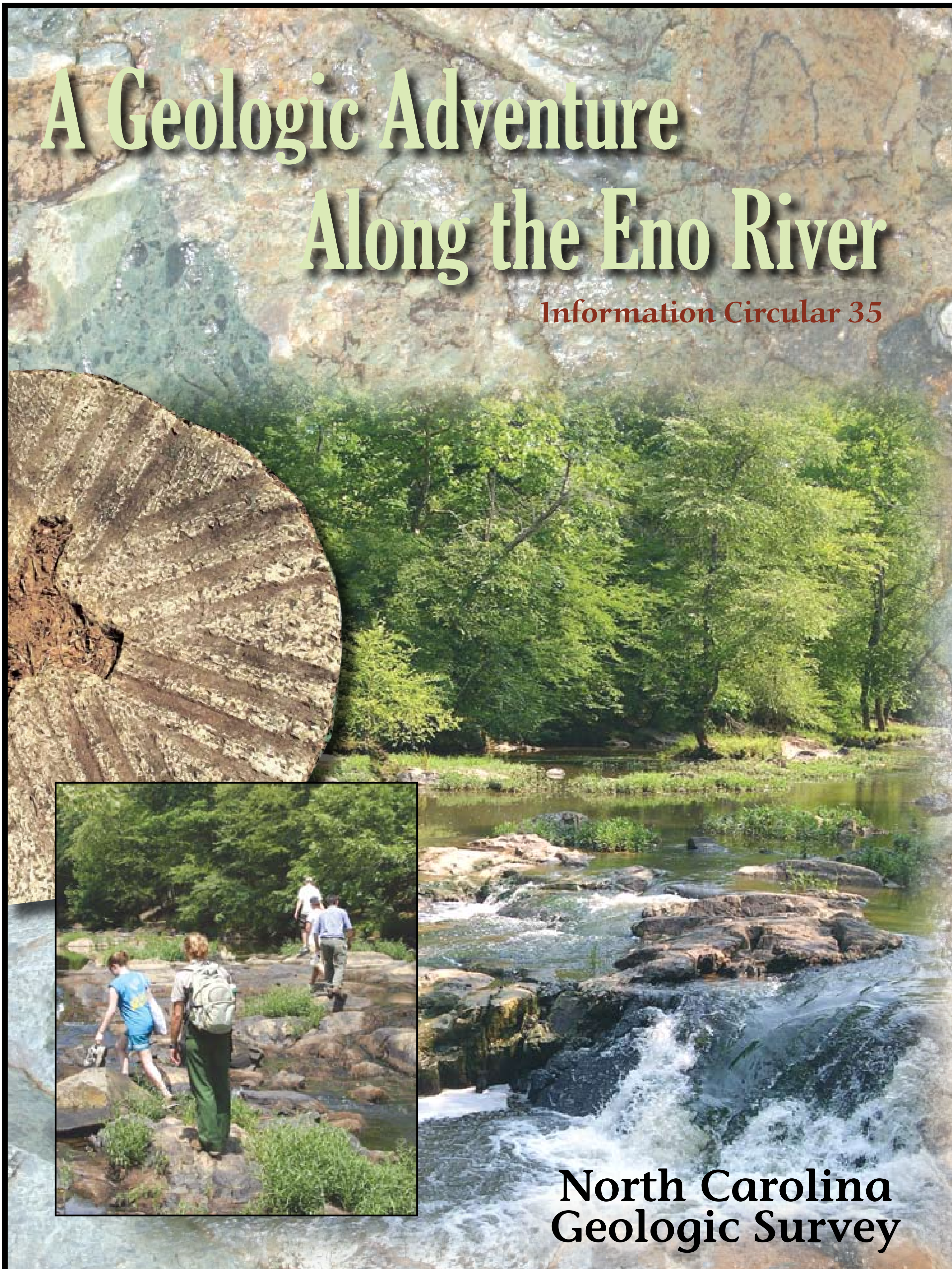
A Geologic Adventure Along the Eno River

Information Circular 35

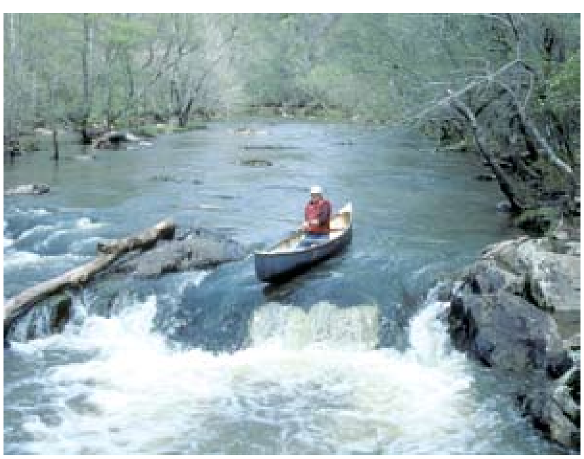


North Carolina Geologic Survey

Few's Ford - Photo by Susan Roemer

Rapids at Few's Ford - Photo by Duncan Heron

Photo by Denise Smith



Rapids at Few's Ford - Photo by Duncan Heron

West Point Mill - Photo by Susan Roemer

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Information Circular 35
by Philip J. Bradley

North Carolina Geological Survey Section
Division of Land Resources
Department of Environment and Natural Resources

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The geologic mapping that forms the foundation for the understanding of the rocks of the Eno River was funded in part by the USGS National Cooperative Geologic Mapping Program – STATEMAP component. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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I. Introduction

The Eno River begins in northwest Orange County and flows approximately 40 miles through the historic town of Hillsborough, Eno River State Park and the city of Durham. The Eno River joins the Flat and Little rivers, just east of Durham, to become the Neuse River, which flows into Falls Lake. This relatively short journey of the Eno flows past a contrasting landscape of steep river bluffs, forests, rolling hills, urban areas, historic mills and river crossings (fords). The rocks exposed along the Eno record a long and sometimes violent geologic past of more than half a billon years of Earth's history.

