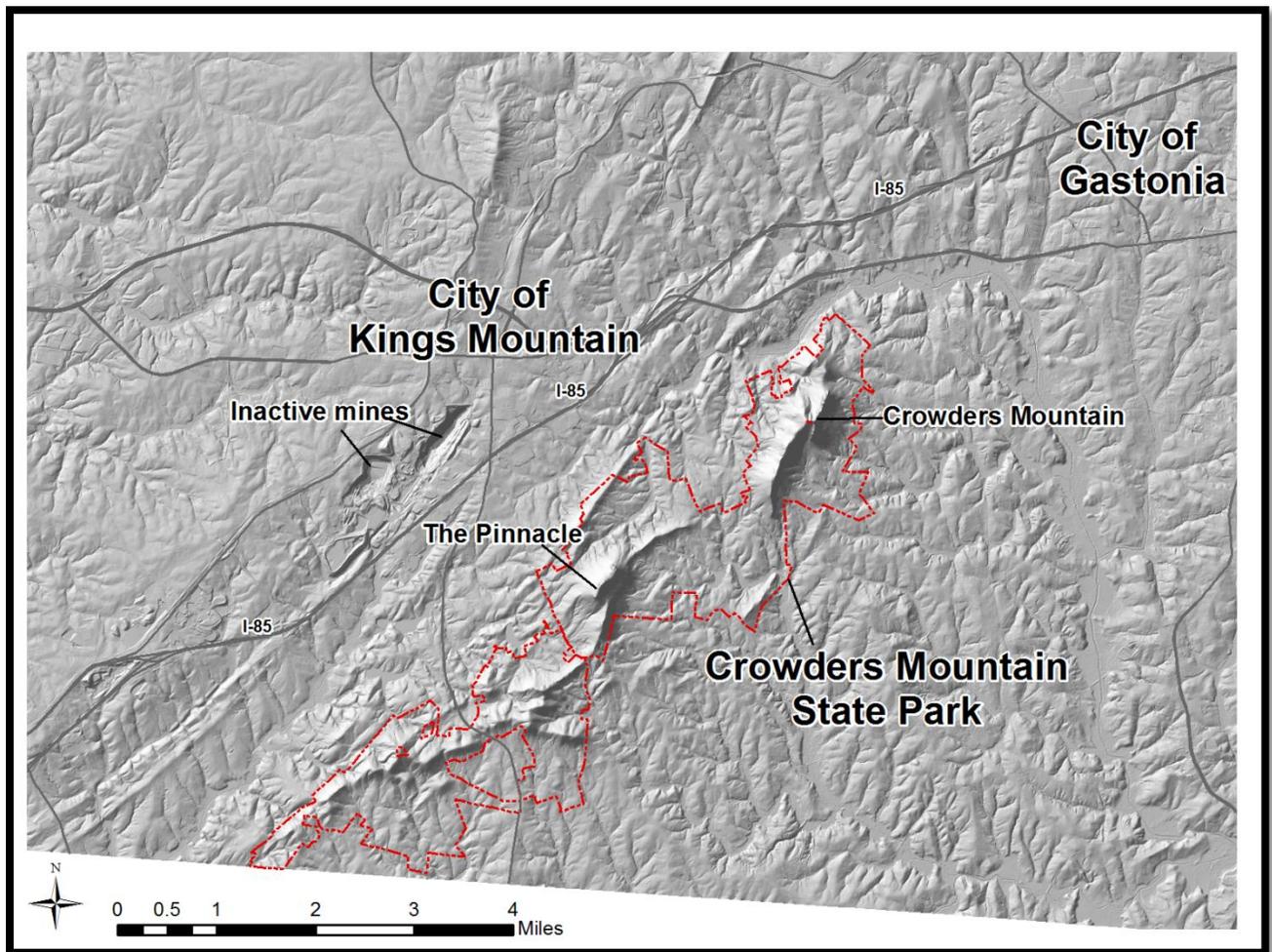


The Geology of Crowders Mountain State Park, North Carolina –

A Guide for the Non-Geologist

By Philip J. Bradley

North Carolina Geological Survey, Raleigh, NC, pbradley@ncdenr.gov



Hillshade elevation map created using LiDAR elevation data showing prominent topographic features in the Crowders Mountain State Park area.



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The Land and the Rocks of Crowders Mountain State Park

Geologic and technical terms used in the text are indicated in ***bold italics*** and defined in the glossary at the back of this guide.

Crowders Mountain State Park lies within the Piedmont ***physiographic province*** of North Carolina in Gaston and Cleveland Counties (fig. 1). The Piedmont is separated from the Blue Ridge physiographic province by the ***Blue Ridge Escarpment***. Far to the east of the Park, the ***Fall Zone*** separates the Piedmont from the Coastal Plain physiographic province. The Piedmont is typically characterized by gently rolling hills, heavily weathered bedrock, and a general scarcity of exposed solid rock, known as ***outcrop***. The relatively humid climate of the Piedmont, receiving approximately 45 inches of rain annually, speeds the chemical breakdown and erosion of rock. Unlike the rugged Blue Ridge physiographic province where rock outcrops are plentiful, rock in the Piedmont is typically found buried beneath a thick (3 to 50 feet) layer of soil and highly weathered rock called ***saprolite***. Outcrops of solid rock are usually restricted to stream valleys where the saprolite layer has been removed by erosion. Generally, the topography of the Piedmont becomes steeper closer to the mountains where ***monadnocks*** of more resistant rock stick up above the Piedmont surface.

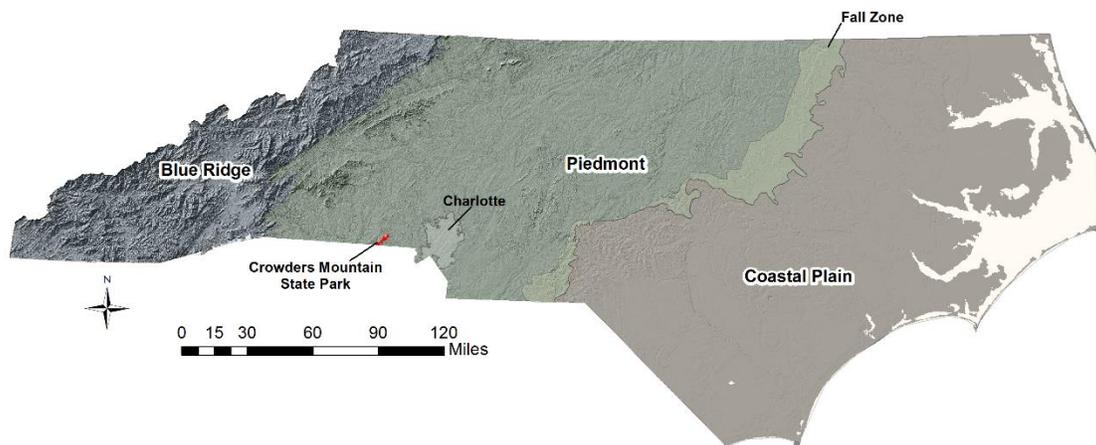


Figure 1: Location of Crowders Mountain State Park and physiographic provinces of North Carolina.

Is There a Monadnock Around Here?

The topography of Crowders Mountain State park is unique. Located near the central portions of the Piedmont (almost half-way between the Blue Ridge and the Coastal Plain), this area has

topography similar to the foothills in the western portion of the Piedmont province near the mountains. The summits of Crowders Mountain (1,625 feet above mean sea level (msl)) and The Pinnacle (1,705 feet msl), sit high above the gently rolling hills of the Piedmont at approximately 800 - 900 feet msl. That is over 800 feet of topographical difference! Compared with typical locations in the Piedmont, rock outcrops are relatively abundant in and around the Park. Crowders Mountain, The Pinnacle, and the series of ridges that the Ridgeline Trail follows, are monadnocks that are prominently displayed on a hillshade elevation map created using *LiDAR elevation data* (fig. 2).

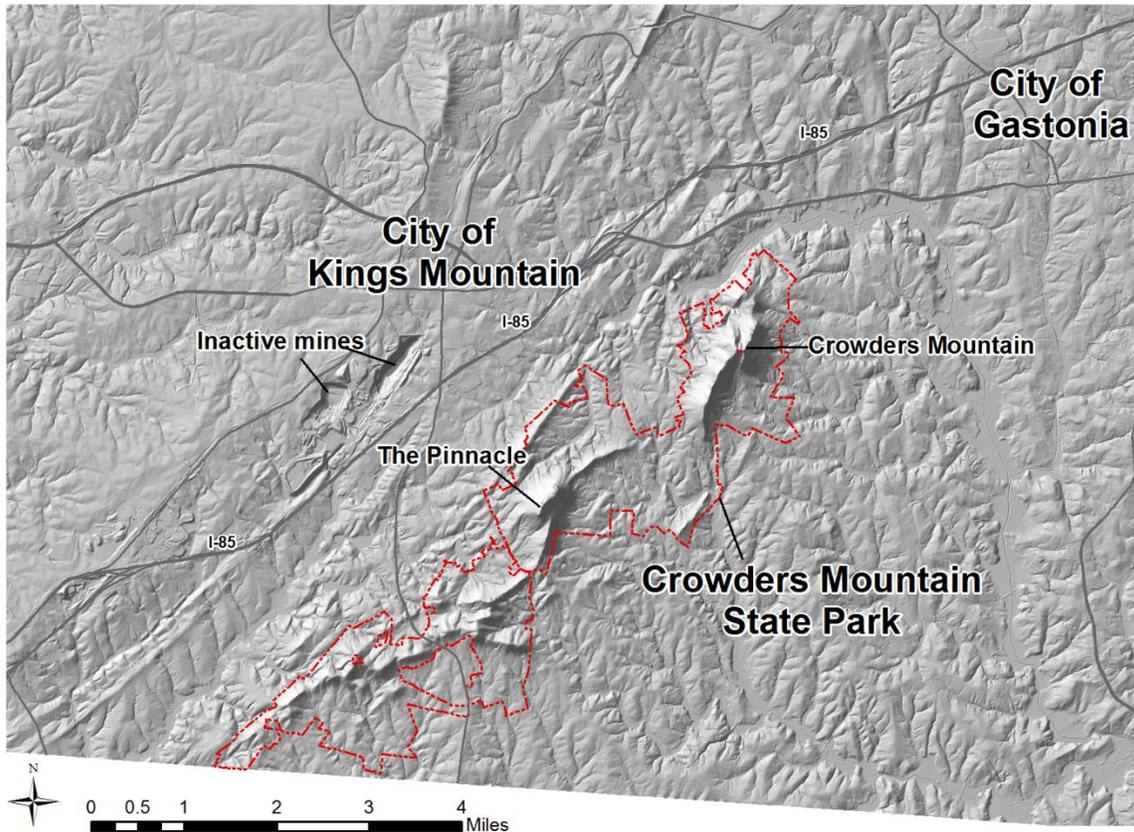


Figure 2: Hillshade elevation map created using LiDAR elevation data showing prominent topographic features in the Crowders Mountain State Park area.

Why Are There Mountains Here?

Simply stated, the rocks that underlie Crowders Mountain, The Pinnacle, and the ridges in and around the Park are harder (more resistant to *erosion*) than rocks of the lower-lying areas. Through millions of years of erosion, wind and rain have sculpted the landscape to what we see today.

Rock types in the Park

Geologic Maps Tell Us the Type of Rock under Our Feet.

Geologic maps (as depicted in plates 1 and 2) show the distribution of rock types and unconsolidated material in an area. The different colors on a geologic map indicate various geologic units. The lines on the map indicate the locations of the **contact** between geologic units, **faults**, and **folds**. Points indicate the location of outcrop, former or active **mines** and **prospects** or other geologic features. To produce a geologic map, a geologist systematically walks and/or drives the subject area looking for rock outcrop, other geologic material, evidence for faults, and active and former mines and prospects. The geologic map is the fundamental starting point in understanding the landscape of an area and the geologic history.

To geologists, rocks are much more than hunks of material – they tell a long, sometimes violent, and sometimes complicated story of the history of our Earth and our state. This section describes the various rocks types and rock units encountered in and around Crowders Mountain State Park.

To learn about the rocks exposed in and around Crowders Mountain State Park, we must first introduce the three basic rock types of geology - **igneous**, **metamorphic** and **sedimentary** rocks. All three of these rock types are present within the Park, making it an excellent place to learn about geology!

The Park contains two fundamentally different types of geologic units: 1) **bedrock** composed of primarily ancient **metamorphic** rocks intruded by a minor but an important **igneous** rock type called **diabase** and (2) surficial **sedimentary** deposits that mantle the slopes of the mountains from geologically recent (less than 2.5 million years old) erosion.

Metamorphic Rocks

The bedrock in the Park is composed of mainly metamorphic rocks. Metamorphism is the changing of a rock due to heat and pressure. Mountain-building events - typically from the collision of islands with other islands, islands with continents, or continents with continents - cause rocks to be buried deep in the Earth. Temperatures and pressures are much higher deep in the crust than at the surface of the Earth. The depth to which a rock has been buried (and the resulting temperature and pressure) determines the degree of metamorphism. A rock buried deep in the Earth generally will have a higher degree of metamorphism than a rock that remained closer to the surface. Metamorphism can be extreme (like extensive plastic surgery) or slight (like someone receiving a suntan at the beach). Extreme metamorphism (called high-

grade metamorphism by geologists) involves the re-crystallization of the rock in which new minerals replace the original ones. This causes the high-grade metamorphic rock to look nothing like the original rock. Slight metamorphism (called low-grade metamorphism) is sometimes so slight that the rocks barely look changed except to the trained eye of a geologist. The rocks associated with Crowders Mountain have been metamorphosed somewhere in between low- to medium-grade metamorphism; subsequently, the prefix “meta” is commonly added to the rock name or metamorphic rock type names are used. The rocks have been changed significantly from the original rocks, however, some rocks retain enough of the original features for geologists to interpret the original rock type with confidence.

