Chapter 2: Rocks of the Southeastern US

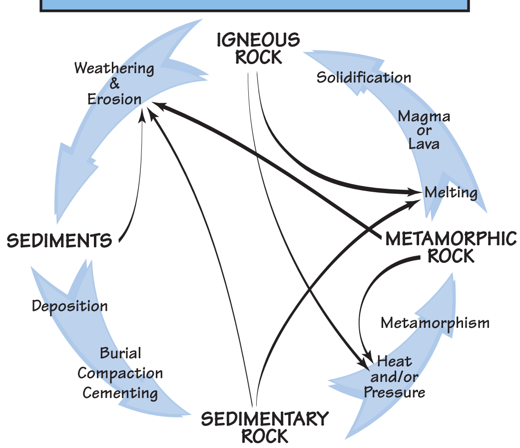
The amazing diversity of rocks in the Southeast records over a billion years of history—from 1.8-billion-year-old **Precambrian gneisses** to sedimentary deposits from the most recent **ice age**. Colliding **plates**, **rifting**, **inland seas**, deposition, **erosion**, igneous and metamorphic activity, 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.*

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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.*

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

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

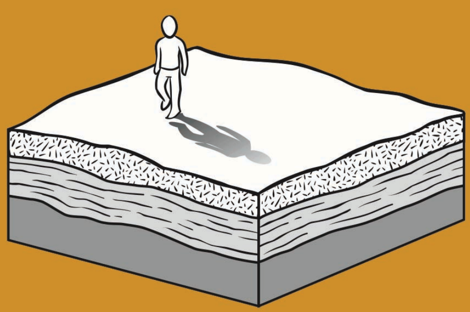
Metamorphic rocks are classified differently depending on the *protolith* (parent rock) they are made from. The following chart shows common rocks and the metamorphic rocks that they can become.

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

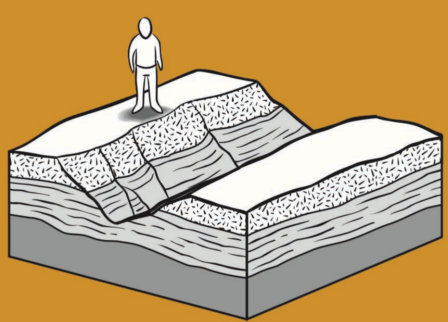
As you read through this chapter, keep in mind that once you understand the geologic events that have affected a given region, you should be able to predict the type of rocks found in that area. For example, when plates collide, compression and friction melt the **crust**. The rising magma forms igneous **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?

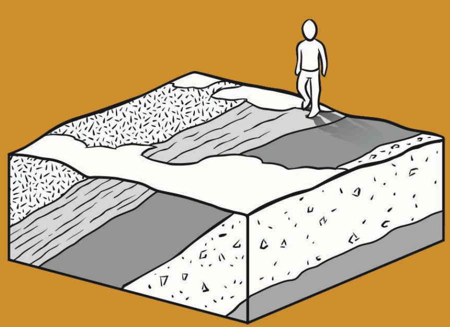
As you walk across the surface of the Earth, you will observe an amazing variety of rock types. If all rocks were flat-lying layers and there was no erosion, then we would only see one type of rock exposed on the surface. Often, however, rocks have been worn away (eroded), and the underlying layers are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

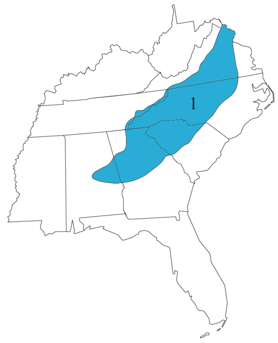
physiography • *a subfield of geography that studies the Earth's physical processes and patterns.*

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.

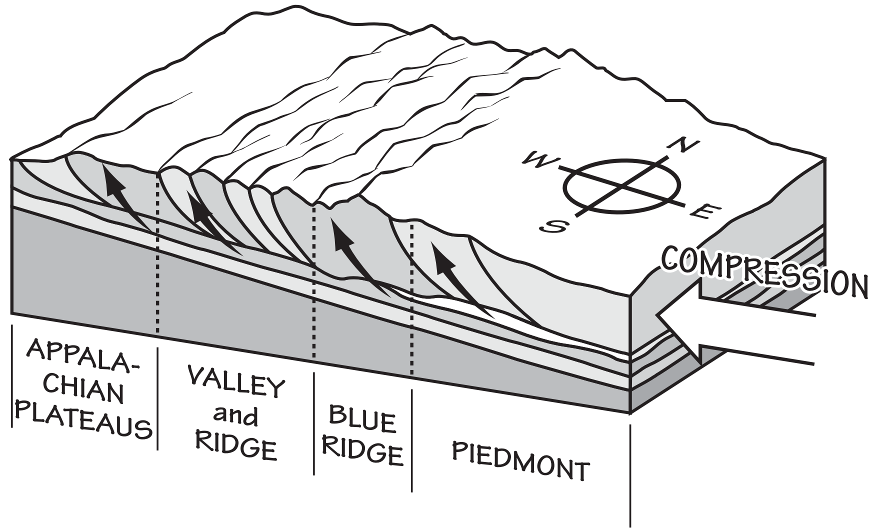


Figure 2.2: The crust of the Blue Ridge and Piedmont was "telescoped" by the compressional forces of Paleozoic mountain building. Slices of crust were thrust over top of each other, stacking like a deck of cards.

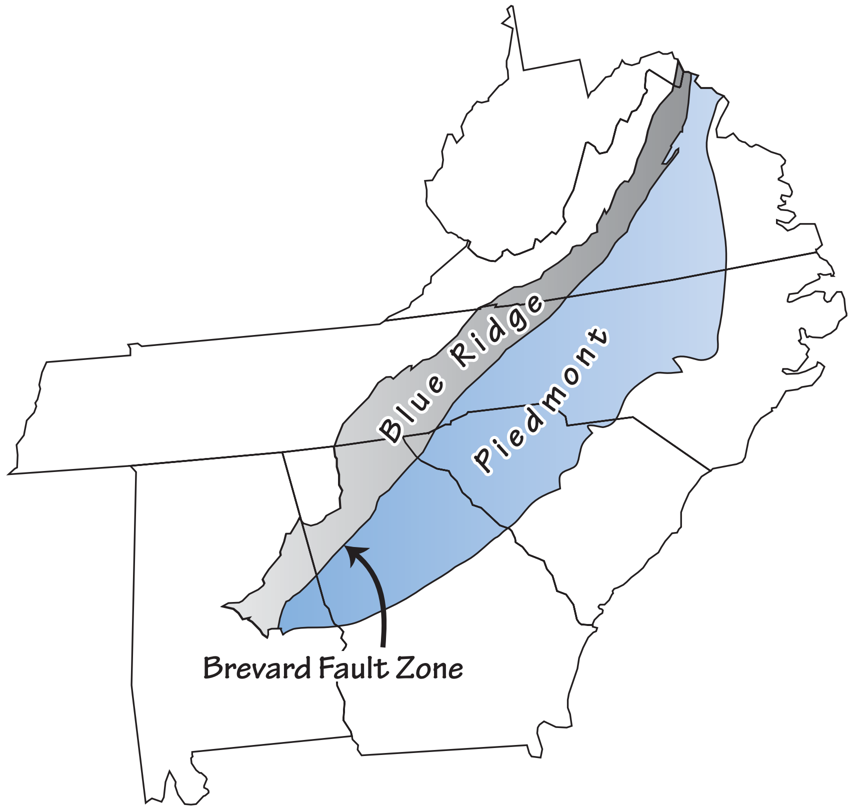


Figure 2.3: The Blue Ridge and Piedmont physiographic regions, as divided by the Brevard Fault Zone.