The Eno River basin includes the river, its tributaries and all the land that they drain. The basin is part of a grand ecosystem composed of smaller systems involving water (hydrologic), air (atmospheric), life (biologic: animal and human) and rocks (geologic). The importance of the hydrologic, atmospheric and biologic systems is easily recognized in everyday life. The role that geology plays in everyday life is much less evident. In many respects the underlying geology along the Eno River is responsible for many features of the hydrologic and biologic systems along the river. For example, the geology controls the path the river travels in some locations. Geology also plays a part in controlling the steepness of the river banks, type of plants that grow in certain places, selection of mill sites by early settlers and the presence of fords used by early settlers.

This Information Circular presents the geologic story of the Eno River with insight into the landscape, and the biological and human interaction with the underlying geology. This guide provides details of the basic land forms and shape of the land (known as physiography and geomorphology) of the Eno River basin. General descriptions and origins of the common rock types found along the Eno River and basic geologic history - "The Geologic Story"- of the area is also presented. Interpretive trail guides for select trails within Eno River State Park and West Point on the Eno Park are also provided.

Two companion maps are provided. A generalized geologic map (pl. 1) shows the distribution of rock types along the Eno River from Hillsborough to Falls Lake. A raised relief map (pl. 2) shows the elevation differences along the Eno River and the locations of select mill sites. The generalized geologic map was derived from detailed geologic mapping funded by the U.S. Geological Survey (USGS) STATEMAP Program and conducted by staff of the N.C. Geological Survey (NCGS) from 2002-2005 (Bradley and Gay, 2005; Phillips et al., 2004). The hillshade elevation map (pl. 2) was constructed by NCGS staff using ***LiDAR elevation data*** processed by the N.C. Department of Transportation (Medina, 2005). Geologic and technical terms used in the text are indicated in ***bold italics*** and defined in the glossary at the back of this publication.

Please remember that rock and mineral collecting is **STRICTLY PROHIBITED** in Eno River State Park as well as land operated by the city of Durham Parks and Recreation Department. The staff of the N.C. Geological Survey and Division of Parks and Recreation hope you enjoy your geologic adventures along the Eno River and urge you to take only memories and photographs away from your experience. Although the river environment remains a peaceful haven, it is vulnerable to the pressures of rapidly expanding urban development and your everyday activities. Please act responsibly and follow all park rules and respect private landowner's rights during your geologic adventures.

This publication is dedicated to the efforts of the Eno River Association, the Triangle Land Conservancy, the N.C. Division of Parks and Recreation, city of Durham Parks and Recreation Department, Friends of West Point and countless other organizations and their members who love and help preserve and protect the land along the banks of the Eno River for all to enjoy.

II. Geographic Setting of the Eno River

The Eno River basin lies within the Piedmont ***physiographic province*** of North Carolina (fig. 1). The Piedmont is separated from the Mountain physiographic province by the ***Blue Ridge Escarpment***. East of the Eno River, 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 (114 centimeters) of rain annually, speeds the chemical breakdown and erosion of rock. Unlike the arid west where rock outcrops are plentiful, rock in the Piedmont is typically found buried beneath a thick (3 to 50 feet / 1 to 15 meters) 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.

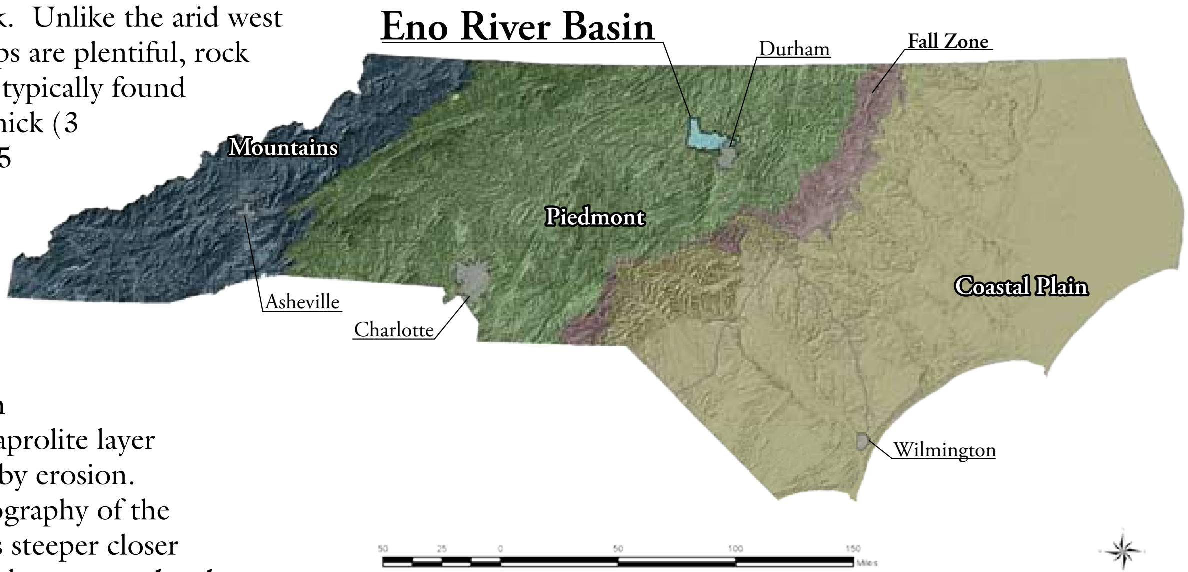


Figure 1 – *Location of Eno River basin and physiographic provinces of North Carolina.*

Is There a Monadnock Around Here?

The topography surrounding the Eno River as it flows between Hillsborough and the Few's Mill area (pl. 2) is unique to the eastern Piedmont. Located near the eastern edge of the Piedmont, this area has topography similar to the foothills in the western portion of the Piedmont province near the mountains. The west summit of Occoneechee Mountain rises more than 300 feet (90 meters) above the nearby Eno River and is the highest point in Orange County, with an elevation of 867 feet (264 meters) above mean sea level (msl). Compared with typical locations in the Piedmont, rock outcrops are relatively abundant in and around the Eno River in this area. Occoneechee Mountain, along with a series of other hills in this area, are monadnocks that are part of a larger northeast-trending dissected plateau clearly visible on Plate 2. The Eno River cuts directly through this plateau causing steep topography of several hundred feet within close proximity to the river (e.g., Occoneechee Mountain, Poplar Ridge and Cox Mountain).