There are many metamorphic rock types (e.g. gneiss, schist, phyllite, quartzite, metatuff, metaconglomerate, marble, etc...); most important to Crowders Mountain State Park are the following:

Schist and **phyllite**: metamorphic rocks formed from sedimentary rocks like mudstone, siltstone, and some sandstones. Schists typically have an abundance of flaky minerals called **mica** (biotite and/or muscovite) whose flakes you can see with the naked eye. Phyllite is composed of similar flaky mica-like minerals but the individual flakes are very small. The flaky minerals align themselves in thin layers and give the rocks a characteristic typical of some metamorphic rocks called **foliation**.

Quartzite: a metamorphic rock formed from sandstone composed of mainly quartz mineral grains. Quartzite is very resistant to erosion since it is mainly composed of the resistant mineral quartz.

Metaconglomerate: a metamorphic rock formed from the sedimentary rock type *conglomerate*. Conglomerate is a rock composed of fragments of rock - that are typically rounded by tumbling in water - in a fine-grained matrix of sand- to silt-sized sediments.

Metatuff: a metamorphic rock formed from tuff. Tuff is a **volcanic** igneous rock formed from the consolidation and **lithification** (process of forming a rock) of volcanic **ash**. Another metamorphosed volcanic rock present in the park is metafelsite. Metafelsite is a type of metamorphosed lava.

Hydrothermally altered Rocks

Rocks showing signs of being altered by **hydrothermal** fluids are common in the Crowders Mountain area. **Hydrothermal alteration** occurs when water, heated by **magma**, permeates through rocks or deposits and changes their composition by adding, removing, or redistributing chemical elements.

Magma associated with the ancient **volcanic** activities in the Crowders Mountain area heated local seawater and circulated it through the volcanic and sedimentary deposits. When the heated water and fluids rose to the surface of the sea floor, they may have formed hydrothermal vents. **Hydrothermal alteration** may drastically change the appearance of rocks, often changing rock into clay. The hydrothermal fluids in the Crowders Mountain area essentially removed most of the elements that are easily dissolved (e.g. potassium, sodium, and calcium) and left behind silica- and aluminum-rich clays. When the area was subjected to metamorphism, the silica- and aluminum-rich clays changed into kyanite-bearing quartzite. Kyanite is a bluish bladed-shaped mineral and, like quartz, is a very resistant mineral. Kyanite is also used in the manufacturing of high-temperature ceramics. The presence of abundant kyanite at Crowders Mountain and The Pinnacle made the location attractive to mining companies. Due to the efforts of a local conservation group, the area was established as a State Park in 1973.

Kyanite and the Blue Daggers:

Kyanite is a metamorphic mineral that is typically blue in color and shaped like little blades (little daggers). In places in Crowders Mountain State Park it can be found in the aluminous quartzite unit (Caq unit on plates 1 and 2). The kyanite at Crowders is more of a blue-gray color.

Kyanite is utilized as an **economic mineral** due to its physical and chemical properties. Kyanite is relatively chemically inert, has a high dielectric strength (a material that has negligible electrical or thermal conductivity), and a high melting point. It is used in the ceramic industry in the production of heat-resistant products such as electrical insulators. It is used in porcelain plumbing fixtures and other ceramics (like dishware) and is used in electrical insulators and abrasives. Kyanite is also used as a semiprecious gemstone.

The kyanite within the aluminous quartzite unit found in Crowders Mountain State Park is also found in many locations within the region occurring as thin strips in North and South Carolina. In South Carolina at Henry's Knob, Kyanite was mined off and on from the 1930's to the 1960's. It was the nation's second largest producer of kyanite for several years in the 1960's (Horton, 1981). In the 1970's, a mineral exploration company began investigating the kyanite resources at Crowders Mountain and the Pinnacle. Due to the threat of Crowders Mountain and the Pinnacle falling to the same fate as Henry's Knob, local conservation groups organized and through their efforts the area was established as a State Park in 1973.

Igneous Rocks

In addition to the metamorphosed igneous rocks present in the Park (metatuff and metafelsite), the igneous rock type called ***diabase*** is present in a very small amount in thin bodies called ***dikes***. Although diabase represents a small portion of the rock types in the Park area, it helps tell an important part of the overall geologic history of the area and the Earth. Diabase will be discussed further in the geologic history section.

Sedimentary Deposits and Rocks

Generally, sedimentary deposits and rocks form from the erosion, transportation and re-deposition of older rock types. Igneous, metamorphic and sedimentary rocks can be eroded and broken down into pieces to become components in a sedimentary deposit or rock. Sediment is naturally occurring material that is formed from the breakdown of rock material through weathering and erosion. Sediment particles can range from ***boulder-, cobble-, sand-, silt-, to clay-size***. Surficial sedimentary deposits mantle the steep slopes of the mountains in the Park and in many places cover the bedrock. The deposits are identified as ***colluvium*** on plates 1 and 2.

The metaconglomerate, quartzites, schists, and phyllites that underlie most of the park began as the sedimentary rock types conglomerate, sandstone, siltstone and mudstone. As the names imply, conglomerate is composed of a conglomeration of rounded to partially-rounded ***boulder-, cobble-, gravel-*** and ***sand-size*** sediment, sandstone is composed of sand-sized sediment, siltstone is composed of silt-size sediment and mudstone is composed of mixture of ***silt-*** and ***clay-size*** sediment.

The Park is underlain by a whole bunch of Schist!

The geologic map of the Park (plates 1 and 2) indicate that the area is separated into two main rock ***formations***: the Blacksburg Formation and the Battleground Formation. The Battleground Formation and its various units form the bedrock that underlies the Park.

On the Park property, the various rock types of the Battleground Formation have been grouped by Horton (2008) into several geologic units (plates 1 and 2). Three of these rock units are composed of the rock types ***schist*** and ***phyllite*** and underlie most of the Park (Geologic units: Cbs: quartz-sericite phyllite and schist; Cbms: biotite-muscovite schist; and Cbfs: ***felsic*** schist and gneiss (metafelsite)).

The presence of these rocks tell geologists that the ancient environment present when the sedimentary rocks were being deposited was at the bottom of an ocean. Additionally, the schists and phyllites are interlayered with rock types named metatuff and volcanic metaconglomerate (ex. Cbct-plagioclase-crystal metatuff, Cbvc-volcanic metaconglomerate and Cbmp-mottled phyllitic metatuff). *Based on the main rock types present under the Park (metamorphosed sedimentary rocks and volcanic rocks), geologists can interpret that the area of the Park was once under water and located near to a volcanically active area! Looking closer at the rock types, we can tell more!*

The presence of thin geologic units in the Park help explain why there are mountains and also unlock important clues to the geologic history of the area and the Earth!

Interlayered with the schists and phyllites are thin geologic units ranging from just a few feet in thickness to only up to a few hundred feet thick. These units may be thin and only underlie a small portion of the Park, but collectively are responsible for the landscape we see at the Park today and offer important clues to the geologic history of the area. Two of these units are composed of **quartzite** (Cbaq: aluminous quartzite) and metaconglomerate (Cbc: Dixons Gap metaconglomerate). Quartzite is metamorphosed sandstone and metaconglomerate is metamorphosed **conglomerate**. These units are important for two reasons:

1) The quartzite and the metaconglomerate are very resistant to erosion compared to the schists and phyllites that underlie most of the Park. Since they are more resistant, they withstand better the effects of erosion and form the ridges and mountains in the Park. The quartzite is the most resistant and is what forms Crowders Mountain and The Pinnacle. The metaconglomerate forms some of the ridges in the Park and is present on a few segments of the Ridgeline trail.

2) In a very general sense, the presence of metaconglomerate and quartzite indicate that there was geologic **uplift** somewhere within a few to up to multiple miles away. The presence of the conglomerate indicates that something geologically *interesting* was taking place. This uplift formed higher ground that began to erode sending tons of rock debris down rivers and possibly into underwater canyons to be deposited underwater in the area to later become Crowders Mountain State Park. The metaconglomerates within and nearby to the Park were the subject of some high-tech geologic research headed by researchers from the University of South Carolina Aiken (Dennis and Baker (2012), Dennis et al. (2012a and b), and Dennis (2014)). According to their research, the metaconglomerate layers may mark the period when the chain of volcanoes, that included modern-day Crowders Mountain State Park, began to separate from the ancient **Gondwana** continent. Additional information about the work of the University of South Carolina Aiken researchers is provided in the side bar text. Details of how the research fits into the geologic history of the area is provided in the geologic story section of the text.

The Geologic Story – How the Rocks Got There

Prologue

The geology presented so far has primarily been a description of the rock types present in Crowders Mountain State Park. However, just a description of these rocks does not tell us how the rocks formed or how the rocks were changed or altered. The following section presents the geologic story of how and when the rocks formed. Through detailed geologic mapping and work by many investigators in the immediate areas surrounding the Park (as well as similar areas throughout South Carolina and North Carolina), the geologic story of the Crowders Mountain State Park was pieced together. This story combines many geologic investigations conducted within the Kings Mountain *terrane*, Carolina *terrane*, and from other locations throughout the Southeast. For a detailed review of some of the most recent geologic interpretations of associated rocks, at the time of publication, see Hibbard et al. (2002) and references therein, Horton (2008), Dennis and Baker (2012), Dennis et al. (2012 a and b), Hibbard et al. (2013), and Dennis (2014).

This story is an *interpretation*, pieced together using facts acquired from scientific field data and laboratory studies of the rocks from many different workers. As more geologic research is performed, some of the interpretations of the geologic story of the area may change. Changing interpretations about the geologic story is a vital part of the scientific process. The rocks will always stay the same in our lifetime but the interpretation of what the rocks tell us may change, and should change, as more knowledge is developed.

Overview

Geologists like to group the rocks of large areas of the Earth into swaths of land that share a similar geologic history. Crowders Mountain State Park lies within the Kings Mountain *terrane* (Dennis et al. (2012 a and b) and Dennis (2014)). The Carolina terrane and nearby Charlotte terrane and other terranes collectively are grouped together and called *Carolinia* by geologists (fig. 3). Carolinia represents an amalgamation of chains of volcanic islands that originally formed far away from ancient North America and through plate tectonics and many millions of years travelled across an ancient ocean and collided with and became part of North America. The terranes that compose Carolinia are also known as *exotic terranes*. The rocks exposed at Crowders Mountain record a small but important piece of the greater than 600 million year history of Carolinia. The rocks associated with Carolinia underlie a significant portion of the southeast US (including over a half of the Piedmont of North Carolina), so the geologic history of Carolinia and Crowders Mountain is a significant part of the overall geologic history of North America and the world.

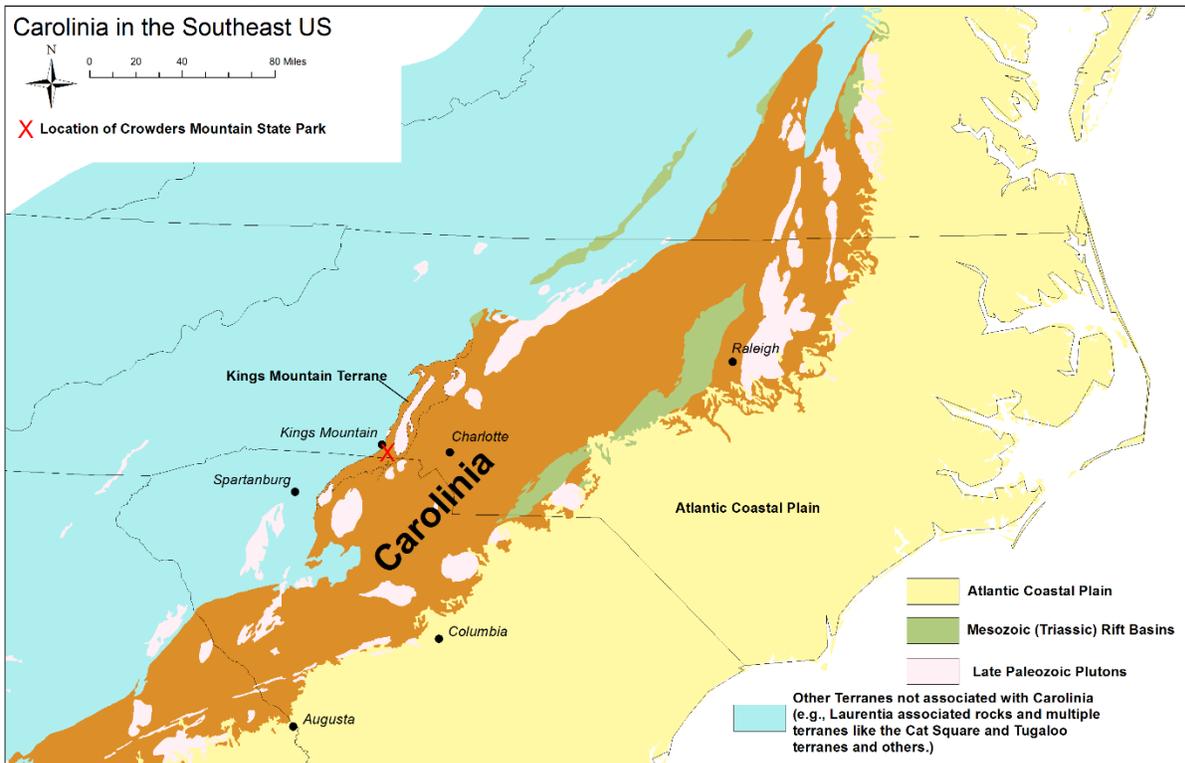


Figure 3: Map showing location of Carolina with respect to the Southeastern US and other major geologic features.