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.

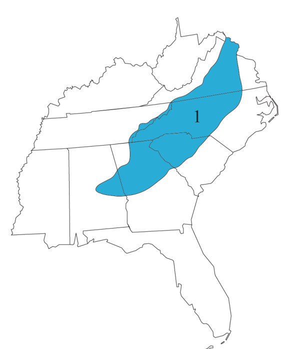
Region 1

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

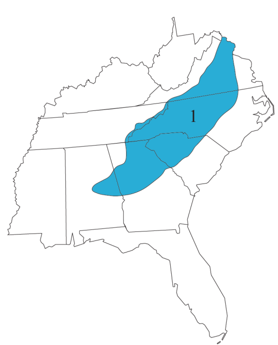
Grenville Orogeny • *a mountain-building event, about 1.3 to 1 billion years ago, that played a role in the formation of the supercontinent Rodinia.*

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.

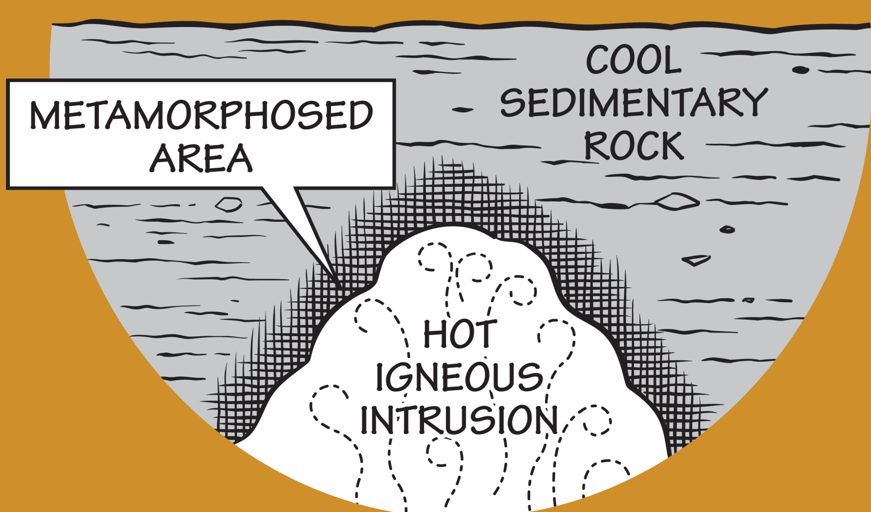
During the Grenville Orogeny, friction between the converging plates pushed magma into the overlying crust. Some magma rose high enough to intrude through the overlying sedimentary rocks, but it remained well below the surface. These amorphous intrusions eventually cooled and crystallized (*Figure 2.4*), 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.

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.



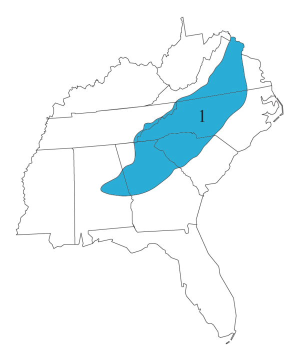
Regional or *dynamic metamorphism* describes a metamorphic rock that has been altered due to deep burial and great pressure. This type of metamorphic rock tends to occur in long belts. Different types of metamorphic rock are created depending on the gradients of heat and pressure applied.

Region 1

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).*

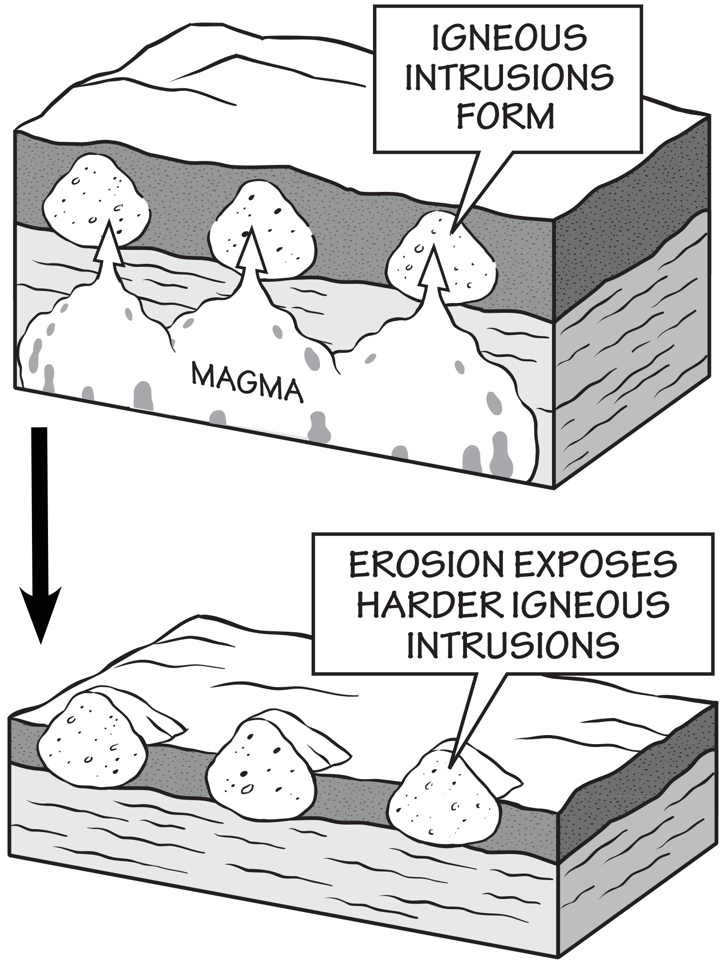


Figure 2.4: Igneous intrusions form when cooling magma is trapped beneath the surface. These rocks, which are more resistant than the surrounding material, can later be exposed at the surface through the process of erosion.

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

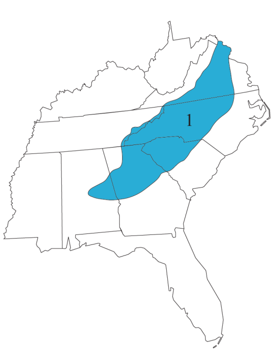
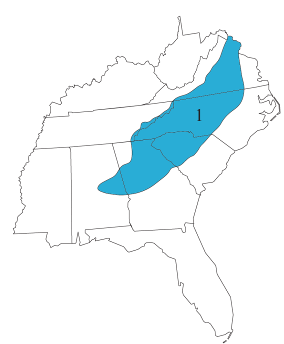


Figure 2.5: The Blowing Rock, an immense 1.05-billion-year-old cliff of gneiss that stands 1200 meters (4000 feet) above sea level in the Blue Ridge Mountains of North Carolina. The rock was named for an updraft of air funneled toward the cliff by the Johns River Gorge below.

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.



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.

