at **subduction zones** between colliding oceanic **plates**, above oceanic **hot spots**, and along mid-ocean ridges. At subduction zones, the friction between the plates generates enough **heat** and pressure to melt some of the crust. In the case of hot spots, islands form as **magma** from the mantle breaks through the sea floor.

v–z Glossary

volcanic, volcanism	the eruption of molten rock onto the surface of the **crust**. Most volcanic eruptions occur along tectonic **plate** boundaries, but may also occur at **hot spots**. Rocks that form from molten rock on the surface are also called volcanic. Prior to eruption, **magma** ascends from the **mantle** to a relatively shallow (1–10 kilometers / 0.5–6 miles) magma chamber. Upward movement reduces the pressure on the magma until it is low enough to permit dissolved gas to **exsolve** (come out of solution and form bubbles). All eruptions are driven by the exsolution of dissolved gas. As the gas forms bubbles, it expands in volume and forces the magma out of the vent/chamber system onto the surface. The combination of magma viscosity and gas content can produce a range of eruptive styles, from gentle, effusive eruptions to violent explosions.
water table	the upper surface of groundwater, that is, the underground level at which groundwater is accessible.
watershed	an area of land from which all water under or on it drains to the same location.
waterspout	a spinning, funnel-shaped cloud over a body of water. "Tornadic" waterspouts are simply **tornados** that originated on land during severe thunderstorms and and moved over water. "Fair weather" waterspouts develop near the surface of the water and grow upward; they form in low **wind** conditions and may move little, but do become tornados if they move to land.
watt	a unit of **power** measuring the rate of **energy** conversion or transfer designated by the International System of Units as one **joule** per second.
weather	the measure of short-term conditions of the **atmosphere** such as temperature, **wind** speed, and humidity. These conditions vary with the time of day, the season, and yearly or multi-year cycles.
weathering	the breakdown of rocks by physical or chemical means. Rocks are constantly being worn down and broken apart into finer and finer grains by **wind**, rivers, wave action, freezing and thawing, and chemical breakdown. Over millions of years, weathering and **erosion** can reduce a mighty mountain range to low rolling hills. Some rocks wear down relatively quickly, while others can withstand the power of erosion for much longer. Softer, weaker rocks such as **shale** and poorly cemented **sandstone** and **limestone** are much more easily worn away than hard, crystalline **igneous** and **metamorphic rocks**, or well-**cemented** sandstone and limestone. Harder rocks are often left standing alone as ridges because surrounding softer, less resistant rocks were more quickly worn away.
wind	the movement of air from areas of high pressure to areas of low pressure. The greater the temperature difference, the greater the air pressure difference and, consequently, the greater the speed at which the air will move.
wind shear	when **wind** speed and/or direction changes with increasing height in the atmosphere. Wind shear can happen when a **cold front** moves rapidly into an area with very warm air. There, the condensing water droplets mix with the cooler, drier air in the upper **atmosphere** to cause a downdraft.
zinc	a metallic chemical element (Zn). Zinc is typically used in metal alloys and galvanized steel.

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On the Earth System Science of North America

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American Geophysical Union, http://agu.org.
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Geological Society of America, http://geosociety.org.
Natural Resources Conservation Service, http://www.nrcs.usda.gov/wps/portal/nrcs/site/national/home/. (NRCS helps US farmers, ranchers and forest landowners conserve soil, water, air and other natural resources.)
Paleontological Research Institution, http://priweb.org. (Publisher of this series.)
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General Earth Science Education Resources

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Resources for Earth Science and Geography Instruction, by Mike Francek, Central Michigan University, http://webs.cmich.edu/resgi/.
Science in Your Backyard, US Geological Survey, http://www.usgs.gov/state/. (State-by-state compilation of Earth science-related data, most of which will need to be adapted for education uses.)
SERC (The Science Education Resource Center) K-12 resources, http://serc.carleton.edu/k12/ index.html. (Hundreds of classroom activities organized by grade level and topic as well as guidance on effective teaching.)
SERC Earth Exploration Toolbook, http://serc.carleton.edu/eet/index.html. (A collection of online Earth system science activities introducing scientific data sets and analysis tools.)
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The Best of Geology and Earth Science on the Web: The Latest from the Blogosphere, http://all-geo.org/.
Geobulletin: News from the Geoblogosphere, by stratigraphy.net, http://www.geobulletin.org/?action=news.
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Sedimentary Environments Box: Jim Houghton