Terranes, Sequences and Belts

Sometimes it seems that geologists can't make up their mind on what to call something. For many years, the term "belt" was used to group rocks of similar metamorphic grade or other similar characteristics (e.x. Carolina slate belt and Charlotte belt). Since the mid-1990's, belt terminology has been abandoned in professional geologic literature for *terranes*. A geological terrane is a fault-bounded fragment of the Earth's crust that shares a common geologic history that is distinct from surrounding terranes or areas. The Kings Mountain area used to be called the Kings Mountain belt. Today, some geologic researchers interpret the Kings Mountain area to be its own terrane (Dennis et al. (2012 a and b) and Dennis (2014)). Other workers interpret it to be a part (a geologic sequence) of the Carolina terrane (Hibbard et al. (2002), Horton (2008), Hibbard et al. (2013)). No matter what you call it, the Kings Mountain area has distinct rock types that tell a wonderful geologic story!

A quick geologic history

Beneath the peaceful forests surrounding Crowders Mountain State Park the rocks record a long, sometimes violent, and complicated geologic past with many different episodes of volcanic activity that span many millions of years. The geologic history of Carolina began more than a half a billion years ago, when, far away from ancient North America, a chain of volcanic islands was forming. Multiple generations of volcanoes were actively erupting billions of tons of ash and other volcanic debris over millions of years. Fast-forward many millions of years later, we find a major part of Carolina undergoing a new phase of volcanism on or very near the ancient continent of Gondwana. Later, Carolina rifts away (breaks away) from Gondwana and slowly makes its way across an ancient ocean toward an eminent collision with ancient North America. Carolina eventually collided with - and welded to - ancient North America. Millions of years later, around 300 million years ago, the ancient African continent collided with ancient North America forming the supercontinent ***Pangea***. During the Triassic period, beginning about 245 million years ago, Pangea split apart, forming a system of ***rift-valleys*** up and down the eastern edge of North America. Approximately 200 million years ago, magma intruded the rocks and formed the multitude of ***dikes*** of the rock type known as ***diabase*** found throughout the Piedmont and in Crowders Mountain State Park. As Pangea continued to split apart, the continents we know today took their shape and the Atlantic Ocean was born. The great mountain range formed from the collision of ancient North America and Africa was eroded away. Its sediment was deposited on the newly formed Atlantic coastline creating the sedimentary deposits of the Coastal Plain. Millions of years of subsequent uplift and erosion slowly formed the landscape visible today within the Park and its surroundings.

The Old Arc - The Early History of Carolina: Circa 630 Million Years Ago

Off the coast of the ancient continent called Gondwana (which included portions of the present day African, South American and Antarctica continents), at the edge of a ***convergent plate boundary***, younger, more buoyant, oceanic crust collided with and rode over older and denser oceanic crust (fig. 4). As a result, the denser oceanic plate was pushed deep into the Earth and a subduction trench was formed. (Examples of modern day subduction trenches are associated with the Aleutian island arc - Aleutian Trench in Alaska, the Java and Sumatra island arc - Sunda (Java) Trench, and the volcanic islands of Japan - Japan Trench.) Plunging deep into the Earth, the subducted crust carried large quantities of water down into the subduction zone. The addition of water, coupled with the extreme heat and pressure allowed a portion of the Earth's mantle above the subducting oceanic slab to melt and form magma. Giant blobs of buoyant magma (imagine a lava lamp but much slower) slowly ascended through the younger oceanic crust all along the forming ***volcanic island arc*** (fig. 5). This island arc represents one of the oldest identified periods of volcanic activity associated with Carolina and was likely more than 600 miles (1,000 kilometers) long.

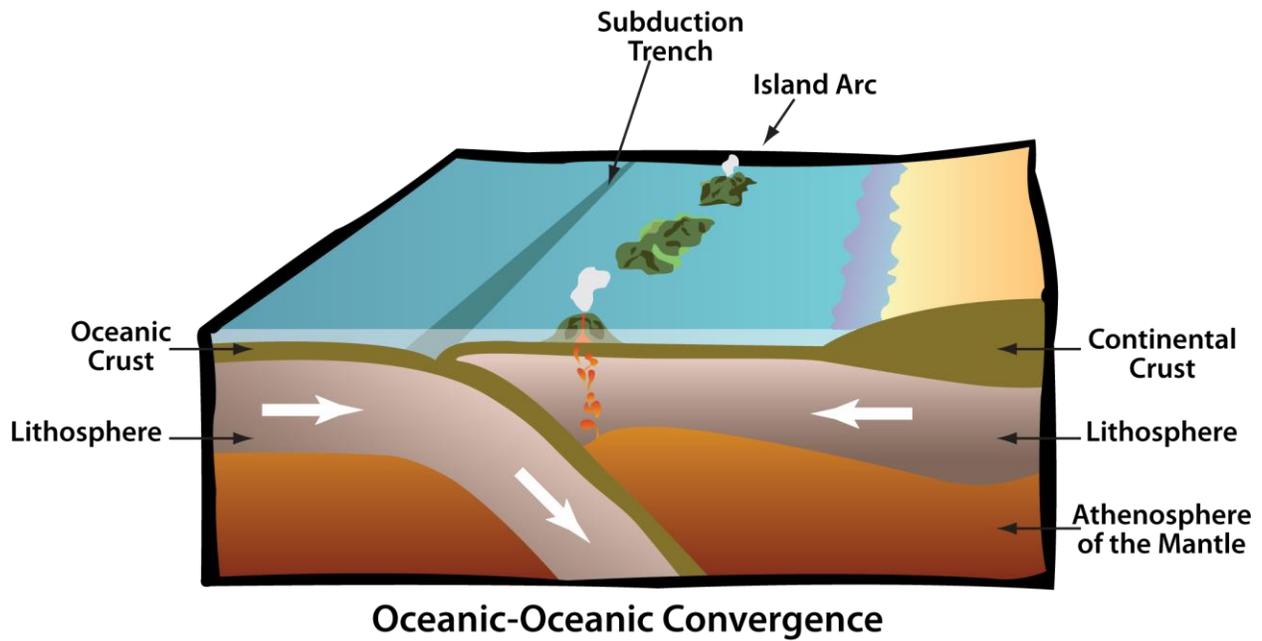


Figure 4: Diagram of an oceanic-oceanic plate convergence zone showing subduction trench and volcanic island arc.

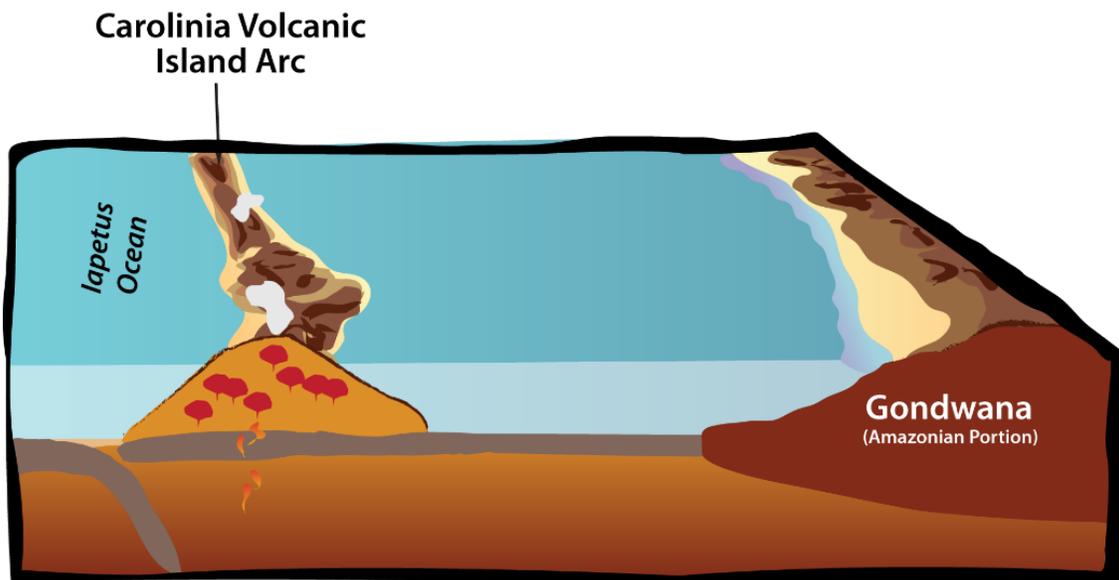


Figure 5: Diagram showing the "Old Arc" of the Carolina Volcanic island arc - ca. 630 million years ago.

To help simplify the long and complicated history of Carolina, geologists have begun referring to the volcanic arc associated with the early history of Carolina (specifically the oldest portion of the Carolina terrane) as the **Old Arc** (see Hibbard et al., 2013 for detailed information). The Old Arc itself has a long and complicated history with multiple periods of volcanism and evidence of slamming into another island arc (which left evidence of a **deformation event**). The rocks associated with this Old Arc are now exposed from parts of the Piedmont of Virginia,

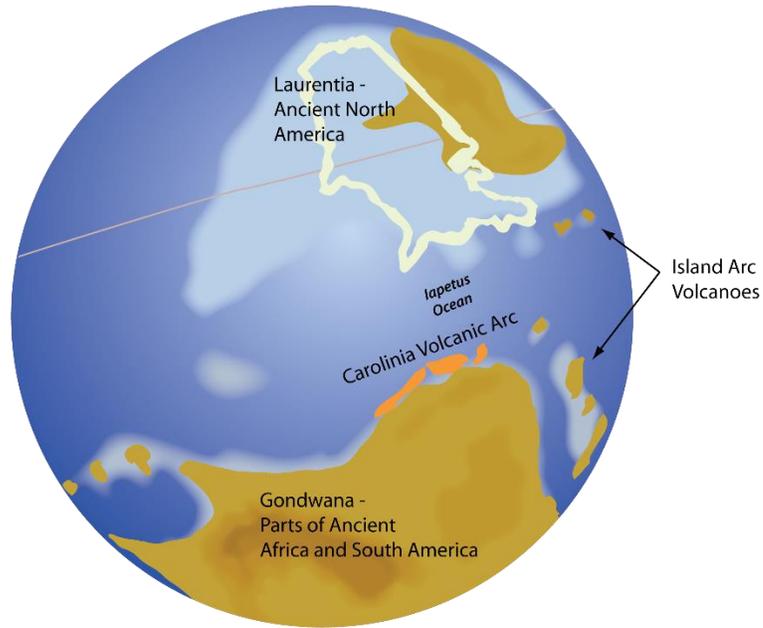


Figure 6: Paleo-reconstruction cartoon of the Earth approximately 550 million years ago indicating relative location of the Carolina arc with respect to ancient North America. Present day outline of North America shown for reference.

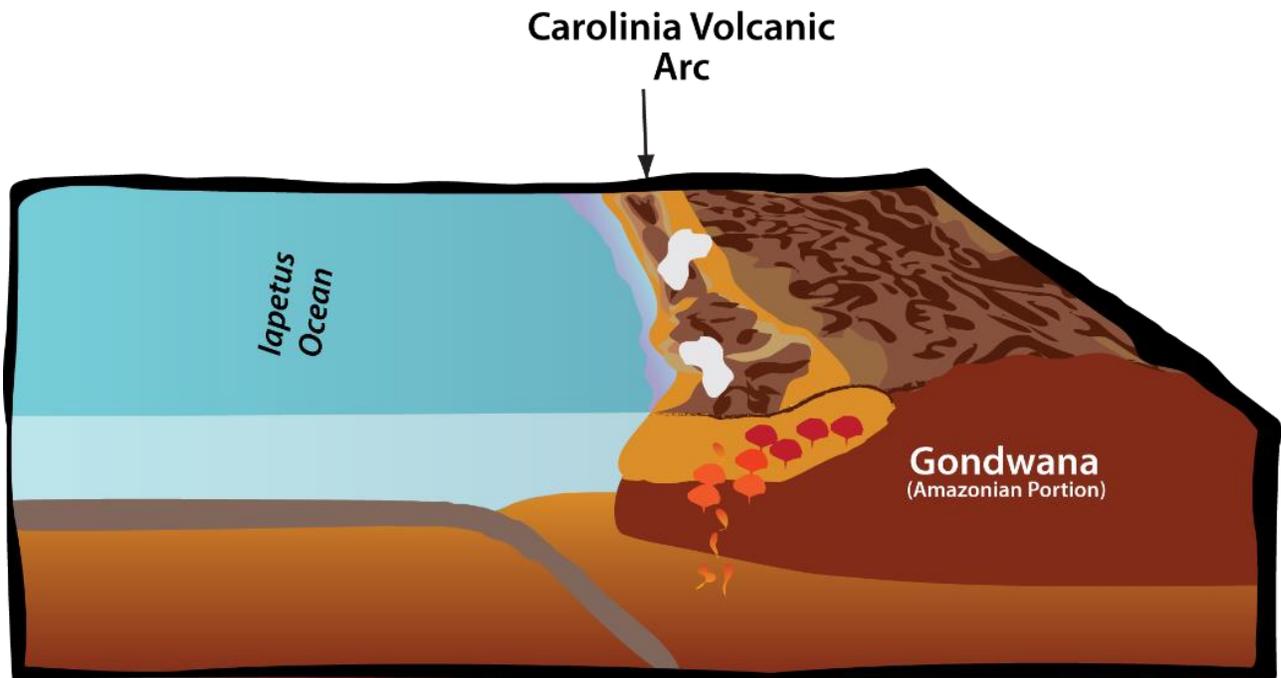


Figure 7: Diagram showing the "New Arc" of the Carolina Volcanic arc during main active volcanic stage - ca. 550 to 545 million years ago.

southwest through Chapel Hill and Siler City, NC. Eno River, Umstead and Raven Rock State Parks are all underlain by rocks associated with the Old Arc.