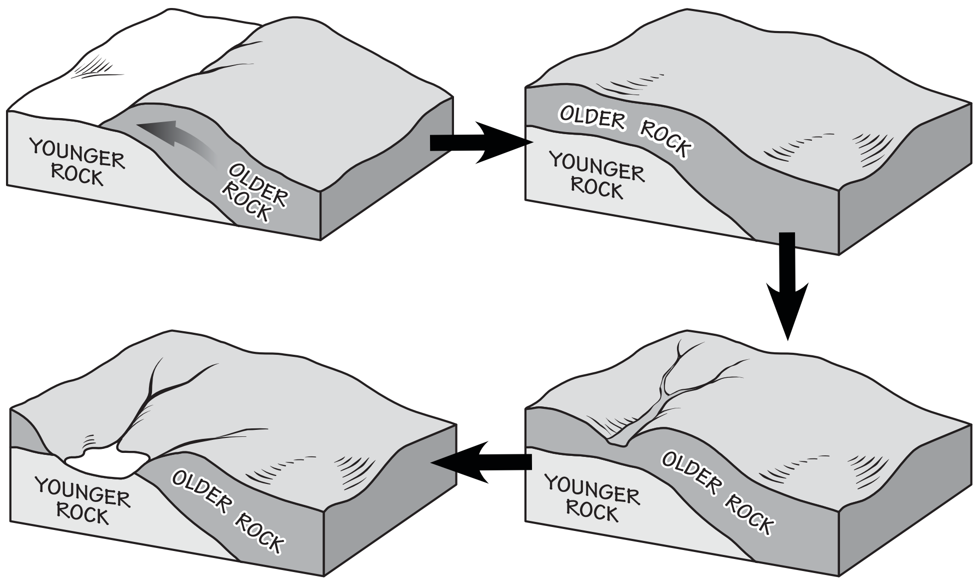


Figure 2.7: The development stages of a window. Older rock is thrust over younger rock. Erosion begins through the older rock, eventually exposing the underlying younger rock.

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*).

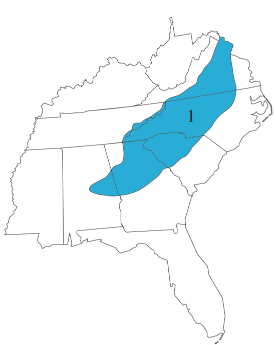
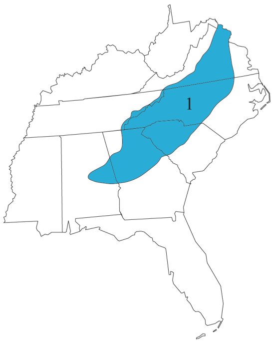


Figure 2.8: The surface of Split Rock, a large weathered boulder at Grandfather Mountain, reveals large pebbles typical of meta-conglomerates.

Figure 2.9: Outstanding geologic windows of the Southeast.



Region 1

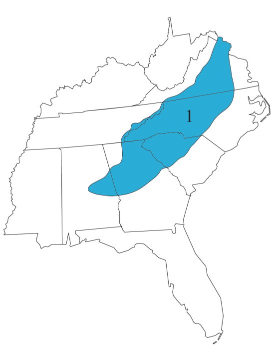
Iapetus Ocean *• the proto-Atlantic Ocean, located against the eastern coast of North America's ancestral landmass before Pangaea formed.*

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.*



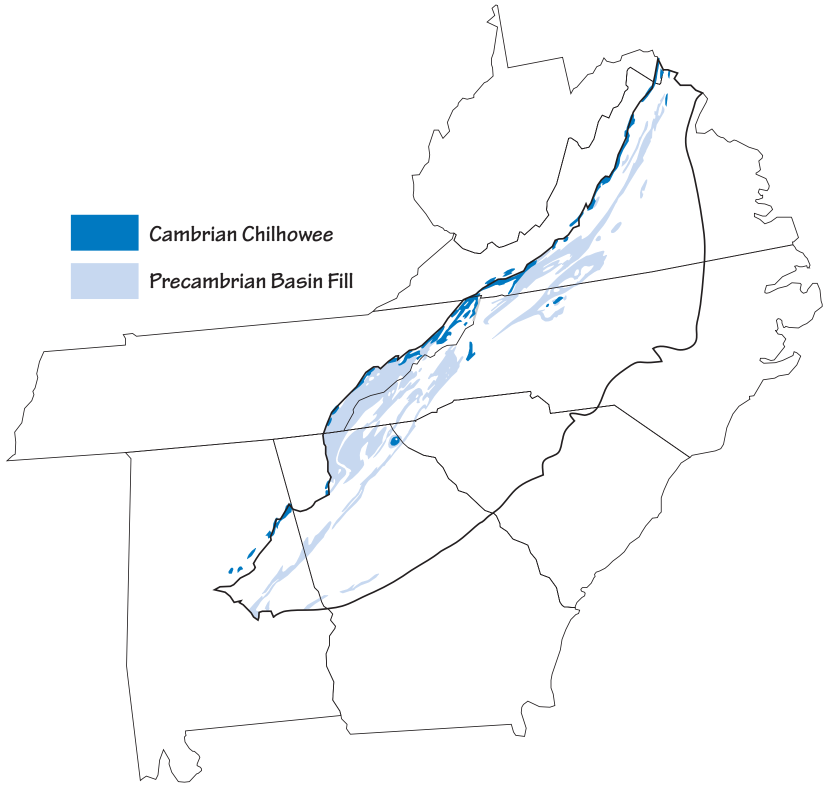


Figure 2.10: Late Precambrian and early Cambrian (Chilhowee Group) rocks of the Blue Ridge and Piedmont region.

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*).

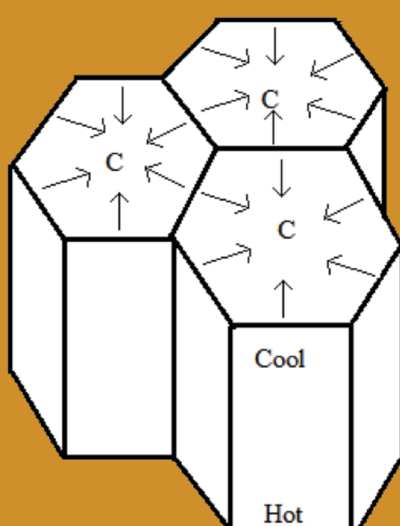
Mt. Rogers is named after William Barton Rogers, Virginia's first state geologist, who was famous for his studies of Appalachian Mountain geology.

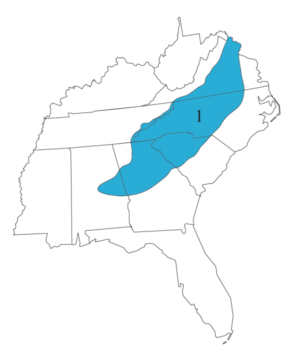
At Mt. Rogers in southwestern Virginia, there is evidence of an explosive rift-related Precambrian volcano that formed around 750 million years ago. The lava from this volcano eventually cooled

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.

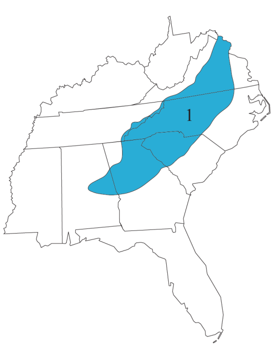


Figure 2.13: Diamictite from the Konnarock Formation at Mt. Rogers, Virginia. This poorly sorted sedimentary rock is believed to be tillite, lithified glacial debris from a major glaciation during the Proterozoic.

