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

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**Igneous Rocks of the Southeast**
- anorthosite
- basalt
- diabase
- diorite
- feldspar
- gabbro
- granite
- pegmatite
- peridotite
- rhyolite

**Unconsolidated Sediments of the Southeast**
- clay
- gravel
- sand
- silt
- mud

**Sedimentary Rocks of the Southeast**
- chalk
- conglomerate
- dolostone
- marl
- siltstone
- chert
- coquina
- limestone
- sandstone
- shale

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

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

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**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.

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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

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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.

<table>
<thead>
<tr>
<th>Sediment size</th>
<th>Sedimentary rock</th>
<th>Environment of deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>gravel</td>
<td>conglomerate</td>
<td>river beds, mountains</td>
</tr>
<tr>
<td>sand</td>
<td>sandstone</td>
<td>beaches, river sand bars, sand dunes</td>
</tr>
<tr>
<td>sand, silt, clay</td>
<td>greywacke</td>
<td>continental shelf</td>
</tr>
<tr>
<td>silt</td>
<td>siltstone</td>
<td>quiet water</td>
</tr>
<tr>
<td>clay</td>
<td>shale</td>
<td>very quiet water, lakes, swamps, shallow oceans</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mineral Content</th>
<th>Sedimentary rock</th>
<th>Environment of deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>calcium carbonate skeletons of marine organisms</td>
<td>limestone</td>
<td>tropical reefs, beaches, warm shallow seas</td>
</tr>
<tr>
<td>precipitated calcium carbonate</td>
<td>travertine, tufa</td>
<td>hot springs, playas (dry lake beds), drying seas</td>
</tr>
<tr>
<td>gypsum</td>
<td>rock gypsum</td>
<td>playas, drying seas</td>
</tr>
<tr>
<td>halite</td>
<td>rock salt</td>
<td>playas, drying seas</td>
</tr>
</tbody>
</table>
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

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### 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**.

<table>
<thead>
<tr>
<th>Crystal size</th>
<th>Felsic</th>
<th>Intermediate</th>
<th>Mafic</th>
<th>Ultramafic</th>
</tr>
</thead>
<tbody>
<tr>
<td>large (plutonic)</td>
<td>granite</td>
<td>diorite</td>
<td>gabbro</td>
<td>peridotite</td>
</tr>
<tr>
<td>small (volcanic)</td>
<td>rhyolite</td>
<td>andesite</td>
<td>basalt</td>
<td>--</td>
</tr>
<tr>
<td>none (glassy)</td>
<td>obsidian, tuff, pumice</td>
<td>obsidian</td>
<td>obsidian</td>
<td>--</td>
</tr>
</tbody>
</table>

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**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 CaCO₃, 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 (CaCO₃).

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

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

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.

**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.

<table>
<thead>
<tr>
<th>Parent Rock</th>
<th>Metamorphic Rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>shale</td>
<td>slate, phylite, schist, gneiss</td>
</tr>
<tr>
<td></td>
<td>(in order of increasing heat and pressure)</td>
</tr>
<tr>
<td>granite</td>
<td>gneiss</td>
</tr>
<tr>
<td>sandstone</td>
<td>quartzite</td>
</tr>
<tr>
<td>limestone</td>
<td>marble</td>
</tr>
<tr>
<td>peridotite</td>
<td>serpentine</td>
</tr>
</tbody>
</table>

**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.
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.*
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, thrust 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.
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.
Rocks

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.

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 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.**

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.
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.
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.

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

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

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 be 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.
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*).

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.

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

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).

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.

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

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.
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.
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,
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.
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.

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
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).

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.
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

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.

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,
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.

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.

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.

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.
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.
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.
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.

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

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.

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 westwards-spreadign 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.

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.

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 cyclothsems: 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 cyclothsems 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.
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.
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.

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.
Region 2

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

1 - JEPHTA KNOB
2 - VERSAILLES
3 - MIDDLESBORO BASIN
4 - WELLS CREEK BASIN
5 - DYCUS STRUCTURE
6 - FLYNN CREEK STRUCTURE
7 - HOWELL STRUCTURE
8 - WETUMPKA
9 - CHESAPEAKE BAY IMPACT CRATER

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 Pangae 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).

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.
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.

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.**

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.
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.)
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).

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.
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. 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
Rocks

Region 3

**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.

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

**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.**

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.

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.
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 "georgiates," and they have modest value as collectibles.

Tektites, natural glass formed when melted rock from the Earth's surface is ejected during meteorite impacts.

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.
State Rocks, Minerals, and Gems

**Alabama**
State rock: marble
Also known as Sylacauga 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.
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]).
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: Lithostrotonella (chalcedony)
Lithostrotonella 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.
Resources

Books


Websites


Rock and Mineral Field Guides


Rocks of the Southeast

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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