At some time before approximately 550 million years ago, the old arc became situated on top of continental crust associated with the Amazonian portion of the Gondwanan continent (figs. 6 and 7). Geologists still do not know the details of how the **Old Arc** got on top of a piece of Gondwanan continental crust and different interpretations exist.

The New Arc – Renewed Volcanism on Carolina: Circa 550 Million Years Ago

Beginning about 550 million years ago, a new chain of volcanoes began to form on top of the now extinct and buried volcanoes of the Old Arc (fig. 7). The rocks associated with this **New Arc** are now exposed near Asheboro, NC and extend southwest into the Uwharrie Mountains (which includes Morrow Mountain State Park) and into South Carolina. In North Carolina, these rocks have been dated at about 550 to about 540 million years old (summarized in Hibbard et al., 2002; Pollock, 2007; and Hibbard et al., 2013). After around 540 million years ago, the New Arc began to pull itself apart (known as arc rifting) (fig. 8). This rifting likely caused additional volcanism but also caused the New Arc to subside (sink) with the deposition of thousands of feet of sediment. These layers of sediment with interlayered volcanic rocks extend from south-central North Carolina into South Carolina and part of Georgia.

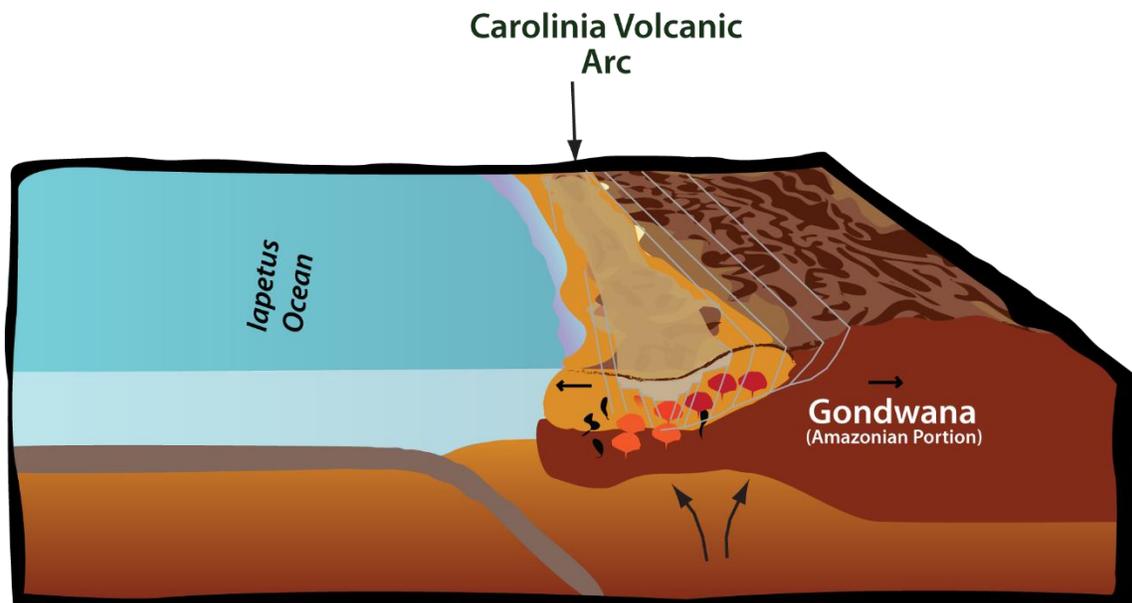


Figure 8: Diagram showing the “New Arc” of the Carolina Volcanic arc during the arc rifting stage – ca. 540 to 530 million years ago.

The rocks of the New Arc are younger but very similar to the rocks of the Old Arc. These volcanoes, like the volcanoes of the Old Arc, went extinct and were eroded and covered with sediments. The oldest rocks exposed in Crowders Mountain State Park are interpreted to be part of the New Arc of Carolina.

Volcanoes and Volcanic Activity of the Old and New Arcs

Geologists studying ancient volcanic regions, like those of the Old and New Arcs of Carolina, use modern volcanoes and their deposits as a guide to help them unravel the geologic history. Many of the rocks exposed within Carolina have identical features to rocks being deposited by volcanoes or from the erosion of volcanoes today. From a comparison to modern day volcanic areas and geologic processes, geologists can piece together a general picture of what it may have been like on ancient Carolina.

The main phases of volcanism on both the Old and New Arcs were from the subduction of oceanic crust either under other ocean crust (Old Arc) or under continental crust or a fragment of continental crust (New Arc). During the subduction process, water in the subducting sediments coupled with the extreme heat and pressure allowed a portion of the Earth's mantle above the subducting oceanic slab to melt and form giant blobs of magma (molten rock). The magma blobs worked their way upward through the crust, the blobs coalesced into larger masses and settled in zones between 2 to 6 miles (3 to 10 kilometers) below the Earth's surface into magma chambers.

The crust above the growing magma chambers began to bulge and swell and some of the magma began to move toward the surface along faults and fractures. If on ocean crust, the magma eventually erupted onto the ocean floor causing underwater volcanic eruptions that discharged billions of tons of lava and ash on the sea floor. The eruptions built enormous piles of volcanic debris many hundreds to thousands of feet thick. The piles of volcanic debris built up high enough that volcanic islands began to break the surface of the water. More eruptions followed, building the islands larger and larger. As these islands emerged above the water surface, erosion began working on their destruction. The islands were barren masses of volcanic debris with no land plants or animals. Land plants would not evolve until over 200 million years later during the ***Silurian*** and ***Devonian*** periods. With no plants to help hold the volcanic debris and soil in place, all of the unconsolidated material would have been easily eroded. Every minor rainfall created torrents of sediment-filled streams and rivers that transported their loads into the surrounding ocean. Frequent earthquakes that accompanied the doming and the subduction activity triggered landslides and submarine slides that contributed to the destruction of the volcanic islands.

The volcanic areas probably went through many cycles of construction and destruction on both the Old and New Arcs. Lava and ash built up small islands or tall land volcanoes only to be destroyed by subsequent explosive eruptions and erosion.

Erosion slowly wore the volcanoes down and produced layer after layer of sedimentary rocks like, siltstones, sandstone, greywacke and conglomerate. These sedimentary rocks are often found interlayered with lavas and tuffs indicating that the volcanic deposits were undergoing erosion in the same time period of active volcanism.

Hydrothermally altered rock (see earlier section “Rock Types in the Park”) are common in volcanic areas and are common in both the Old and New Arcs’ rock record. Both Arcs would have had abundant **hot springs** and/or hydrothermal vents where hot water, heated by the magma, circulated through the previously deposited ashes and volcanic debris. The hydrothermal activity extracted silica and other minerals and elements from some rock types or added silica to other rock types forming hydrothermally-altered rocks. Other rock types may directly precipitate due to abundant minerals and elements dissolved in heated water and form distinct layers (called an **exhalative deposit**). Many important **economic minerals** and metals can form in hydrothermal systems and/or other volcanic processes (ex. gold, copper, pyrophyllite, kyanite, and barite, etc). The entire Kings Mountain terrane of Carolina (the specific rocks that underlie the Park) have a long history of mining activities and are discussed in another section of this guide. The Park has abandoned mineral prospects, open pits, a mine shaft and other features that reveal the mining history of the past (plates 1 and 2).

Carolina Rifts Away from Gondwana – The Story of Crowders Mountain State Park

Beginning sometime around 520 million years ago, tectonic forces in the Earth began to pull part of Carolina away from Gondwana (fig. 9). This was the beginning of the rifting of Carolina from Gondwana and the birth of a new ocean called the Rheic Ocean by geologists. Carolina began to separate from Gondwana along a system of faults. As the faults moved, one side of the fault moved up and the other side moved down. Generally, when faults move, geologic **uplift** occurs on the side of the fault that moved up. This uplift formed higher ground that began to erode sending tons of rock debris down rivers and into the newly formed ocean. The quartzites and metaconglomerates present in Crowders Mountain State Park are examples of some of these deposits.

Based on interpretations from Dennis (2014) and the analysis of rock samples from locations throughout the Crowders Mountain area (see side bar section on research for more details), the first sediment to be deposited (and now preserved in Crowders Mountain State Park) was derived from the erosion of volcanic and other rocks associated with Carolina and the Gondwana continent (fig. 10). As rifting continued, the rifted portion of Carolina rapidly

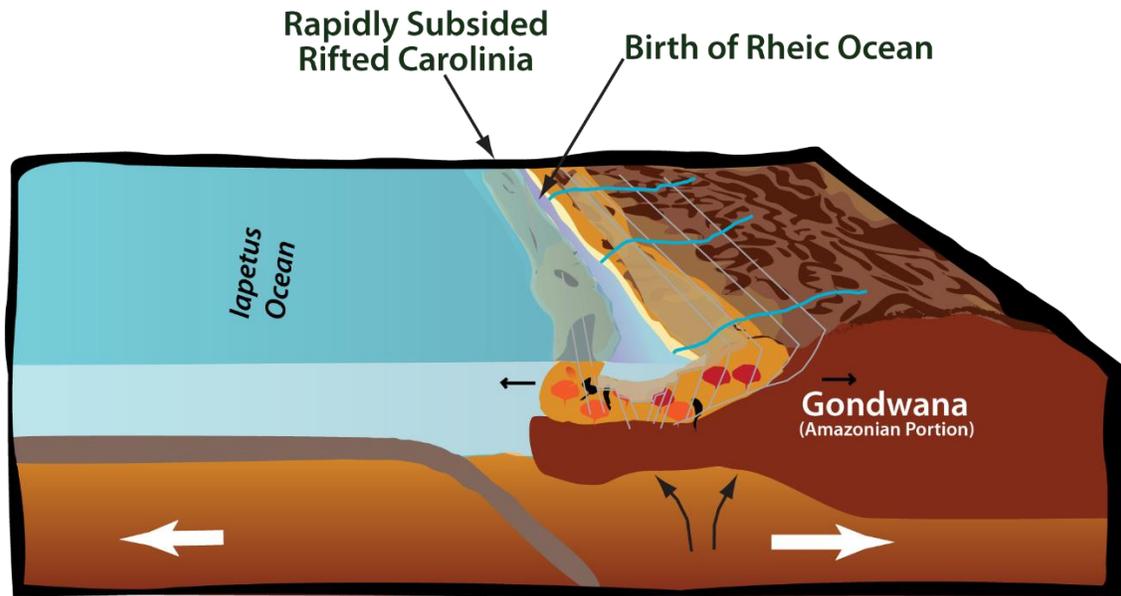


Figure 9: Diagram showing Carolina during the initial stages of rifting away from Gondwana with the birth of the Rheic Ocean – ca. 520 million years ago.

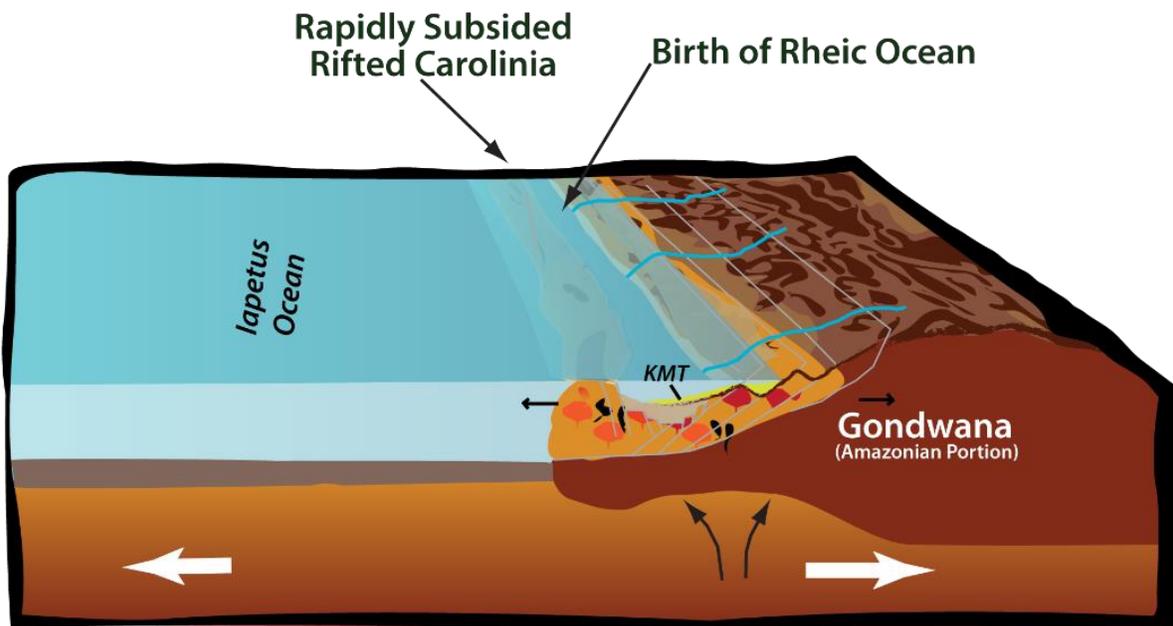


Figure 10: Diagram showing Carolina in the process of rifting from Gondwana. Rapid subsidence caused thousands of feet of sediment from Gondwana to be deposited in the forming Rheic Ocean (yellow colored unit labeled KMT). This sediment later became the rocks of the Kings Mountain terrane and of the Park.