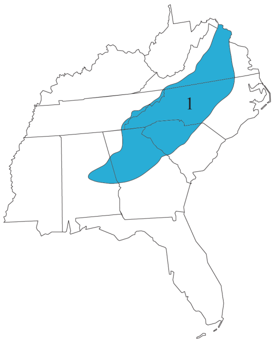
Avalon • *an early Paleozoic microcontinent offshore of what is now the eastern coast of North America.*

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.



Region 1

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.*

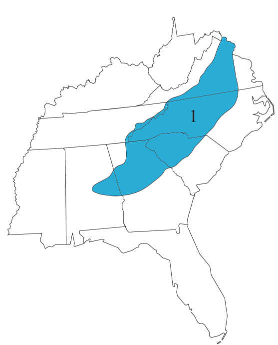


Figure 2.14: Murphy Marble, collected from a quarry near Tate, Georgia. Specimen is 7.6 centimeters (3 inches) wide.

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,

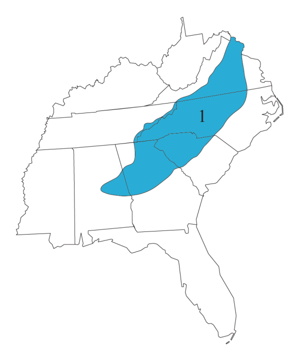
pillow basalt • *basaltic lava that forms in a characteristic "pillow" shape due to its extrusion underwater.*

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.*



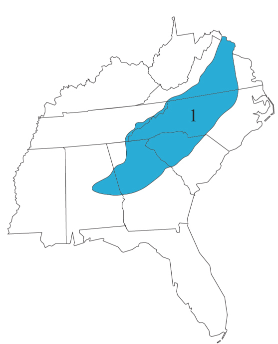
Rocks

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.*



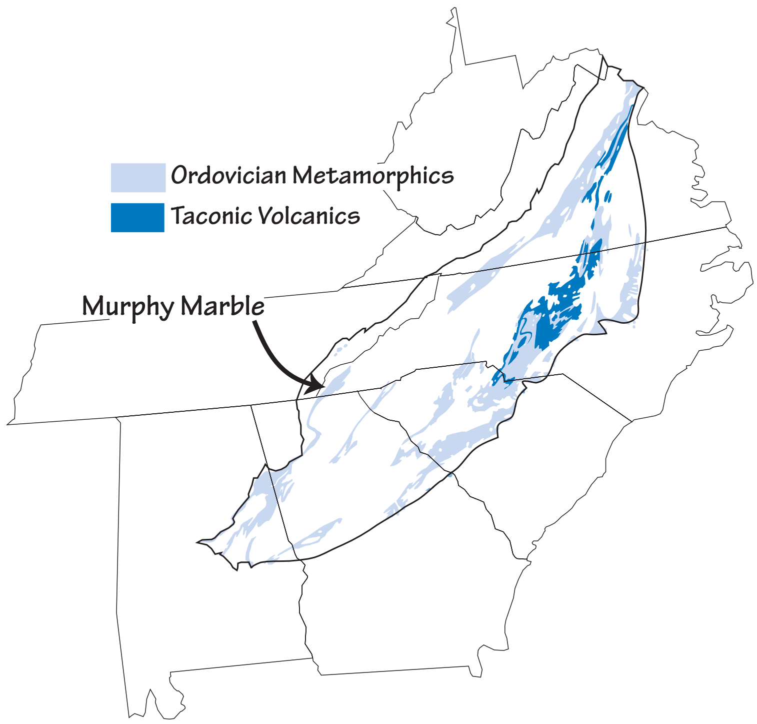


Figure 2.15: Metamorphic and volcanic rocks related to compression and accretion during the Taconic Orogeny.

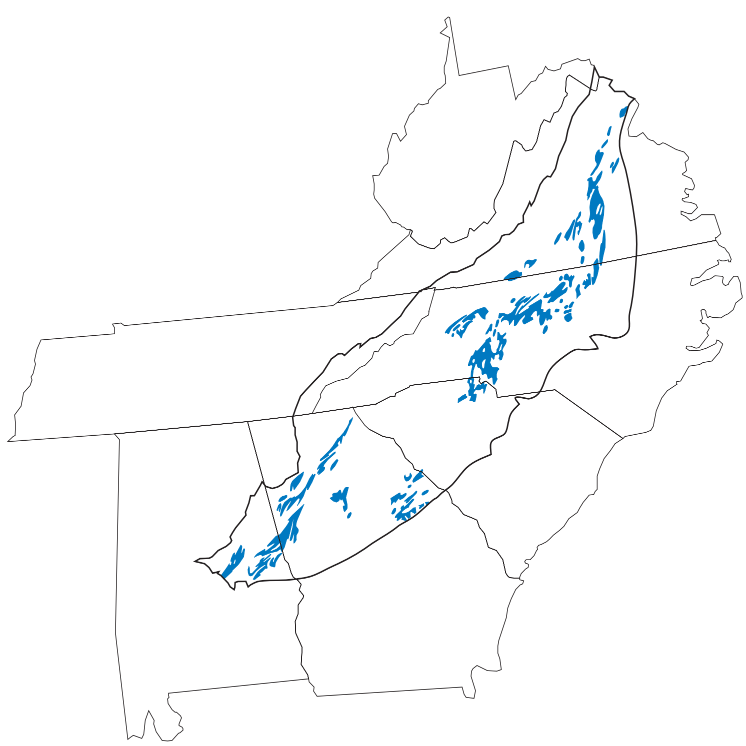


Figure 2.16: Granite intrusions related to the Taconic Orogeny.

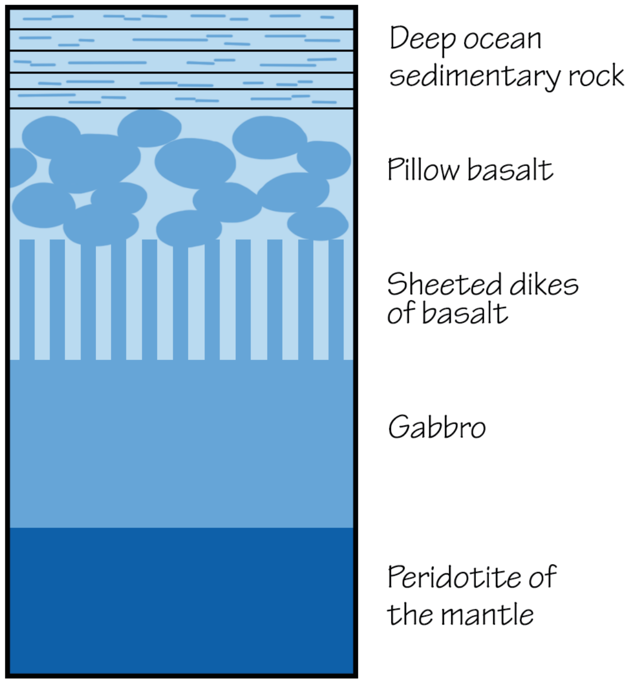


Figure 2.17: Structure of an ophiolite.

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.