Topography and the Character of the Eno River (Modified from Heron, 1978)

The Eno River is located in the Eno River basin (fig. 2). It drains approximately 155 square miles of land in Orange and Durham counties and is a tributary of the Neuse River. The Eno River basin is technically a sub-basin of the larger Neuse River basin. In some respects, the story of the Eno River is the story of "two" rivers. "One" river is characterized by a narrow river valley with steep banks and narrow to nonexistent floodplain. The "other" river is dominated by a generally curving flow path that is characterized by a meandering river with a wide floodplain. The Eno River is not two rivers but one river that flows over two drastically different rock types. It is the character of the rock types that controls the nature of the topography and therefore the nature of the river.

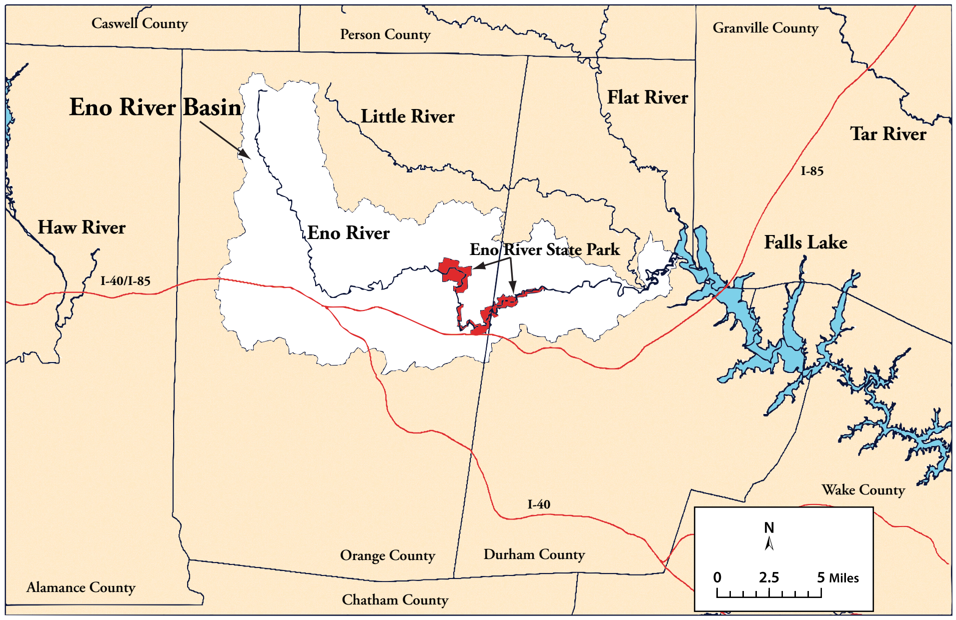


Figure 2 – *Detailed location of Eno River Basin and the Eno River with respect to the Little and Flat Rivers and Falls Lake.*

A significant topographic break occurs along the Eno River just east of West Point on the Eno Park and Roxboro Road in Durham (pl. 2). At this location, the Eno River flows from a portion of the Piedmont sometimes referred to as the ***Piedmont upland*** into another portion of the Piedmont known as the ***Triassic lowland***. This topographic break is caused by two fundamentally different rock types. The Piedmont upland is underlain by very hard and resistant ***metamorphosed igneous*** rocks and the Triassic lowland are underlain by relatively soft and less resistant ***sedimentary*** rocks of the Durham Triassic basin. The characteristics of these rock types will be discussed in detail later. West of Hillsborough within the Piedmont upland, the elevation of the Eno River is approximately 550 feet (168 meters) above msl. The elevation of the Eno near Roxboro Road in Durham, located at the transition between the Piedmont upland and the Triassic lowland, is about 275 feet (84 meters) above msl. After the Eno joins the Flat and Little Rivers and flows into Falls Lake, the elevation of the river is approximately 250 feet (76 meters) above msl. A 3-D generalized diagram of the Eno River is provided to illustrate the change in topography from the Piedmont upland to the Triassic lowland (Fig. 3).

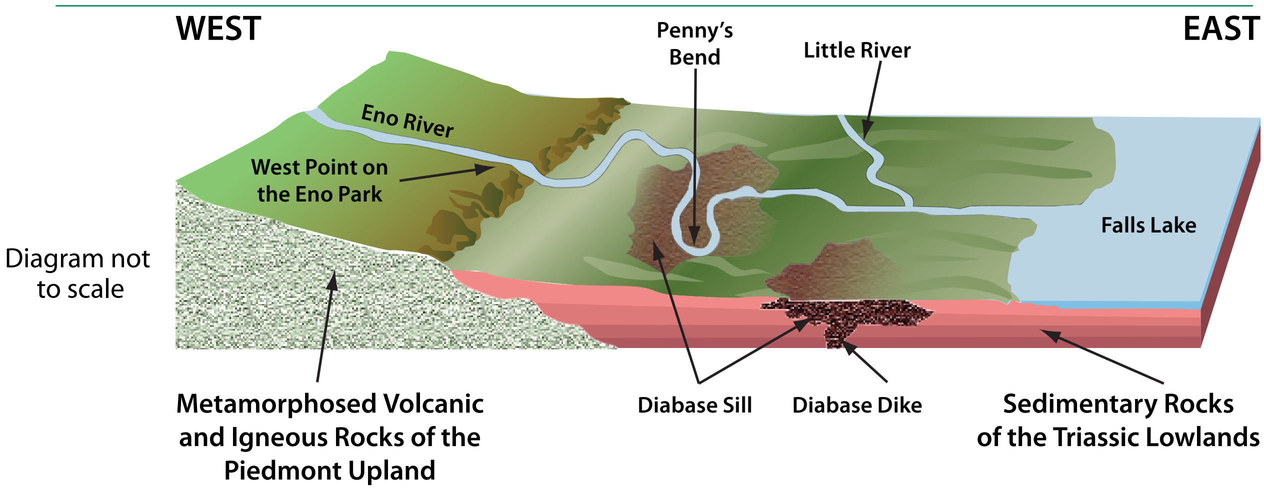


Figure 3 - 3-D generalized diagram of the Eno River as it flows over the boundary of the Piedmont upland and Triassic lowland.