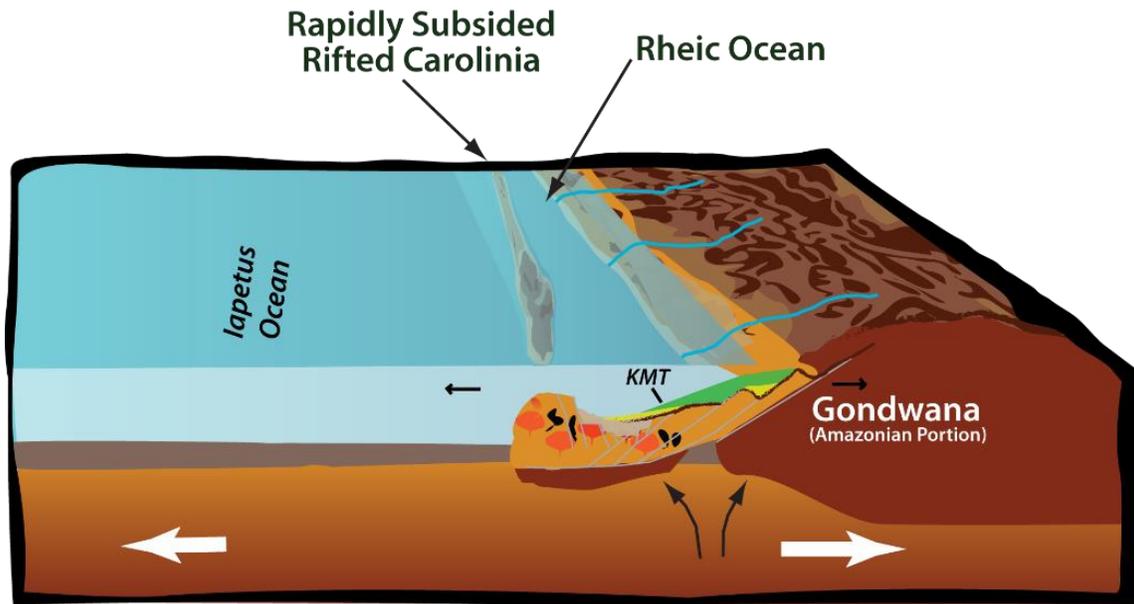


Figure 11: Diagram showing Carolina in the later stages of rifting from Gondwana. Additional sediment sourced from Gondwana is deposited (green colored unit labeled KMT). This sediment later became the rocks of the Kings Mountain terrane and of the Park.

subsided (sank) and was rapidly (in just a few million years) buried by thousands of feet of sediment that was washed into the new Rheic Ocean from the Gondwana continent (fig. 11). Dennis and his collaborators interpret that the rocks of Crowders Mountain State Park represent the rocks that mark the beginning phases of the rifting of Carolina and the **drifting** of Carolina as it started its journey toward ultimate collision with ancient North America.

Part of the Evidence of the Rifting of Carolina from Gondwana is Found in the Park.

Specifically, in the Park, three rock units (plates 1 and 2): Dixons Gap metaconglomerate (Cbc), aluminous quartzite (Cbaq), and the Jumping Branch Manganiferous Member (Cbj) play important roles in providing scientific evidence that the rocks in the Park represent the rifting and initial drifting of Carolina. Horton (2008) interprets the Dixons Gap metaconglomerate and the aluminous quartzite as being stratigraphically equivalent – which means they were deposited during the same time and under the same geologic conditions but display different grain sizes. So, not only are the aluminous quartzite and Dixons Gap metaconglomerate important to the Park because they form the ridges, but are important because they may represent some of the first pulses of sediment to be deposited as Carolina rifted from Gondwana.

The Jumping Branch Manganiferous Member is a thin, distinctive, and unique rock unit composed of manganese-rich minerals (mainly in the form of the metamorphic mineral – garnet). This unit likely represents the deposition of manganese-rich minerals (now metamorphosed) as the rifted Carolina rapidly subsided and began to break away from Gondwana (see Dennis, 2014)

Over One and a Half Miles of Sediment – a Whole lot of Sediment in a Short Amount of Time.

As Carolina subsided during the initial stages of rifting away from Gondwana, enormous amounts of sediment were deposited on top of Carolina. This sediment piled up in thousands of feet of layers of siltstones, sandstones, conglomerates and **limestones** – well over one and a half miles of sediment. West of the Crowders Mountain State Park, the Kings Mountain terrane includes two marble units (metamorphosed limestone). Scientific data from the marble units indicate that they were deposited in the Middle Cambrian probably just a few million years after the deposition of the rocks in Crowders Mountain State Park.

How do they know that? – Through years of work and building on the work of others.

Since the arrival of the first European settlers in the 1750's in the Kings Mountain, NC and Gaffney, SC area, geological materials have been utilized. Iron, marble, lead, gold, etc. have all been mined. Early entrepreneurs and geologists knew the rocks produced a bounty of geologic materials but did not understand how the rocks formed or how old they were. In 1931, a geologic map of the area was published (Keith and Sterrett, 1931). With a geologic map, in-depth studies could begin! Each subsequent researcher built upon the others work. Multiple geologists conducted additional geologic mapping and other research in the Kings Mountain terrane area. Much of that research is summarized in Horton et al. (1981). In subsequent years, additional work and/or refinement of previous work took place (example Horton, 2008). One of the most recent researchers in the area - Dr. Allen Dennis from the University of South Carolina Aiken (Dennis and Baker (2012), Dennis et al. (2012a and b), and Dennis (2014)) along with other researchers – has collected high-tech data that has led to the fascinating new interpretations on the age and origin of the rocks in the Kings Mountain terrane. The new data includes age-dating of the metamorphosed sedimentary rocks by a technique using **detrital zircons** and **carbon isotope stratigraphy** of the marbles present in the Kings Mountain terrane.

Allen Dennis and his collaborators collected rock samples from key rock types in the Kings Mountain terrane (including a sample of Dixons Gap metaconglomerate from Crowders

Mountain State Park at the Boulders Access Area). The rocks were crushed into a fine powder and the mineral zircon was separated out. Zircon is a naturally occurring mineral that contains the elements uranium and lead that are used in uranium-lead dating methods to determine the age of the rock by the age of the zircon. Dr. Dennis sampled the metamorphosed sedimentary rocks because they contain zircons that were eroded out of other rocks. The age of the youngest zircon in the rock will give you an estimate of the oldest age that the sedimentary rock was deposited (example: if the youngest detrital zircon is 522 million years old, then the sedimentary rock containing that zircon can be no older than 522 million years old).

The zircons were analyzed using high-tech analytical machines with equally high-tech names. Some of the zircons were analyzed by Dr. Dennis at the laser ablation system at the University of Arizona Laserchron Center and others were analyzed by Dr. Brent Miller at Texas A&M University by the Isotope Dilution – Thermal Ionization Mass Spectrometer. The analytical machines measure the concentrations of uranium and lead. The ratios of uranium to lead for the individual zircons are plotted on graphs and using equations for radioactive exponential decay, the age of the zircon is determined. The new data yielded ages of the youngest zircons to be approximately 522 million years old – which means the sedimentary rocks of the Kings Mountain terrane are no older than 522 million years old.

Similar to the detrital zircon analyses, the carbon isotope stratigraphy data involved the collection of rock samples of marble (metamorphosed limestone), crushing the samples to a fine powder, and analysis on a high-tech chemical analytical machine called a mass spectrometer. The concentrations of the isotopes of carbon-12 and carbon-13 were measured and carbon isotope ratios were determined. The ratios were then compared to carbon ratios worldwide through time. Data and interpretations from the carbon isotope stratigraphy indicate that the marbles in the Kings Mountain terrane were probably deposited sometime before approximately 500 million years ago. So the whole package of sedimentary rocks – over 1.5 miles of sediment – in the Kings Mountain terrane were deposited in an approximately 20 million year length of time.

Collision of Carolina with Ancient North America

One thing is for certain, Carolina traveled across the ancient ocean called Iapetus on a collision course with ancient North America. The exact details and timing of the collision are debatable with several geologists having differing interpretations (ex. Dennis (2007), Merschat and Hatcher (2007), and Hibbard et al. (2012)). The information presented in this guidebook attempts to simplify how Carolina accreted to ancient North America. As part of this simplification, important aspects of the contrasting interpretations are not discussed. The figures and timing estimates presented in this guide roughly follow that of Hibbard et al. (2012).

After approximately 520 million years ago to just before 450 million years ago, Carolina journeyed across the ancient Iapetus Ocean toward ancient North America (fig. 12). Around 450 million years ago, Carolina – which included the rocks of the Old Arc, New Arc, and deposits of the Kings Mountain terrane - began colliding with ancient North America (fig. 13). By 440 million years ago, the collision was nearly complete (fig. 13).

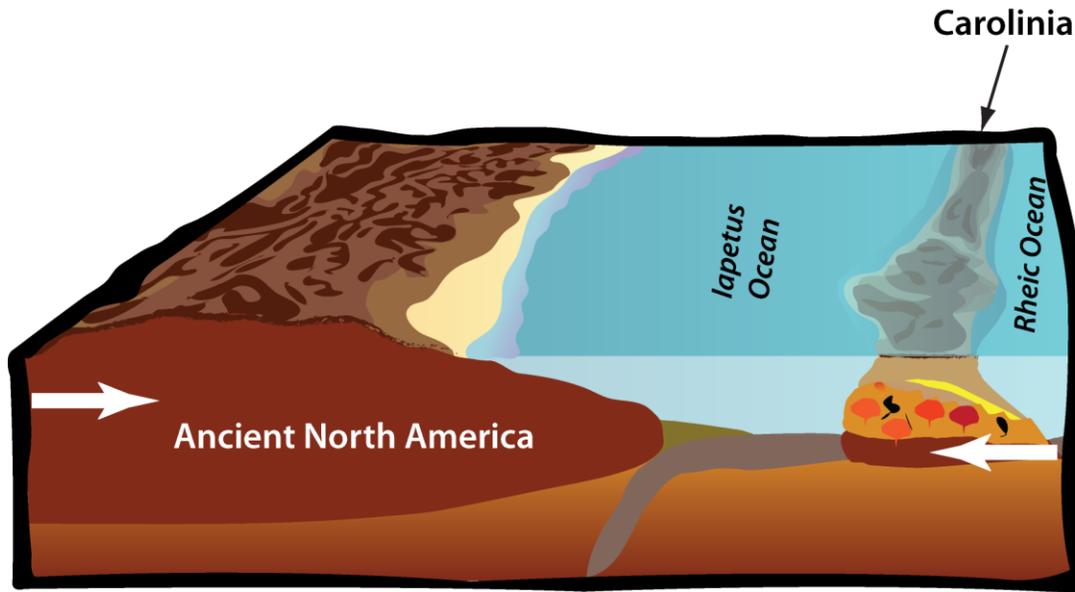


Figure 12: Diagram showing Carolina approaching the Ancient North America continent – ca. pre- 450 million years ago.

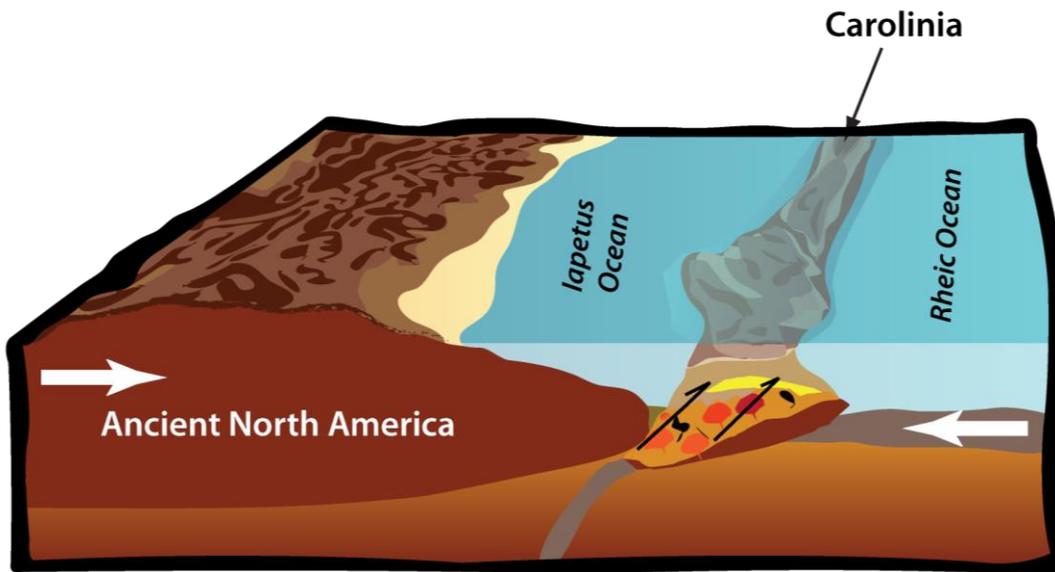


Figure 13: Diagram showing Carolina in the initial stages of colliding with the Ancient North America continent – ca. 450 million years ago.

Typically when volcanic chains collide with continents, the layers of rock are deformed into large folds called **anticlines** and **synclines**. Metamorphism usually accompanies the folding. Parts of Carolina (specifically the New Arc portions exposed in south-central North Carolina and into South Carolina) did undergo folding and low grade metamorphism. It is unclear whether the rocks of the Kings Mountain terrane were folded and metamorphosed at that time, but likely experienced some folding.

The Collision of Africa and the Formation of the Supercontinent Pangea

As Carolina was colliding with ancient North America, the ancient Atlantic Ocean (called the Iapetus Ocean by geologists) closed and the ancient African and North American continents were headed for collision (fig. 14).