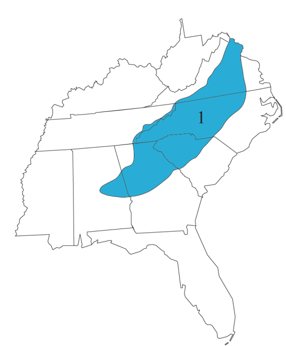
Africa collided with North America during the Alleghanian Orogeny of the late **Pennsylvanian** and **Permian**, uplifting the Appalachian Mountains and resulting in the formation of the supercontinent **Pangaea**. The collision resulted in intense metamorphism of the Blue Ridge and Inner Piedmont, moderate 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.*

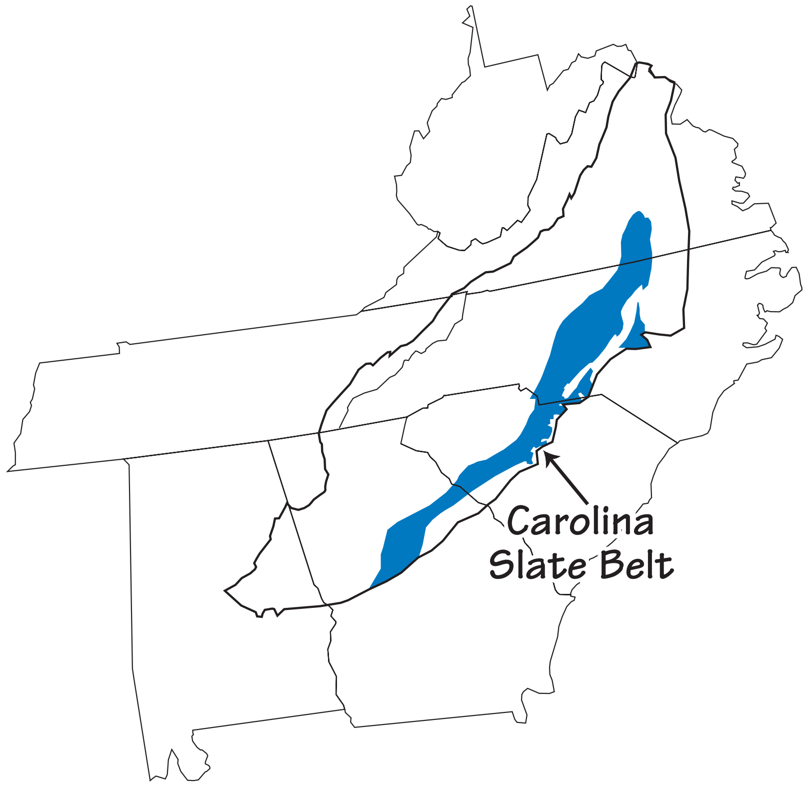


Figure 2.18: Extent of the Carolina Slate Belt.

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

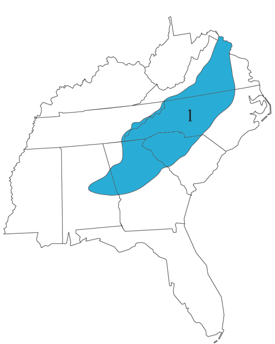
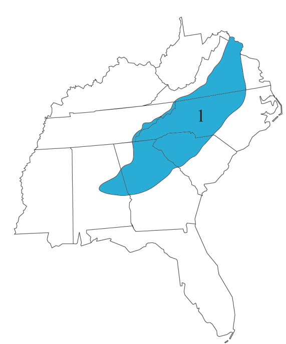


Figure 2.19: An aerial view of Stone Mountain, DeKalb County, Georgia.

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.*

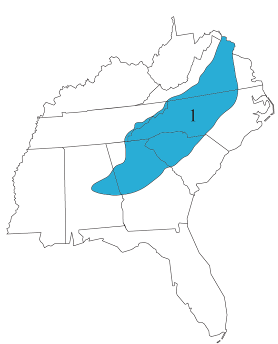
Triassic- and Jurassic-aged rift basin deposits are part of a sequence of rocks known as the **Newark Supergroup**, which can reach thicknesses of up to six kilometers (four miles). They are found at the surface in Virginia and North Carolina, where they expose characteristic reddish-brown sedimentary 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

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.*

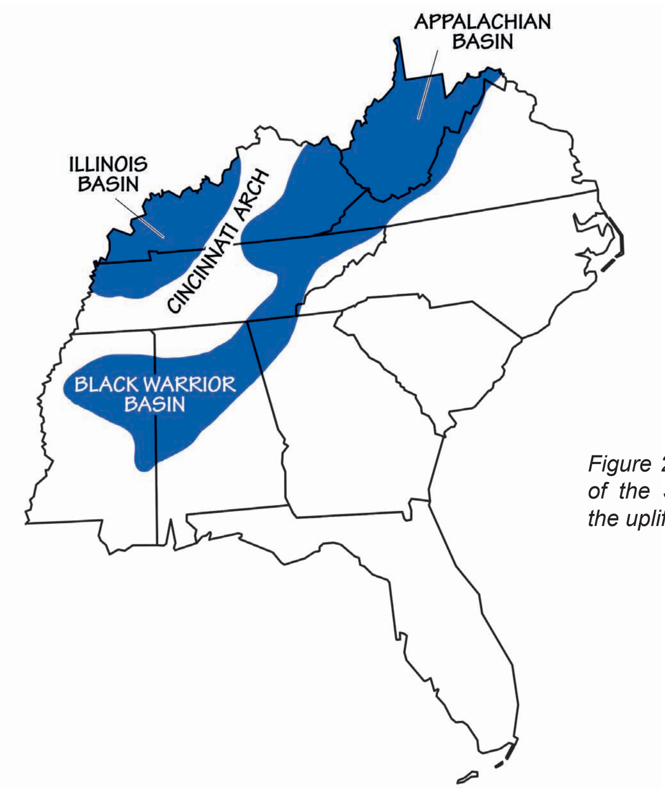
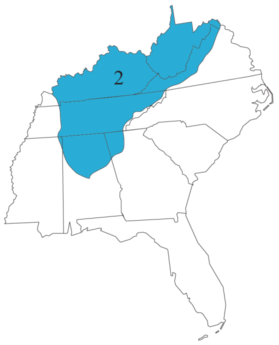


Figure 2.21: Sedimentary basins of the Southeast, separated by the uplifted Cincinnati Arch.



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

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.

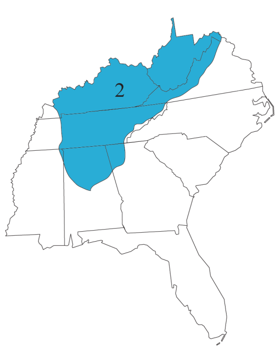
relief *• the change in elevation over a distance.*