The difference in elevation and rock type between the Piedmont upland and the Triassic lowland affects the speed at which the water flows and the shape of the river's ***floodplain***. In the Piedmont upland, the Eno River is characterized by fast moving water, where erosion has deeply cut the rock into a relatively narrow, V-shaped river valley. Floodplain deposits are typically restricted to thin strips (10 to 100 feet / 3 to 30 meters wide) on the banks of the river. Locally, slightly larger floodplain deposits may be present upstream of very resistant layers of rock. These resistant layers form a ***local base level*** that temporarily slows the river, allowing sediment to be deposited, and prevents the river upstream of the base level from eroding and deepening its valley.

Downstream of Roxboro Road in Durham, where the Eno flows across the sedimentary rocks in the Triassic lowland, the river ***meanders*** through a much broader valley. The river is not cutting down as much as it was in the Piedmont upland, and the sedimentary rocks over which it is flowing are soft and easily eroded. The river is able to meander across a much wider valley and develop a wide floodplain.

The difference in character between the Eno in the Piedmont upland and the Eno in the Triassic lowand is reflected in the ***gradient*** of the river. The gradient is a measure of the change in elevation of the river as it flows. The higher the gradient of a river or stream, the faster the velocity of the water and the more erosive the flow. In the Piedmont upland, from the Occoneechee Mountain area to Roxboro Road, the Eno has an approximate gradient of 11 feet for each mile of flow (2 meters per kilometer). Locally, behind a resistant layer of rock, the gradient is lower, and at rapids the gradient is higher. In the Triassic lowland, between Roxboro Road to where the Eno enters Falls Lake, the approximate gradient of the river is 2.6 feet per mile (0.5 meters per kilometer). This lower gradient causes the large bends and meanders in the river (pl. 1 and 2). A river will not meander unless it has a reasonably gentle gradient.

Photo of Eno River by Duncan Heron

Mills and Topography (adapted from Heron, 1978)

Introduction

Before supermarkets and convenience stores, mills were the economic and social centers of rural America in the 18th and 19th centuries. Mills were the locations where raw materials were converted to usable commodities, such as grain into flour and cornmeal and logs into lumber (See Anderson (1978) for additional information on mills of the Eno.). The choosing of a mill site was very important for the mill owners. A mill's location contributed to its economic success in two ways: 1) ease of construction and long-term maintenance costs of the mill house and dam; and 2) ease of access for mill customers. The underlying geology of mill sites directly affected these aspects and contributed to the success of a mill.

Choosing a Mill Site

A water mill can be constructed just about anywhere that water is available if one can cause the water to develop a ***head***; that is, a difference in elevation between the dam and the mill wheel. Due to the relative abundance of mill sites in the Piedmont upland of the Eno River, it appears that local geology controlled, or at least influenced, the location of mills. The people who selected the mill sites along the Eno River were aware of the difference between the Piedmont upland and the Triassic lowland and each area's suitability for mill sites. Along the Eno River in the Piedmont upland, below Hillsborough, there were more than 15 mills, but along the Eno River in the Triassic lowland there were only two mills.

Construction of a dam in the Piedmont upland was "easy" because of the following:

- The river exposes fresh, hard igneous and metamorphic rock in the bed of the stream and in the adjacent walls of the V-shaped valley.
- The dam could be placed on hard rock in the stream bed and could abut against the solid rock in the valley walls (dams often fail when placed on soft rock or ***alluvium***).
- The narrow valleys of the Piedmont upland enabled the span of a dam across the river to be short.
- The higher gradient of the Eno River in the Piedmont upland meant that the ***headrace*** did not have to be long in order to maintain the necessary "head" or fall of the water betwee n the dam and the mill wheel.
- The higher gradient also meant that for a given height of the dam, the millpond would be smaller and would not necessitate the purchase of as much land on either side of the river to contain the pond.
- The hard rock in the river bottom would contribute to the location of a favorable ford. With a good ford, patrons could access the mill from both sides of the river, contributing to the economic success of the mill.
- Resistant rock bodies often form rapids and natural drops in the river. These rapids and drops form natural mini-dams in some locations. Mill construction was easier in these locations because the resistant rock bodies could be used as sturdy anchor points for the dam.

One example of a Piedmont mill site is Cabe Mill. The remains of Cabe Mill and the headrace are in the Cabe Lands portion of Eno River State Park (see geologic trail guide for Cabe Lands trail). The former mill site is located on the edge of a small floodplain upstream from a resistant layer of rock. The mill dam is located about 1,000 feet upstream, on another resistant rock layer, in a narrow portion of the river with rock outcrops on both sides. The long headrace is dug in the soft sediment of the floodplain. This headrace is longer than most on the Eno River and the length was necessary for the water to flow to the mill on the edge of the floodplain. The headrace was relatively easy to dig because it is in the soft alluvium of the floodplain.

In the Triassic lowland (east of West Point on the Eno Park), the dams were more difficult to build and maintain. The problems in the Durham Triassic basin are essentially the reverse of the condition in the Piedmont upland.

- There is a lack of large, hard rock to build the dam. Typically, the river lacks solid rock for the dam abutments. Consequently the dam could easily wash out. One exception is Cameron's New Mill (pl. 1), built from local, relatively small boulders from the igneous (diabase) ***sill*** in the area.
- Higher dams were required to provide the needed hydraulic head due to the low gradient of the river in the Triassic basin. A higher dam required more land for the mill pond.

III. The Rocks of the Eno River

Overview

To learn about the rocks exposed along the Eno River, we must first learn about the three basic rock types of geology - ***igneous***, ***metamorphic*** and ***sedimentary*** rocks. All three of these rock types can be found along the Eno, making it an excellent place to learn about geology! The Eno River traverses two different bodies of rock: the Carolina terrane (formally known as the Carolina slate belt) and the Durham Triassic basin (fig. 4). From its headwaters in northern Orange County to just east of Roxboro Road in Durham, the Eno River flows over the slightly-metamorphosed igneous rocks of the Carolina terrane. Rocks of the Carolina terrane are approximately 630 million years old and are very resistant to erosion. You can observe these rocks at Eno River State Park and West Point on the Eno Park. As the Eno flows east from Roxboro Road and into Falls Lake, it traverses two younger rock types in the Durham Triassic basin: 1) approximately 225 million-year-old sedimentary rocks; and 2) approximately 200 million-year-old igneous rocks called diabase. The sedimentary rocks are more easily eroded than the resistant diabase that intruded the Triassic basin.