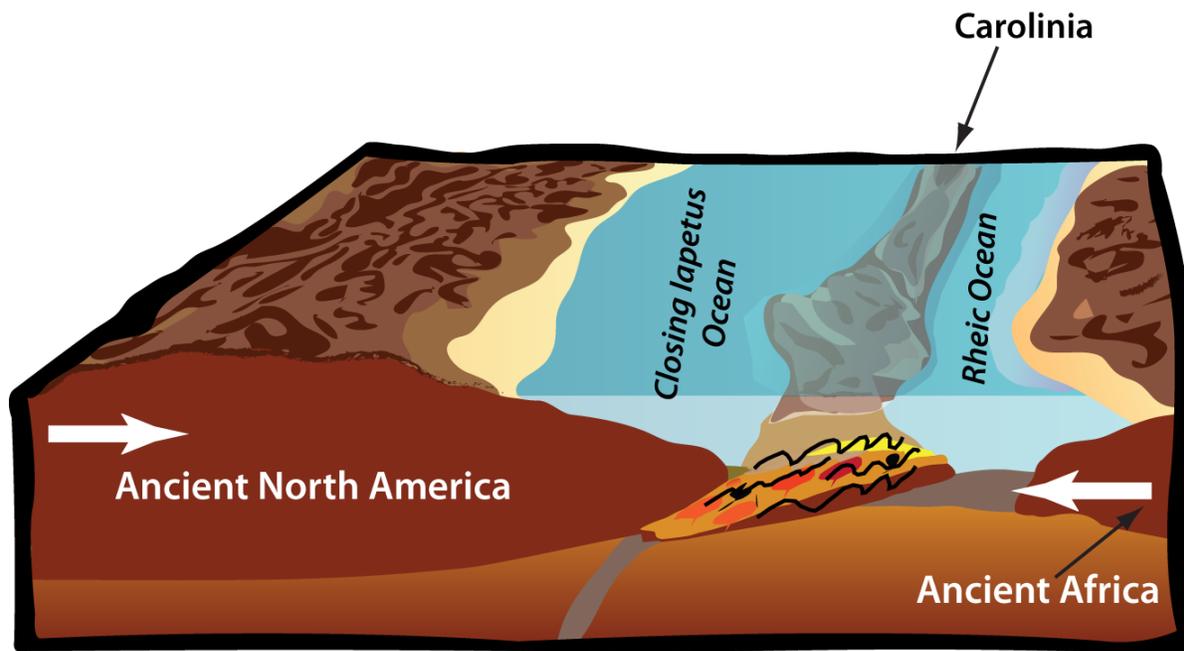


Figure 14: Diagram showing Carolina in the final stages of colliding with the Ancient North America continent – ca. 440 million years ago.

Beginning approximately 320 million years ago, ancient Africa began its collision into ancient North America. By 300 million years ago, the collision was nearly complete (fig. 15). This collision was so powerful that thick slabs of rock (miles thick) were transported to the northwest (present-day direction) over 100 miles, buried deeply in the Earth, metamorphosed, and folded into large scale folds and faults in many areas (fig. 15). In contrast, some areas of the Piedmont were spared from the deformation, however, the rocks of the Kings Mountain terrane were not. Existing geologic evidence suggests that the majority of the folding, faulting,

and metamorphism in the terrane is from the ca. 300 to 320 million year old event. During the folding, the layers of sedimentary and volcanic rocks were metamorphosed and essentially turned on their side. Many of the fin-shaped rock outcrops and ridges in Crowders Mountain State Park are actually the layers of the rock standing on end.

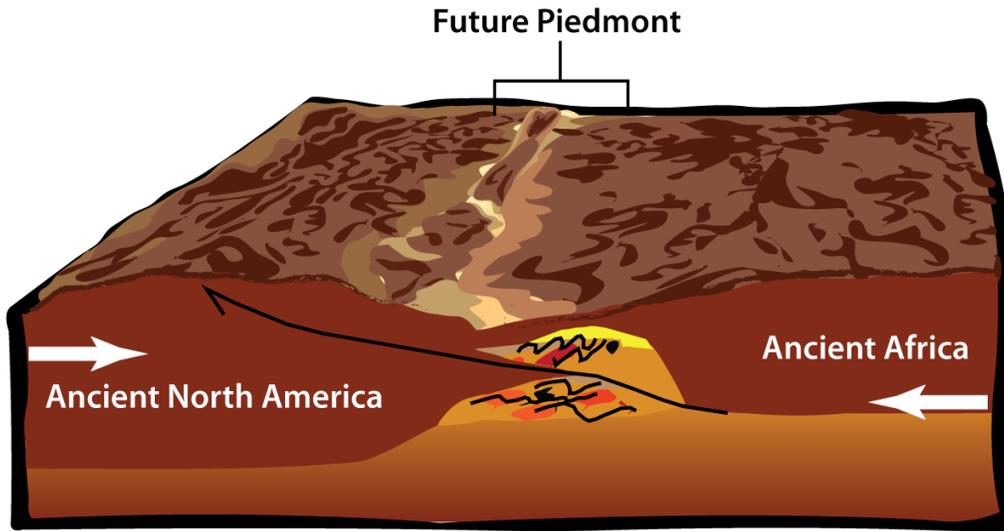


Figure 15: Diagram showing the simplified result of the collision of Ancient Africa and North America – ca. 300 million years ago.

This was the final chapter in the construction of the 1,000-mile long Appalachian Mountain chain (from Newfoundland to Alabama) and the supercontinent Pangea (fig. 16). When the continents were assembled into the single great continent called Pangea, North Carolina would have been deep in its interior with the coastline many thousands of miles away.

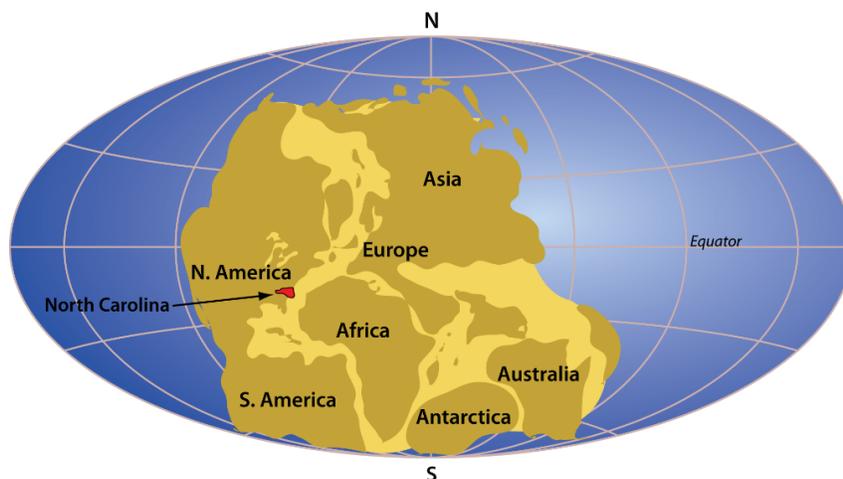
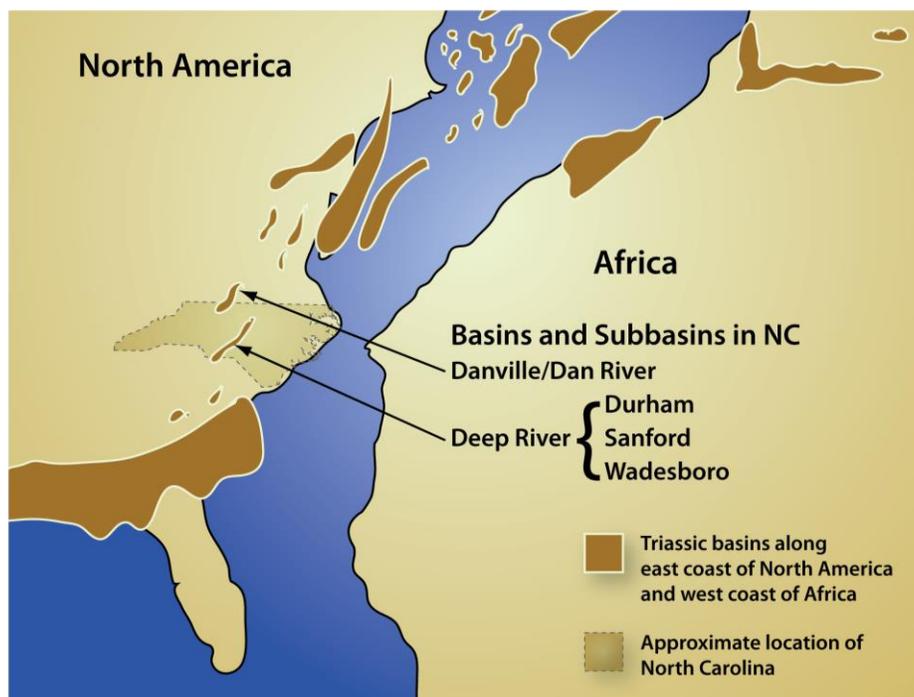


Figure 16: Cartoon sketch of the Supercontinent Pangea at end of Paleozoic era.

The Rifting of Pangea and the Formation of the Triassic Basins

North Carolina sat in the center of the supercontinent Pangea for almost 70 million years until the middle of the Triassic period (circa 230 million years ago), in the Mesozoic era, when great forces deep in the Earth initiated the breakup of Pangea. The breakup (or rifting), on the eastern margin of North America, can be described as the unzipping of a continent. The unzipping began east of the present-day southeastern United States and progressed up the continent toward New England and the Canadian Maritime Provinces (Olsen, 1997).

The continents did not rift apart in a simple line. Rifting initially progressed in a piecemeal manner with a main rift and many smaller rifts. Several rifts opened a short distance but stopped when the main rift became dominant. The main rift later became the Atlantic Ocean. The rifts that opened a short distance and stopped (failed rifts) became **rift-valleys** that quickly began to fill with sand, silt and clay. These failed rifts are part of a system of rift basins, called the Newark Supergroup (Olsen, 1978; Froelich and Olsen, 1984), that formed all along the east coast of North America (fig. 17).



(Modified from Ralph Lewis, Connecticut Geological Survey, www.wesleyan.edu/ctgeology/CtLandscapes/).

Figure 17: Generalized map of the major exposed and buried Triassic basins of the Newark Supergroup in North America and similar aged basins in Africa.

The rift basins are similar to the modern day East African Rift system. The cities of Durham and Sanford, NC sit within one of these rift basins, called the Deep River basin. The sand, silt and clay deposited within the Triassic basin later turned into the red to maroon-colored sandstones, siltstones and mudstones common in the Durham and Sanford areas. Parts of Eno River State

Park near Durham, NC; parts of Umstead State Park in Raleigh, NC; and Mayo River State Park near Mayodan, NC have rocks associated with the Triassic basins. The northern tip of the Kings Mountain terrane ends near a small Triassic basin called the Davie County basin (fig. 3).

Dikes Intrude the Piedmont as Pangea Splits Apart

Mafic magma from deep in the Earth welled up through fractures in the crust at the beginning of the Jurassic period (approximately 200 million years ago). This magma intruded the sediments of the Triassic basin and surrounding crystalline rocks of Carolina. At this same time, to the east of the Triassic basins, the main rift separating the North American and African continents was growing, causing the continents to slowly move away from each other. Mafic magma also welled up through the main rift zone, known as the mid-Atlantic ridge, and provided the raw material for the expanding ocean basin. Away from the main rift, the mafic magma squeezed into virtually any open crack throughout the Piedmont, the magma solidified into rock known as diabase. Diabase is a mafic rock with a composition similar to ocean floor **basalts**. Diabase **dikes** are present as thin (up to 200 feet wide – but more typically from a few feet to 40 feet wide) bodies that cut across the native (country) rock all throughout the Piedmont.

In Crowders Mountain State Park, diabase makes up a very small proportion of the rock under the Park. Diabase occurs in thin dikes in a few areas in the Park and is identified as thin lines labeled *Jd* on plates 1 and 2. When present on the surface, diabase usually occurs as brown-weathered spheroidal boulders strewn across the land surface. Diabase is composed of minerals that contain abundant iron and magnesium in comparison to the older metamorphic rocks. Because of the abundance of iron and magnesium, unique plant communities sometime develop on top of areas underlain by diabase. Diabase, although a very hard rock, is typically very fractured and often contains abundant water-bearing **fractures** or **joints**. Water-supply wells installed within diabase are typically high-yield wells (produce abundant water).

Destruction of the Mountain Chain and the Formation of the Coastal Plain

As soon as Pangea began to split apart, erosion began wearing down the mountains at a fast pace. From the Late Triassic to the end of the Cretaceous periods (66 to 230 million years ago), the great mountain range formed during the creation of Pangea was eroded down forming the Piedmont.

The mountains were essentially broken down into sand, silt and clay and transported along streams and rivers to the present-day east and southeast and gradually covered the faulted continental margin. The sediment was deposited in layers starting in the Jurassic period and

continues today. These sediments make up the Coastal Plain portion of the state. The Coastal Plain is an east-dipping wedge of sediment that is only a few feet thick just east of Raleigh but thickens to almost 10,000 feet below Cape Hatteras.

Uplift of the Piedmont and Formation of the Modern Landscape

From 66 million years ago to present, the Piedmont has continued to erode. The Piedmont experienced periods of slow uplift and erosion punctuated by periods of relatively rapid uplift and erosion. The uplift of the Piedmont is due in part to isostatic forces in the Earth's crust. Isostatic forces are similar to the buoyancy of a boat in water. The heavier the cargo, the lower the boat sits in the water. Conversely, the lighter the cargo the higher the boat sits in the water. The continental plates essentially float on top of the mantle. As rock is removed by erosion, the Earth's crust will react by uplifting a proportional amount - similar to a boat that will "sit high in the water" when its cargo is removed.