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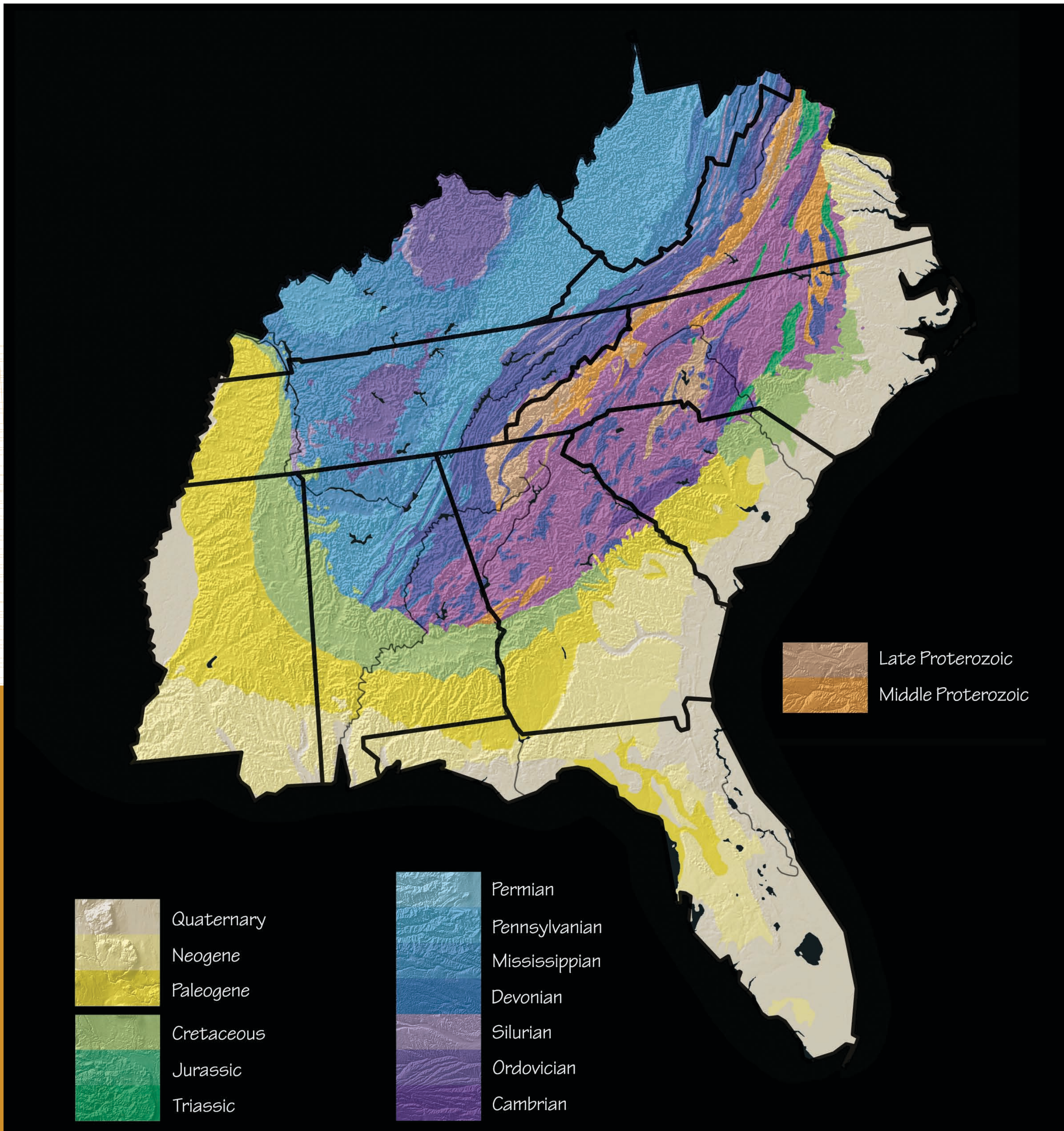
Chapter 10: Fieldwork

10.1–10.2: PRI
10.3: Don Duggan-Haas

Appendix

A.1–A.3: Next Generation Science Standards



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