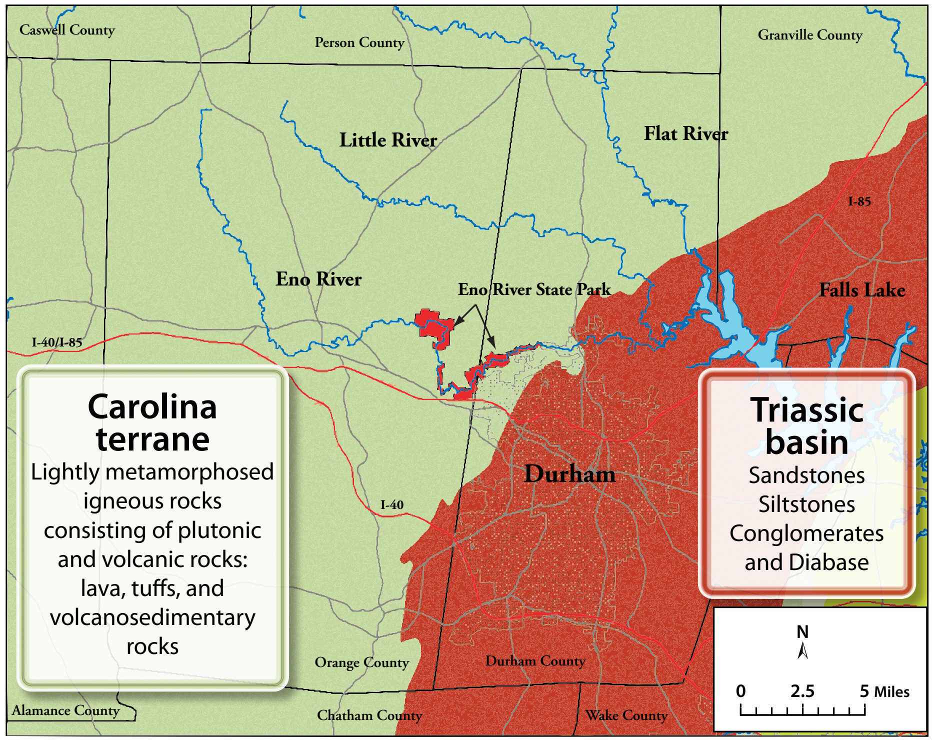


Figure 4 – *The location of the Eno River with respect to the two main rock bodies – the Carolina terrane and Triassic basin.*

Age of the Rocks

The age of the rocks of the Eno River are very old compared to the life span of human beings. Geologists talk about the age of rocks in the millions of years. Geologic time is separated into eons, eras and periods based on the age in millions of years. For example the 630 million-year-old rocks of the Carolina terrane in the Eno River area were formed in the Late Proterozic era (also known as the Precambrian), the 225 million-year-old sedimentary rocks were formed in the Triassic period of the Mesozoic era and the 200 million year old diabase was formed in the Jurassic period of the Mesozoic era. All geologic ages provided are approximate ages based on published scientific data. The actual age of the rocks may vary by 5 to 10 million years (For example: The approximate age for diabase along the Eno is 200 million years old. The actual age may be between 195 and 205 million years old.). A geologic time scale is provided on the inside of the back cover of this publication.

Igneous Rocks

Introduction

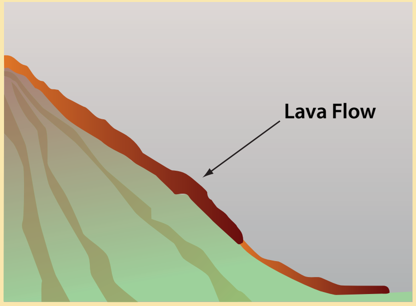
Igneous rocks, born from molten rock called ***magma***, dominate the western portions of the Eno River. All igneous rocks originate deep in the Earth as magma that rises toward the Earth's surface at temperatures ranging from 1,800 to 2,200 degrees Fahrenheit (°F) (1,000 to 1,200 degrees Celsius (°C)). Igneous rocks are separated into two main categories: intrusive and volcanic rocks. Intrusive rocks form when magma solidifies within the Earth's crust. Volcanic rocks form when magma solidifies on top of the Earth's crust on land or in water.

Figure 6 – *Outcrop of dike of diabase.*
Photograph shows typical spheriodal weathering pattern of diabase and typical rust-colored weathering rind.

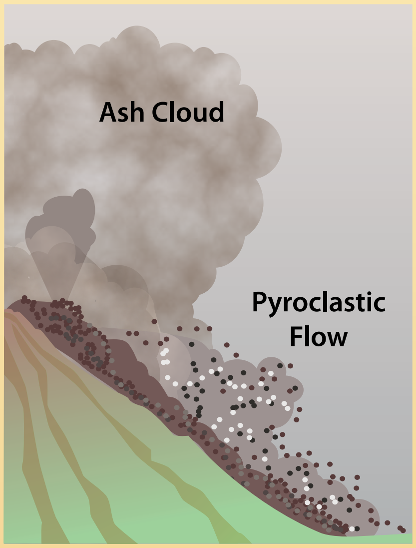
Figure 5 — *Example of a 630 million year old igneous intrusive rock of the Carolina terrane.*
Medium-grained granodiorite (light-colored) intrudes fine-grained granodiorite (gray portion of rock). Enclaves of fine-grained granodiorite are suspended in medium-grained granodiorite.
Photograph from abandoned quarry north of Eno River State Park – Few's Ford access area.