Generally, it is believed that the Piedmont was uplifted differentially (some parts uplifted faster than others) at different times since 66 million years ago. The timing of more rapid uplift and erosion of the Piedmont is not well understood by geomorphologists (scientists who study landforms), but generally occurred during the later stages of the Miocene epoch approximately 10 to 5 million years ago (Pavich, 1989; and Pazzaglia and Brandon, 1996; Poag and Sevon, 1989). So, very generally, the landscape we see today has been forming for about the last 5 million years. In that 5 million year span, erosion has worn away the land forming monadnocks where rock more resistant to erosion occur.

In the last 2.5 million years, the Earth has gone through several glacial periods ("Ice Ages"). The Earth was in the last Ice Age about 12,000 to 35,000 years ago. Although glaciers never covered North Carolina – glaciers were restricted to the northern portion of the North American continent - during the Ice Ages, North Carolina's climate was much colder and wetter than today with abundant rainfall and snow. Near freezing temperatures were likely the norm even during the day time. At night and during colder periods, water trapped in the cracks of rocks remained frozen most of the time. When the sun came out and heated the rock up just enough, the ice would melt in the cracks of the rock. At night, the water in the cracks re-froze splitting the rock a little more. This **freeze-thaw cycle** over hundreds and thousands of years broke-up the rock (**called ice wedging**) in the higher elevation portions of the Park depositing large amounts of cobble- and boulder-size blocks of quartzite on the slopes of Crowders Mountain and The Pinnacle. This rock debris called **colluvium** is identified as Qc on the geologic maps (plates 1 and 2).

Over time, the rock debris is broken down into smaller-sized sediment and washed into area streams and rivers. The sand, silt and clay deposits present in the stream beds in the Crowders Mountain area are slowly making a long journey toward the Atlantic Ocean. During flood

events, as the water level rises, sand, silt and clay particles are transported over the stream banks and are deposited. These deposits are known as **alluvium** or **floodplain** deposits. Alluvium is the youngest geologic unit in the area and is identified as Qal on the geologic maps (plates 1 and 2). Someday the sand, silt and clay material that composes the alluvium will be deposited at the mouth of the Cooper River (the final destination of sediment from the Crowders Mountain area) at Charleston, SC. If buried deep enough and long enough, it will become sandstone, siltstone and mudstone.

Mining History

To geologists, the Kings Mountain terrane and nearby areas is internationally known for its historic mineral wealth. The long list of geologic resources extracted from the Kings Mountain terrane and nearby areas include: iron, marble, gold, lead, barite, kyanite, lithium, scrap mica, feldspar, clay, and crushed stone. The early cultural history was strongly influenced by the mineral resources of the area. Today, the mining of rock for crushed stone and a company that is a major supplier of lithium are important parts of the area economy. A thorough review of the history of mining in the area is found in Horton (1981) and Moss (1981). An extensive review of the mineral resources is found in Gair (1989).

Settlers in the 1750's began utilizing iron deposits found in a zone from Gaffney, South Carolina to the Catawba River in North Carolina. By 1860, there were 13 iron works in the Lincoln, Cleveland, and Catawba counties area. These iron works contributed greatly to the war effort during the Civil War. Beginning in the late 1880s and 1890s, the Lake Superior region of Michigan and Minnesota were producing vast quantities of iron ore. The smaller deposits of North and South Carolina (although of local economic importance) could not be economically competitive with the iron ore from the Lake Superior region. So due to depleted resources and competition, this was the end of the economic exploitation of the iron industry in the Kings Mountain terrane.

Beds of marble extend from Gaffney, South Carolina into eastern Catawba County, North Carolina. The marble was first utilized in conjunction with the early iron industry (as a **flux** in the iron furnaces). Later the marble was utilized for the production of **lime** for agricultural uses, building products (most commonly cement) and chemical purposes.

The Kings Mountain terrane is dotted with over 75 former gold mines and prospects. A lead mine near Gaffney, South Carolina produced tons of lead ore during the Civil War. Barite (a barium sulfate mineral) was extensively mined in the Kings Creek area of South Carolina from the 1880's to 1960's. Additional barite mining occurred on land that is now part of Crowders Mountain State Park. Kyanite (like that present at Crowders Mountain State Park) and sillimanite have been mined in several locations in the Kings Mountain terrane.

The occurrence of abundant deposits of a lithium-bearing mineral named spodumene have been an important facet of the local economy and mining history. Spodumene occurs within **pegmatites** that intrude rocks of an adjacent geologic terrane (Cat Square terrane of the Inner Piedmont). Spodumene is no longer actively mined in the area but an important lithium processing plant is still active in Bessemer City, North Carolina. The facility in Bessemer City, processes lithium ore from South America. Lithium is used in pharmaceuticals (drugs with lithium as an ingredient), batteries, as a lubricant, and in many other industrial applications. Two inactive mine pits associated with the long history of lithium mining can be easily seen on figure 2. These inactive mines show up as large depressions northwest of The Pinnacle in Crowders Mountain State Park.

Historic mining activities in Crowders Mountain State Park

Evidence of the mining past is present within and nearby to Crowders Mountain State Park. Deposits of Iron, barite, and kyanite have been actively explored and in some cases exploited on present day Park property. Gold and manganese deposits also occur just outside of the Park boundaries. Plates 1 and 2 indicate the location of several abandoned pits, a shaft, an **adit**, and multiple prospects. Near the top of Crowders Mountain is an abandoned mine shaft that was sunk to explore for iron ore. An abandoned adit also associated with iron exploration is present on the northeast side of Crowders Mountain. Various open pits for barite and kyanite mining are present, and numerous prospects are indicated on Plates 1 and 2. **Old mines, prospects and their workings are dangerous places. Care should be taken when walking around the features. Under no circumstances should anyone enter the workings. Injury and/or death can occur.** Please remember that rock and mineral collecting is **STRICTLY PROHIBITED** in the State Park.

Glossary

The following is a geologic glossary of terms and concepts used in this guide. Many of the definitions are modified from the American Geologic Institute Glossary of Geology, edited by Bates and Jackson (1987). Other definitions are modified from the USGS National Park Service Geologic Glossary. Some of the terms below have multiple, non-geologic meanings.

Adit – A horizontal opening into a mine. Like a tunnel.

Alluvium – Clay, silt, sand, gravel or similar unconsolidated detrital material deposited during relatively recent geologic time by a stream or other body of running water. Alluvium usually contains rounded particles and usually collects in the channels and floodplains of creeks, streams, rivers and lakes.

Anticline - An upward-curving (convex) fold in rock that resembles an arch. The central part of an eroded anticline contains the oldest section of rock.

Ash - Fine particles, measuring less than 2 millimeter in diameter, of volcanic rock and glass blown into the atmosphere by a volcanic eruption.

Basalt - A dark, fine-grained, *extrusive* (volcanic) igneous rock with a low silica content (40% to 50%), but rich in iron, magnesium and calcium. Basalt makes up most of the ocean floor and is the most abundant volcanic rock in the Earth's crust.

Bedrock – Solid rock that lies beneath soil and other loose surface materials.

Blue Ridge Escarpment – The Blue Ridge Escarpment is a zone of steep, east-facing slopes that mark the transition from the mountain region to the Piedmont region.

Boulder – Loose particles of rock (sediment) larger than 10.1 inches (256 millimeters). Grapefruit to watermelon or greater size.

Carbon isotope stratigraphy – A method of determining the relative ages of sediments based on measurements of carbon isotopes. The basic principle is that the proportions of carbon isotopes incorporated in biogenic minerals (like the calcium carbonate in marbles) change through time due to changing geological and environmental conditions. Carbon isotope data can be compared to similar data throughout the world and correlated to an approximate age range.

Carolina terrane – A composite volcanic arc that formed in the Precambrian through Cambrian exotic (far away) to North America.

Carolinia – The name given by geologists for the amalgamated volcanic terranes that compose Carolinia and include the Kings Mountain, Carolina, Charlotte, Raleigh, Falls Lake, Crabtree, Spring Hope, Roanoke Rapids, and other terranes. The components of Carolinia all formed as **exotic terranes** from North America.

Cobble – Loose particles of rock (sediment) that range in size from 2.5 – 10.1 inches (64 - 256 millimeters) in diameter. Cobbles are larger than pebbles, but smaller than boulders.

Conglomerate – A sedimentary rock composed of fragments of rock that are typically rounded by tumbling in water.

Clay-size – Sediment size for any particle smaller than 0.000078740 inches (1/256 of a millimeter) in diameter.

Colluvium – A term used for loose and unconsolidated earth material usually on slopes or at the base of a slope or cliff.

Contact – The surface or area where two rock types contact (touch) each other. On a geologic map, a contact is displayed as a line where rock type or the rock unit changes.

Convergent plate boundary - A convergent plate boundary refers to when two lithospheric plates of the Earth meet and one plate is forced down into the mantle. One plate is subducted (pushed down) under the other plate. Volcanoes typically occur at convergent plate boundaries.

Diabase –The name of an igneous intrusive rock of Jurassic age and mafic composition that intruded the east coast during the rifting of Pangea. Diabase has a similar composition to ocean basalts.

Deformation event – A geologic event that causes folding, faulting, with or without metamorphism. A deformation even may be caused by the colliding of volcanic arcs with continents, continents with continents, or the rifting of continents, etc.

Dike - A sheet-like or tabular-shaped igneous intrusion that cuts across the sedimentary layering, metamorphic foliation or other texture of a pre-existing rock.

Detrital zircons – Zircon is a naturally occurring mineral that forms in igneous rocks with the chemical formula $ZrSiO_4$. Zircon also contains the elements uranium and lead, in trace amounts, that are used in uranium-lead dating methods to determine the age of the rock by the age of the zircon. Detrital zircons are zircons that have been eroded out of their parent rock and deposited as sediments. Detrital zircons can tell you the age of the rocks eroded that supplied the sediment source of a sedimentary rock.

Devonian – A geologic time period from approximately 415 to 360 million years ago.

Drifting – A general term when used in association with the movement of continents or volcanic arcs refers to the movement of land masses via plate tectonics.

Economic mineral – Refers to minerals or other earth material that can be removed profitably by humans for industrial or other purposes.

Erosion – The removal of soil and rock material by weathering (e.g. rain, wind, waves).

Exhalative deposit – Refers to a deposit that is interpreted to have been formed from the release of metal- or mineral-rich hydrothermal fluid into water that precipitates the deposit in layers on top of sediments.

Exotic terrane – A land mass (separated from other terranes by faults) that is interpreted to have originated away from ancient North America.

Extrusive – Igneous rocks that cool and solidify rapidly at or very near the Earth's surface; also known as volcanic rocks.

Fall Zone – The Fall Zone marks the transition from the crystalline rocks of the Piedmont to the sedimentary deposits of the Coastal Plain. The Fall Zone corresponds to the location of the fall line. The fall line is an imaginary line that connects waterfalls of parallel rivers which marks the transition from the Piedmont to the Coastal plain in the eastern United States.

Fault - A fracture in the Earth along which one side has moved relative to the other. Sudden movements on faults cause earthquakes.

Felsic – Felsic is a term used in geology to refer to magma or rocks formed from magma enriched in silica, aluminum, sodium and potassium. Rocks formed from felsic magmas typically contain the minerals quartz, and sodium and potassium feldspars. The word is derived

by combining the words *feldspar* and *silica*. Older literature often uses the synonym *acid* or *acidic* when referring to a felsic magma or rock.

Floodplain - A relatively flat surface next to a stream. During floods, when the stream overflows its banks, water flows over the floodplain. Streams construct floodplains by depositing their sediment load as a flood event wanes.

Flux – A term used in metallurgy for any substance that can be added to melting ore to promote fluidity and remove contaminants. Limestone is a common flux in the smelting of iron ore.

Fold – A geologic fold occurs when bodies of rock are bent or curved from deformation. See anticline and syncline.

Foliation - Aligned layers of minerals characteristic of some metamorphic rocks. Foliation forms in metamorphic rocks when pressure squeezes flat or elongates minerals so that they become aligned.

Formation – Formation refers to a body or package of rocks that cover a defined area that have distinctive characteristics that can help geologists map the extent of the rocks.

Fracture - Any break in rock along which no significant movement has occurred.

Freeze-thaw cycle – Water trapped in cracks in rock can repeatedly freeze and thaw as the temperature changes to below and above freezing. This repeated freezing and thawing will help break down rocks.

Gondwana – An ancient continent formed in the southern hemisphere and included parts of South America, Africa, India, Australia, and Antarctica.

Hot Springs – Naturally occurring springs that discharge hot water to the surface. The water is heated by magma located deep in the earth.

Hydrothermal – Hydrothermal (hydro = water; thermal = hot) refers to systems that are related to naturally occurring water that is heated by magma.

Hydrothermal alteration – Hydrothermal alteration refers to the change of rock and the minerals that make up the rock due to the presence of hot water that is heated by magma.

Hydrothermal alteration of rock can be considered a type of low temperature and low pressure metamorphism.

Ice wedging – A type of mechanical weathering of rocks in which water as it freezes in fractures breaks the rock by expansion.

Igneous – Pertains to rock formed when molten rock (magma) cools and solidifies (crystallizes).

Interpretation – Related to the act of providing an explanation for something. In geology, interpretations are based on data. Different scientists may formulate different interpretations using the same set of data depending on their background and experience.

Intrusive – Igneous rock that cools and solidifies beneath the Earth's surface. (= plutonic rock)

Joint – A narrow crack in rock along which there has been no significant movement of either side. Joints commonly form in parallel sets.