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 ($CaMg(CO_3)_2$).*



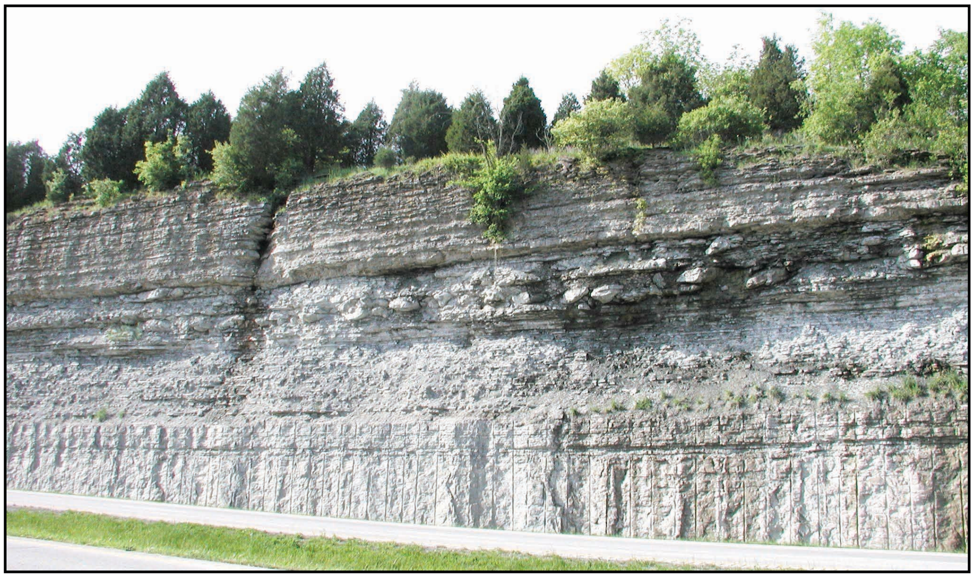
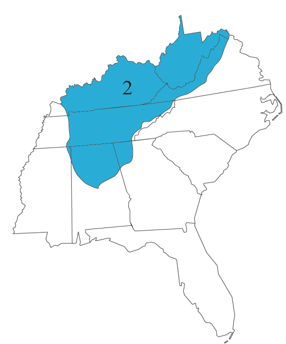


Figure 2.22: Rocks of the Lexington Limestone, which include limestone strata as well as shale layers, are exposed along this roadcut on the Martha Layne Collins Bluegrass Parkway near the Kentucky River.

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.



Region 2

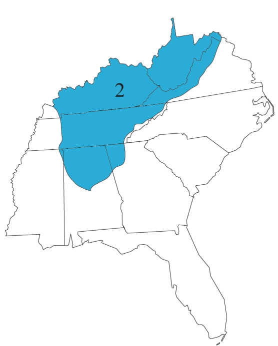
bentonite *• a clay, formed from decomposed volcanic ash, with a high content of the mineral montmorillonite.*

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*).

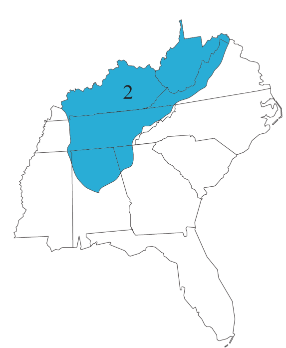
Figure 2.24: The United States Post Office and Courthouse, better known as the Knoxville Post Office, is a historic federal building constructed from Tennessee marble in the early 1930s.

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.



Region 2

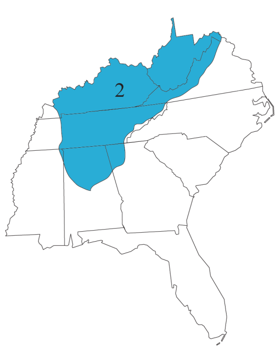
delta *• a typically wedge-shaped deposit formed as sediment is eroded from mountains and transported by streams across lower elevations.*

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.

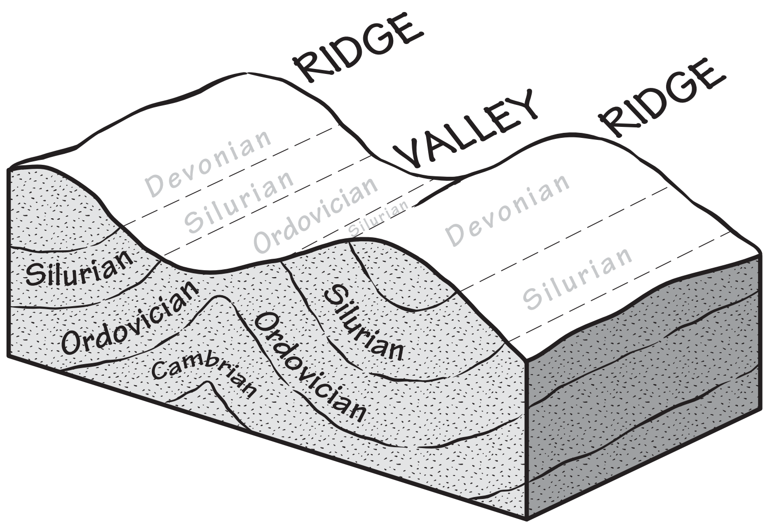


Figure 2.25: The Ordovician, Silurian, and Devonian rocks of the Inland Basin are found in long thin ribbons formed by the way layers of rock have been folded and then sliced at the surface by erosion. In the Valley and Ridge, the rocks were compressed into tight, elongated folds along the Blue Ridge 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.

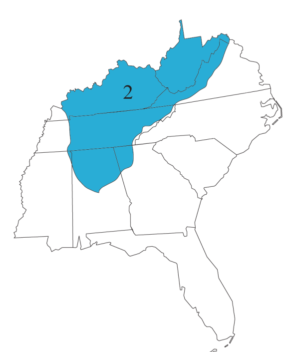
iron • *a metallic chemical element (Fe).*

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.*

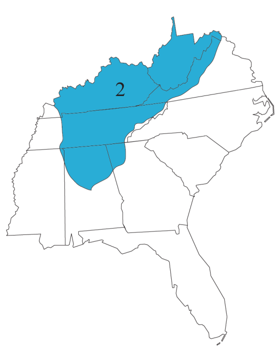
lacustrine • *of or associated with lakes.*

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.



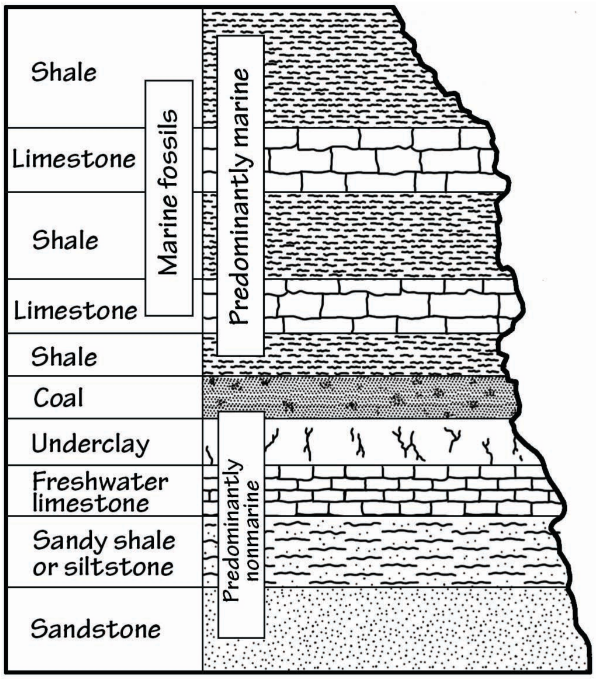


Figure 2.28: An example of a cyclothem.

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.

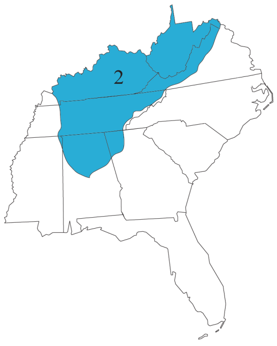
See Chapter 8: Climate to learn how changing climates through geologic time have influenced the environment.