Intrusive Igneous Rocks

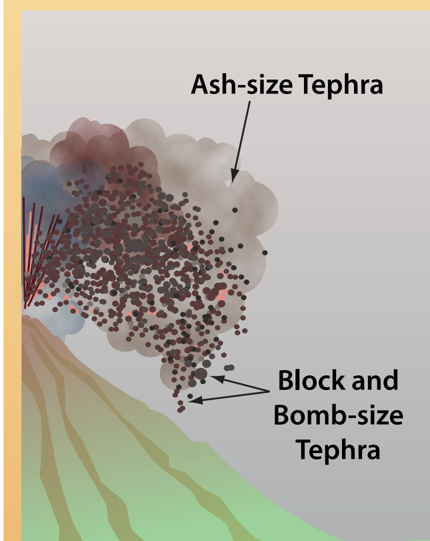
Magma that cools and solidifies before reaching the surface of the Earth forms intrusive igneous rocks. Intrusive rocks are also commonly known as plutonic rocks. The word ***plutonic*** comes from Pluto, the Roman god of the underworld. Plutonic rocks form bodies known as plutons. Intrusive rocks cool slowly since they are insulated by the surrounding earth. This slow cooling allows the chemical elements within the magma to organize themselves into individual crystals that are visible with the naked eye. Figure 5 shows an example of a circa 630 million-year-old intrusive rock from the Eno River area. East of Roxboro Road, in the Triassic basin, a relatively young intrusive rock called diabase is present. The diabase is around 200 million years old and is present as tabular-shaped bodies that either intruded the surrounding sedimentary rocks parallel to the existing layering as ***sills*** or cut across the existing layering as ***dikes*** (fig. 6)



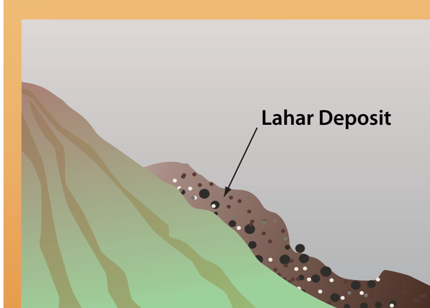
Lava Flows
Lava is molten rock (magma) that pours or oozes onto the Earth's surface.



Pyroclastic Flows
Pyroclastic flows are hot avalanches of lava fragments and volcanic gas formed by the collapse of lava flows or eruption clouds.



Tephra
Explosive eruptions blast fragments of rock high into the air. Large fragments fall to the ground close to the volcano. Small fragments (called ash) from the largest eruptions can travel hundreds of miles.



Lahars
Lahars are fast-moving slurries of rock, mud and water that look and behave like flowing wet concrete.

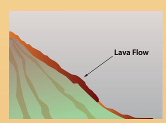
Landslides can transform into lahars. Pyroclastic flows can generate lahars by melting snow and ice.

Figure 7 – Four basic volcanic deposits found associated with modern volcanoes and with the ancient volcanoes of the Eno River area. (Modified from USGS)

Volcanic Igneous Rocks

Volcanic rocks, also born from molten magma, form when hot magma erupts out of a volcanic vent or when magma explodes from volcanoes. The word volcanic comes from Vulcan, the Roman god of fire. Geologists studying ancient volcanic regions, like the Eno River area, use modern volcanoes and their deposits as a guide to help them unravel the geologic history. Modern volcanic terranes are dominated by four basic volcanic deposits: a) lava flows, b) pyroclastic flows, c) tephra and d) lahars (fig. 7). The Eno River area has evidence of all four types of these deposits.

Lava flows, pyroclastic flows and tephra deposits are also known as ***extrusive*** volcanic rocks. Extrusive refers to the magma being extruded onto the surface of the Earth. As magma is extruded on the surface, it cools very quickly and individual chemical elements do not have time to grow into minerals visible to the naked eye and produce a fine-grained or ***aphanitic*** rock. This is in contrast to the intrusive rocks, that cool slowly, and typically have mineral grains that are visible with the naked eye.



Lava flows

When hot magma is erupted onto the surface of the Earth, it is called lava. The word lava is used to describe both moving melted rock, and cooled and hardened rock that originated as lava. Lava flows are streams of molten rock that pour or ooze from an erupting volcanic vent. Lava comes in many types defined by the range of minerals in the rock.

Millions of years ago, lava flowed in the Eno River area. One type of rock common in the Eno River area formed from solidified lava is called ***dacitic lava*** (fig. 8a). When molten, dacitic lava is viscous (thick and sticky) and does not flow very far from the volcanic vent. It forms steep-sided mounds of lava called domes. Lava domes grow by the extrusion of many individual flows over time. The lava domes within the crater of Mt. St. Helens in Washington State are examples of recent dome formation (fig 8b).

Another type of rock in the Eno River area of solidified lava is ***basaltic lava*** (fig. 8c). Basaltic lava, or basalt, is typical of the Hawaiian Islands (fig. 8d). Basaltic lava differs from dacitic lava (dacite) in that it is less viscous (able to flow easier and faster) and tends to spread out from the vent forming thin sheets of lava. This results in thinner geologic deposits when compared to the larger dome-like deposits of dacitic lava.

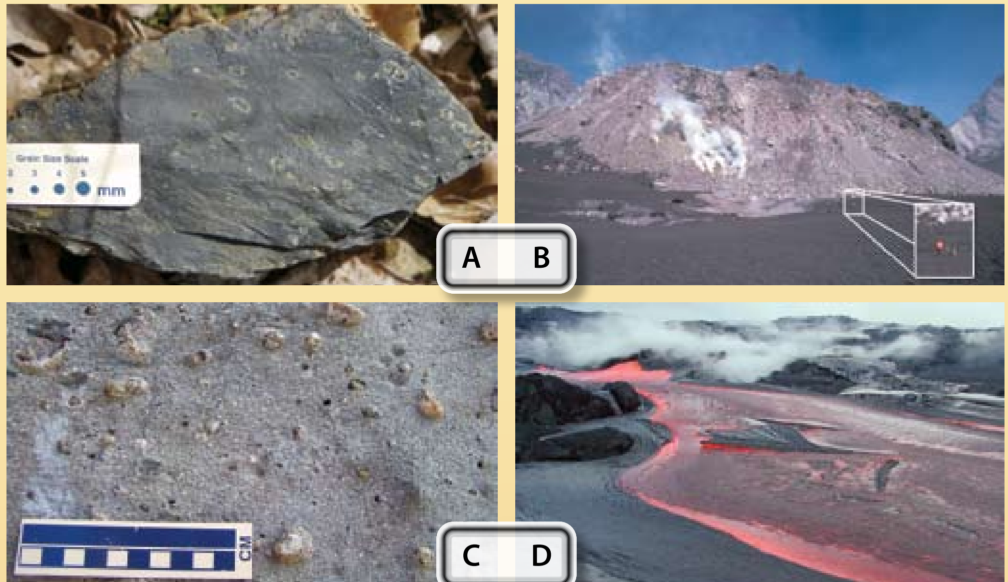
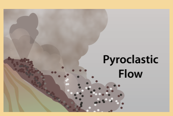


Figure 8 – *Examples of ancient and modern day lavas.*
A. Sample of dacitic lava from the Eno River area.
B. Modern day example of a dacitic lava dome in the crater of Mt. St. Helens in Washington State. Note people for scale *(USGS)*.
C. Example of basaltic lava exposed in the Eno River area.
D. Basaltic lava eruption in Hawaii *(USGS)*.