Jurassic – A geologic time period of approximately 145 to 201 million years ago.

LiDAR elevation data – LiDAR is an abbreviation for **L**ight **D**etection **A**nd **R**anging. LiDAR elevation data is acquired using an airplane-mounted laser transmitter that sends beams of light down to the ground. The laser beam makes distance measurements to and from the surface of the earth from instrumentation on the airplane. Very accurate elevations data is later derived.

Lime – In agriculture, lime is a soil additive made from pulverized limestone and/or marble. Lime made from heating pulverized limestone and/or marble is used in building products (most commonly cement) and chemical purposes.

Limestone – A sedimentary rock composed mainly of the mineral calcite – usually from shells of once-living organism or other organic processes.

Lithification –The change of unconsolidated sediment or volcanic material into rock.

Mafic - Mafic is a term used in geology to refer to magma or rocks formed from magma enriched in magnesium and iron. Rocks formed from mafic magmas typically contain dark colored minerals like pyroxene, amphibole and olivine. Mafic rocks may also contain calcium-rich plagioclase feldspar. The word is derived by combining the words *magnesium* and *ferric*

(iron-containing). Older literature often uses the synonym *basic* when referring to a mafic magma or rock.

Magma - Molten rock. Magma may be completely liquid or a mixture of liquid rock, dissolved gases and crystals. Molten rock that flows out onto the Earth's surface is called lava.

Metaconglomerate – Metamorphosed conglomerate. Conglomerate is a sedimentary rock composed of fragments of rock that are typically rounded by tumbling in water.

Metamorphic - Pertains to a rock that has undergone chemical or structural changes produced by increase in heat or pressure, or by replacement of elements by hot, chemically active fluids (related to metamorphosed).

Metatuff – Metamorphosed tuff. Tuff is a volcanic rock made up of rock and mineral fragments in a volcanic ash matrix.

Mica - Group of minerals composed of varying amounts of aluminum, potassium, magnesium, iron and water. All micas form flat, plate-like crystals. Crystals cleave into smooth flakes. Biotite is dark, black or brown mica; muscovite is light-colored or clear mica.

Mine – An excavation in the Earth for extracting geologic materials (minerals, rock, etc.).

Monadnock - A mountain or area of greater elevation that has resisted erosion and stands isolated in an essentially level area.

New Arc – A non-technical term used to simplify the geologic history of the Carolina terrane. Refers to the volcanic and sedimentary rocks associated with the ca. 550 to 530 million year old Albemarle arc in the Carolina terrane.

Old Arc - A non-technical term used to simplify the geologic history of the Carolina terrane. Refers to the volcanic and sedimentary rocks associated with the ca. 630 to 612 million year old Hyco arc in the Carolina terrane.

Outcrop – A mass of rock that appears at the Earth's surface.

Pangea - The supercontinent which formed at the end of the Paleozoic Era and began breaking up about 245 million years ago to form today's continents.

Pegmatite – A type of granite containing very large (usually one inch or more) mineral grains.

Phyllite - A very fine-grained, foliated metamorphic rock. Similar to slate but distinguished by its sheen, which is produced by barely visible flakes of mica (usually sericite).

Physiographic province – A region in which all parts are similar in general geologic rock type, climate and geomorphic history. Its topographic relief differs significantly from adjacent regions.

Prospect – A location that has been identified as a potential site of economic mineral deposits. Prospects may be in the form of pits, shafts, adits, etc. A prospect is different from a mine in that no production of economic minerals had or has occurred.

Quartzite – A metamorphic rock formed from sandstone composed of mainly quartz mineral grains. Quartzite is very resistant to erosion since it is mainly composed of the resistant mineral quartz.

Rift-valley – A rift-valley is an elongated valley bounded by faults that is created by the splitting apart of the Earth's crust. The Triassic basins are located in rift-valleys.

Sand-size - Loose particles of rock or mineral (sediment) that range in size from 0.079 – 0.0025 inches (0.0625 - 2.0 millimeters) in diameter.

Saprolite - Partially decomposed rock that is soft, typically rich in clay and remaining in its original place. Saprolite is also known as rotten rock.

Schist – A metamorphic rock typically formed from the metamorphism of sedimentary rock types like mudstone, siltstone, shale, etc. Schist typically contain abundant mica minerals like biotite and muscovite.

Sedimentary - Sedimentary rocks are formed from pre-existing rocks or pieces of once-living organisms. They form from deposits that accumulate on the Earth's surface. Sedimentary rocks often have distinctive layering or bedding.

Sericite – A white, fine-grained potassium mica that occurs as small flakes. In a general sense, sericite may be considered the fine-grained variety of muscovite mica.

Silt-size - Loose particles of rock or mineral (sediment) that range in size from 0.002 - 0.0625 millimeters in diameter. Silt is finer than sand, but coarser than clay.

Silurian – A geologic time period of approximately 415 to 440 million years ago.

Syncline - A downward-curving (concave) fold in rock that resembles the letter “U”. The central part contains the youngest section of rock.

Terrane – A defined area of land that is separated from other areas by geologic faults. The rocks in a terrane share a common geologic history. A geologic terrane is differentiated from other terranes by its different geologic history, rock types, deformation history, etc.

Uplift – A geologic process in which land masses are uplifted in response to natural causes. Uplift may occur along faults as one side of the fault moves up relative to the other side. The relative movement may form higher elevation areas that are then eroded.

Volcanic – Pertains to igneous rock that cools and solidifies at or very near the Earth’s surface. Volcanoes produce volcanic rock.

Volcanic island arc - Arcuate chain of volcanoes formed in association with a subducting plate. The arc forms where the downgoing descending plate becomes hot enough to release water and gases that rise into the overlying mantle and cause it to melt. Volcanic island arc rocks are mostly volcanic rocks from the volcanoes and sedimentary rocks made up of eroded debris from the volcanoes.

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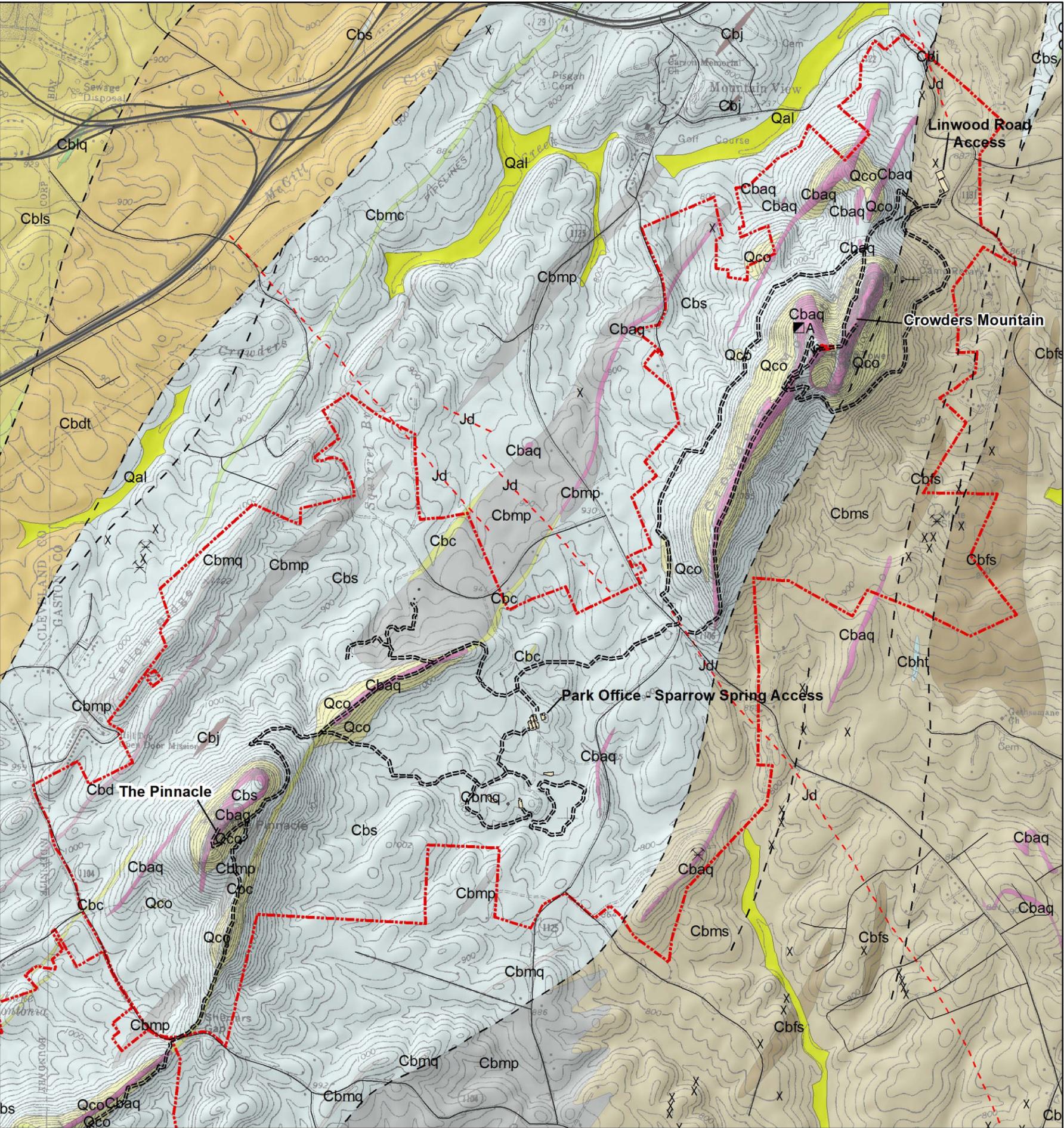
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Geologic Map of the Northeast Portion of Crowders Mountain State Park, NC

Geology Modified From Horton (2008)

Park Boundary and Trails Provided By NC Parks
 LiDAR Hillshade from NC Floodplain Mapping



SURFICIAL DEPOSITS

- Qal - Alluvium (Holocene)
- Qco - Colluvium (Holocene and Pleistocene)

INTRUSIVE ROCKS

- Jd - Olivine diabase

KINGS MOUNTAIN SEQUENCE

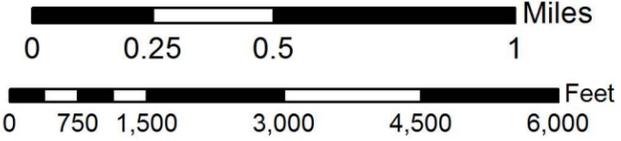
Blacksburg Formation

- Cblc - Chlorite phyllonite
- Cbls - Phyllitic metasiltstone
- CZblq - Laminated micaceous quartzite

Battleground Formation

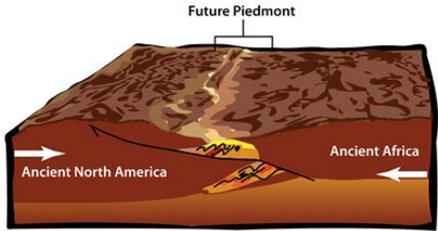
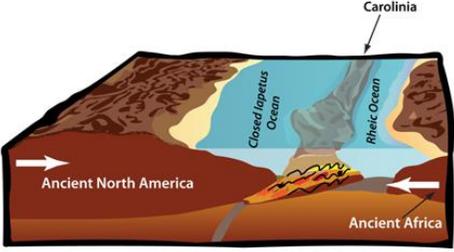
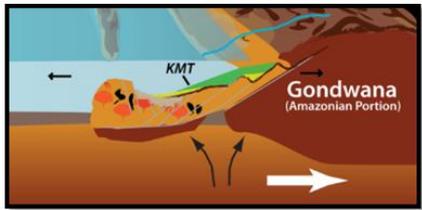
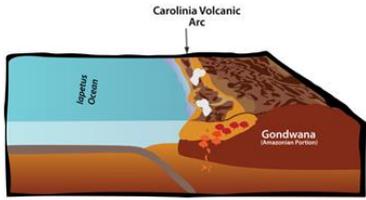
- Cbdt - Metadacite and metatromphemite
- Cbs - Quartz-sericite phyllite and schist
- Cbmc - Crowders Creek Metaconglomerate Member
- Cbmq - Micaceous quartzite
- Cbd - Draytonville Metaconglomerate Member
- Cbj - Jumping Branch Manganiferous Member
- Cbc - Dixon Gap Metaconglomerate Member
- Cbaq - Aluminous quartzite
- Cbmp - Mottled phyllitic metatuff
- Cbvc - Volcanic metaconglomerate
- Cbms - Biotite-muscovite schist
- Cbfs - Felsic schist and gneiss (metafelsite)
- Cbht - Metavolcanic hornblende gneiss

- hiking trails
- park boundary
- park facilities - (parking lots and buildings)
- - - - - fault
- - - - - diabase dike trend
- Historic Mining Features
- ⊗ open pit - abandoned
- mine adit - abandoned
- x prospect
- A shaft - abandoned



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Approximate Age Age (millions of years ago)	Illustration of Simplified Major Geologic Events with respect to Carolina and the Kings Mountain Terrane	General Event
5 - Present		Period of renewed erosion and formation of landscape present at Crowders Mtn State Park
66 - 5		Erosion and continual formation of Coastal Plain
245 - 66		Rifting of Pangea (Formation of Triassic basins, intrusion of diabase and formation of the Coastal Plain)
300		Collision of Ancient Africa and Formation of Pangea
450 - 440		Collision of Carolina with Laurentia
520 - 500		Deposition of Kings Mountain terrane rocks as Carolina rifts from Gondwana
550 - 530		New Arc (Built on top of old arc near or on top of Gondwanan crust)
630 - 610		Old Arc