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

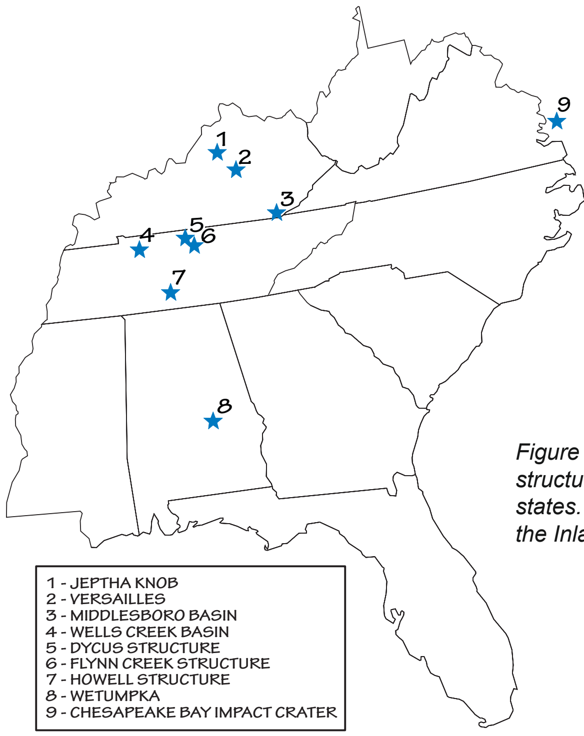


Figure 2.29: Known meteorite impact structures throughout the Southeastern states. Most of these structures are found in the Inland Basin.

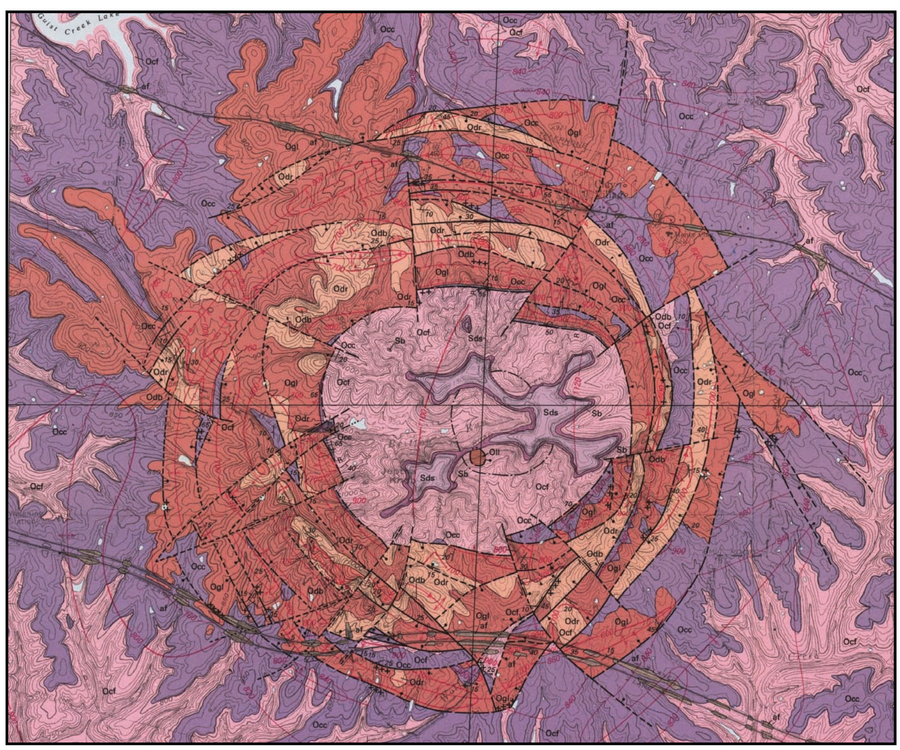
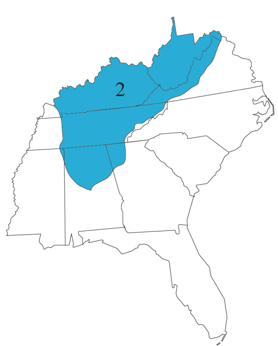


Figure 2.30: A geologic map of the Jeptha Knob impact structure in Shelby County, Kentucky, and associated fault lines. This structure was formed over 440 million years ago when a meteorite impact fractured the landscape and uplifted multiple fault blocks. As the highest point in the county, Jeptha Knob 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*).

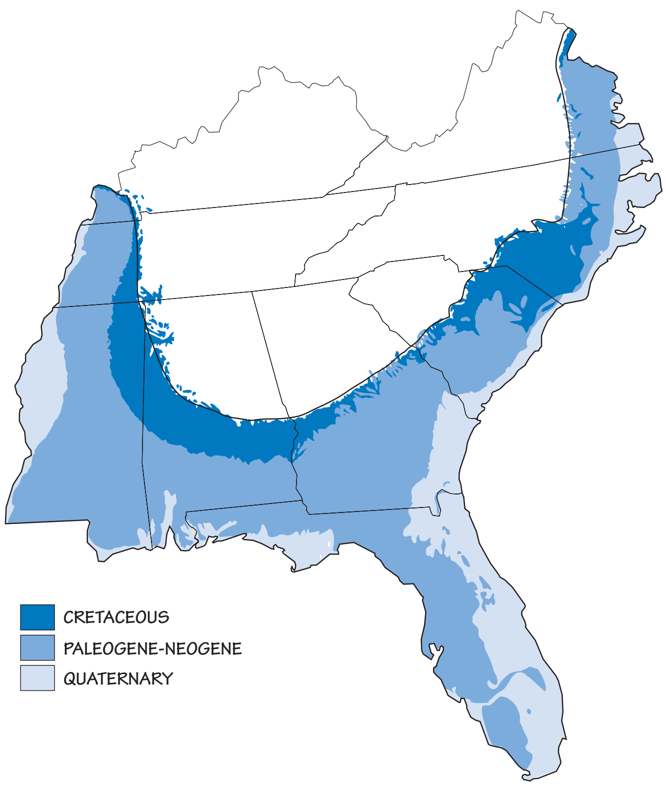


Figure 2.31: A generalized geologic map of the Coastal Plain.

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.*

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.

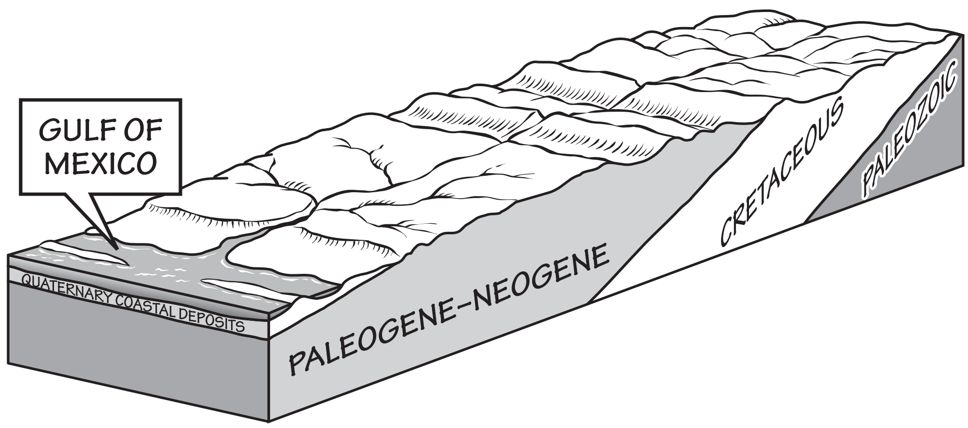


Figure 2.32: Millions of years of sediment accumulation in the Gulf of Mexico and Atlantic Ocean caused coastal areas to subside, creating a gentle slope toward the ocean.