Pyroclastic flows

Pyroclastic flows are formed from explosive volcanic eruptions and are fast-moving clouds of hot gas, rock fragments and ash. The rock fragments can range in size from ash to boulders and can travel across the ground hurricane-force speeds often more than 60 miles per hour (100 km per hour). Pyroclastic flows are violent and will knock down, shatter, bury or carry away nearly all objects in their path. These flows are also very hot, generally between 400°F and 1,300°F (200°C and 700°C) and will virtually incinerate anything in their path. Pyroclastic flows typically form during the collapse of lava domes or after the collapse of dense eruption clouds. Rocks interpreted to have been deposited via pyroclastic flows are common in the Eno River area interlayered with dacitic lavas (fig. 9).

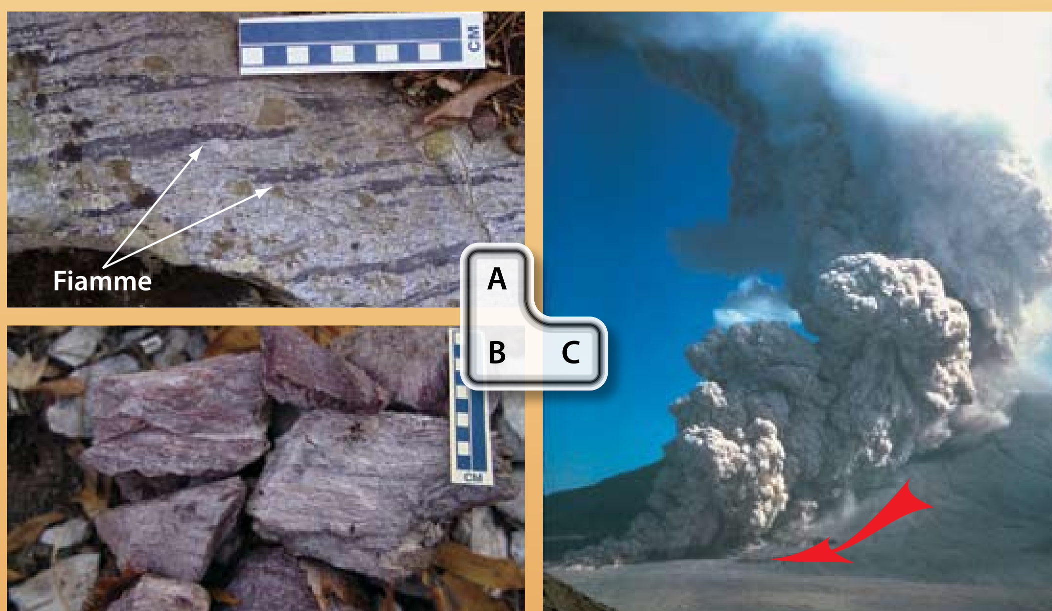
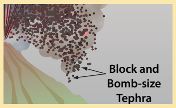


Figure 9 – *Examples of ancient and modern day pyroclastic flow deposits.*
A. Outcrop of welded lithic tuff with flattened pumice (fiamme) from the Eno River area.
B. Reddish-colored welded tuff from the Eno River area.
C. Modern day pyroclastic flow eruption at Mt. St Helens on August 7, 1980 *(USGS)*.



Tephra

Tephra is the general name for fragments of volcanic rock that are blasted into the air by volcanic explosions or carried upward by hot gases in eruption clouds above volcanic vents. Tephra can range in size from less than 1/32 inch (2 millimeters) to more than 3 feet (1 meter) in diameter. Tephra less than 2 millimeters diameter is called volcanic ***ash***.

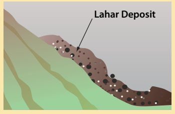
Tephra consists of a wide range of rock particles, including combinations of pumice, glass shards, crystals from different types of minerals, and shattered rocks of all types (igneous, sedimentary and metamorphic). The largest-sized tephra (rocks several meters in diameter) typically is deposited close to the erupting volcanic vent. The fine-grained ash may be blown by the wind hundreds to thousands of miles away. A single eruption can rain down tephra and blanket the landscape close to the volcanic vent with hundreds of feet of ash and volcanic debris. Farther from the volcanic vent, the tephra that falls to the ground is smaller in size and forms only a thin layer of ash a few centimeters thick. When the tephra is buried and hardens into rock it become a rock named ***tuff***. The tuffs exposed today in the vicinity of the Eno River (fig. 10) record hundreds, possibly thousands, of ancient eruptions.

Figure 10 – *Examples of tuff and a modern day ash deposit.*
A. Sample of tuff with white-colored weathering rind from Eno River area.
B. Sample of crystal tuff from former Eno Quarry on Eno River State Park land. White specks in rock are plagioclase feldspar crystals.
C. Layered ash deposits from 1990 eruption of Redoubt volcano in Alaska *(USGS).*

It's the Gases!

Why do some types of volcanoes just ooze lava and some explode in cataclysmic eruptions?...It's the gases! There are two basic end-member types of magma: ***felsic*** and ***mafic***. Felsic refers to magma and rocks that are rich in silica and aluminum-bearing minerals. Mafic refers to magma and rocks that are rich in iron and magnesium-bearing minerals. The more silica a magma has the more viscous it will be. Therefore, felsic magmas are more ***viscous*** than mafic magmas.