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.

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.

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.*

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.

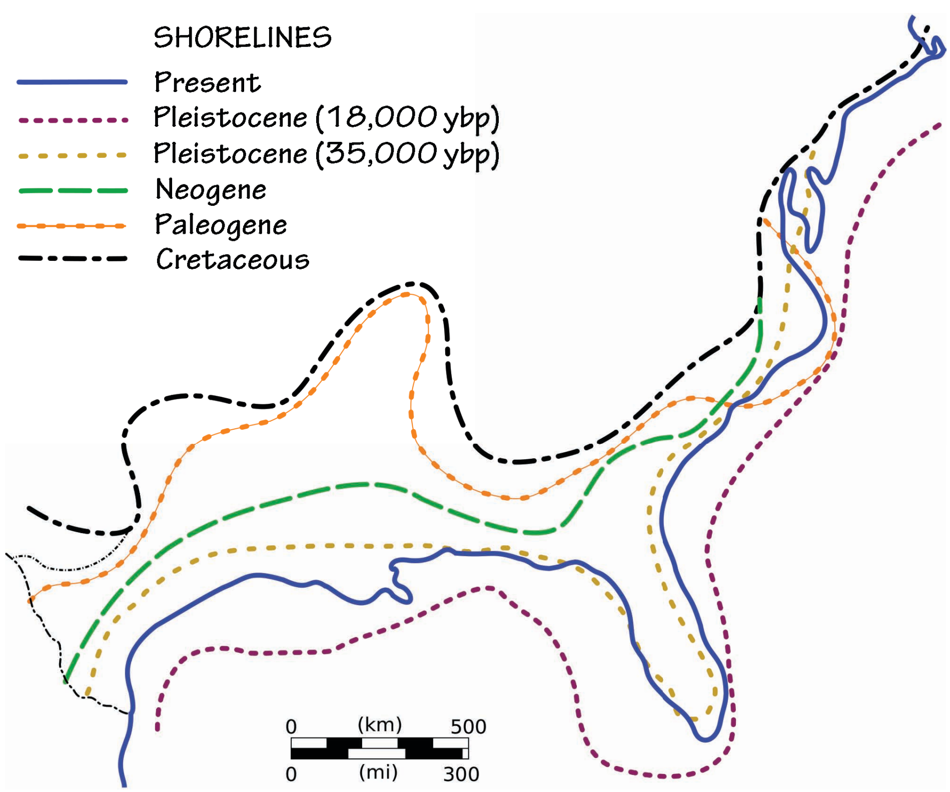


Figure 2.36: Shoreline positions along the Coastal Plain during the past 70 million years. (See TFG website for full-color version.)

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.

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

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.*

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

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.*

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*

Region 3

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.*

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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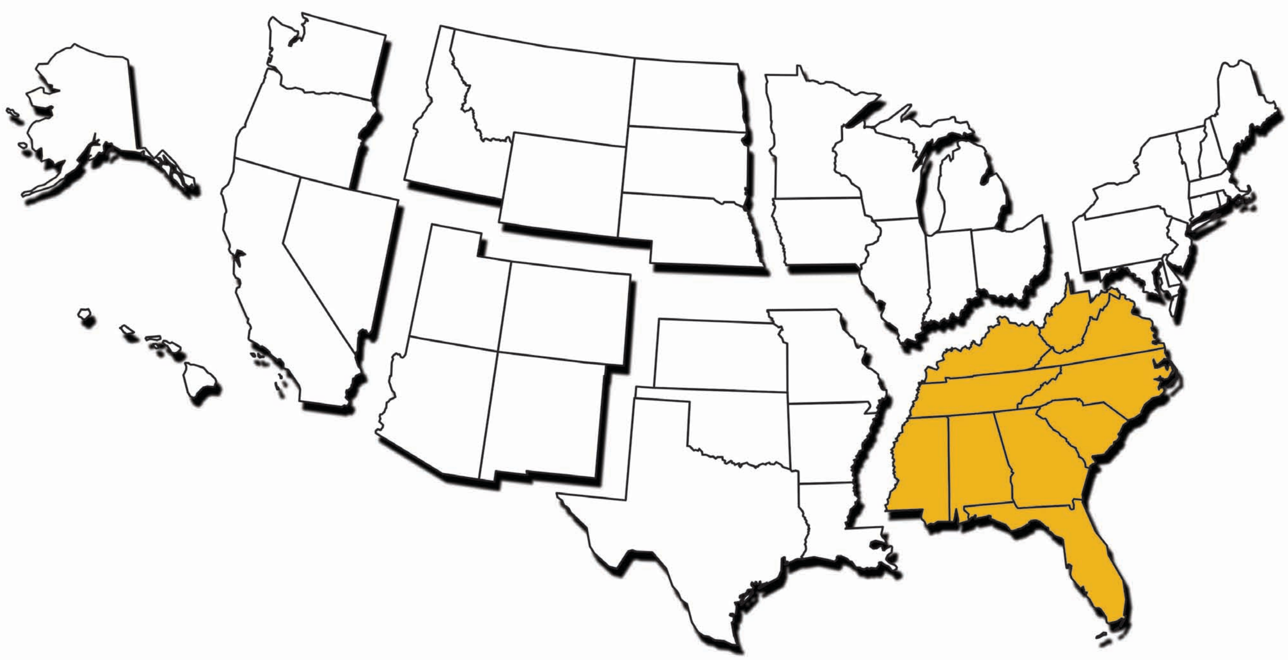
The *Teacher-Friendly* Guide™

to the Earth Science of the Southeastern US

2nd ed.



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

Paleontological Research Institution
2016

ISBN 978-0-87710-512-1
Library of Congress no. 2016930925
PRI Special Publication no. 50

1259 Trumansburg Road
Ithaca, New York 14850 USA
priweb.org

First printing January 2016

This material is based upon work supported by the National Science Foundation under grant DRL-0733303. Any opinions, findings, and conclusions or recommendations are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. The publication also draws from work funded by the Arthur Vining Davis Foundations and The Atlantic Philanthropies.

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

The Teacher-Friendly Guide™ series was originally conceived by Robert M. Ross and Warren D. Allmon. The first edition of this volume was published as Special Publication no. 42 in 2003 (online) and 2012 (hard copy). Original illustrations in this edition are mostly by Jim Houghton (The Graphic Touch, Ithaca), Wade Greenberg-Brand, and Christi A. Sobel.

Layout and design by Paula M. Mikkelsen, Elizabeth Stricker, Wade Greenberg-Brand, Katherine Peck, and Christine Dubé.

Cite this book as:
Swaby, A. N., M. D. Lucas, and R. M. Ross (eds.), 2016, *The Teacher-Friendly Guide to the Earth Science of the Southeastern US, 2nd edition.* Paleontological Research Institution, Ithaca, New York, 460 pp.

Cite one chapter as (example):
Allmon, W. D., 2016, Fossils of the Southeastern US. Pages 87–146, in: A. N. Swaby, M. D. Lucas, & R. M. Ross (eds.). *The Teacher-Friendly Guide to the Earth Science of the Southeastern US, 2nd edition.* Paleontological Research Institution, Ithaca, New York.

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.