Great quantities of gases are dissolved in magma (similar to dissolved gases in a bottle of soda). Deep in the Earth's crust, the pressure is sufficient to keep the gases dissolved in the magma. As the magma travels upward and the pressure decreases, gases slowly begin to exsolve (the opposite of dissolve) out of the magma. If a magma is more mafic (contains less silica), it is less viscous and will gradually release the escaping gases. If a magma is more felsic (contains more silica), it is more viscous which inhibits the easy release of gases and typically stores the gas in tiny bubbles called vesicles. A magma with abundant trapped gas within vesicles is called a vesiculated magma. If enough gas exsolves from the magma, a giant frothy cap of vesiculated magma may be present just under the surface of the earth. Like the removal of the cap from a recently shaken warm soda bottle, a volcano with large quantities of ***vesiculated*** magma will explode if the pressure is released. Vesiculated magma puts enormous pressure on the walls of the magma chamber, inevitably resulting in a breach in the sides of the volcano and an eruption. As the volcano erupts, the magma instantly shatters into billions of fragments of volcanic debris.



Lahars

Lahar is an Indonesian word used by geologists to describe a mudflow associated with volcanic activity. Lahars are very powerful and are capable of moving great quantities of debris (as large as house-sized boulders) long distances in a short amount of time. Modern lahars look and behave like flowing wet concrete and destroy virtually everything in their path – including houses, cars, trees, etc. (fig. 11a). Volcanic eruptions may initiate lahars when snow or glacial ice is rapidly melted and travels down the mountain. Lahars may also be initiated during steam explosions or the collapse of a volcano from earthquakes. Intense rainfall, years after a volcanic eruption, may destabilize volcanic debris and initiate a lahar. Lahars typically follow the topography and flow into, and fill in, valleys on the flanks and base of a volcano. Lahars are one of the most dangerous features of modern volcanoes. An example of an ancient lahar deposit is visible at Few's Ford in Eno River State Park (Allen and Wilson, 1968 and Rochester, 1978) (fig. 11b). The lahar deposits at Few's Ford are described as part of the field trip guides of this publication.

Figure 11 – *Example of ancient and modern lahar deposits.*
A. Lahar deposit from 1995 on southwest flank of Unzen volcano, Japan *(Tom Pierson-USGS).*
B. Ancient lahar deposit located at Few's Ford in Eno River State Park.

Metamorphic Rocks

The majority of the rocks in the Piedmont upland of the Eno River have been metamorphosed. 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 igneous rocks associated with the Carolina terrane have been subjected to low-grade metamorphism; subsequently, the prefix "meta" is commonly added to the rock name. The metamorphosed igneous rocks should technically be called meta-intrusive rocks (e.g., metagranodiorite, metagranite) and metavolcanic rocks (e.g., metatuff and metabasalt). Since many of the rocks exposed along the Eno River retain the original intrusive and volcanic textures present in the rock at formation, geologists often leave off the "meta" prefix.

Hydrothermal Alteration – a form of metamorphism

Rocks altered by ***hydrothermal*** fluids are common in the Piedmont upland portion of the Eno River. Hydrothermal alteration occurs when water, heated by magma, permeates through rocks or deposits and changes their composition by adding, removing or redistributing chemical elements. Hydrothermal alteration can be considered a low temperature and very low-pressure type of metamorphism.

Most hydrothermally-altered rocks in the Eno River area are associated with the edges of small intrusive bodies. As these intrusive bodies of hot magma ascended upward in the Earth's crust, they intruded pre-existing volcanic deposits. The intrusive bodies heated the local groundwater and circulated it through the volcanic deposits. When the heated water and fluids rose to the surface, they formed ***hot springs***, ***geysers*** and ***fumaroles***. Hydrothermal alteration drastically changes the appearance of rocks, often forming rocks that are white in color. In the Eno River area, hydrothermally-altered rocks are often identified by their white coloration with red and yellow mottling (fig. 12a and b). Hydrothermally-altered rocks are sometimes very resistant to erosion and weathering when the alteration has been via the process of silicification. Silicification occurs when silica-rich hydrothermal fluids replace virtually all minerals in the rock with quartz, which is a very resistant mineral. Other types of hydrothermally-altered rocks may be easily eroded (e.g. ***sericite*** and ***pyrophyllite phyllites***).

Figure 12 – *Photographs of hydrothermally altered rock.*
A is an example of a sericite and quartz rock with red and yellow mottling.

B is an example of pyrophyllite from Occonechee Mountain

Ancient Hydrothermal Activity and the Altered Rock of Occoneechee Mountain

The northwestern face of Occoneechee Mountain is home to an active mine and an abandoned quarry that contains a white rock with one of the softest minerals known in geology – pyrophyllite (fig. 12b). Ironically, the western peak of Occoneechee Mountain is the highest point in Orange County. ***So, why does a mountain that is partly composed of one of the softest minerals form the highest peak in Orange County?***

The short answer:

The same geologic process that formed the soft mineral pyrophyllite also formed abundant quartz. Quartz is very resistant to erosion and forms the central spine of Occoneechee Mountain.

The long answer:

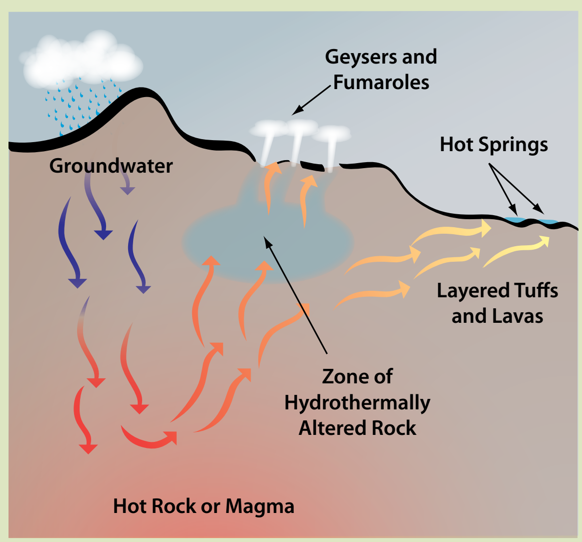


Figure 13 - *Sketch of the hypothetical hydrothermal system associated with the formation of the rocks of Occoneechee Mountain (Modified from USGS).*

The long answer to this question begins millions of years ago when the Hillsborough area was in the middle of an active volcanic center. Hot magma intruded the thick pile of volcanic ash and lava deposited during the active life of the area's volcanoes. Rainwater and/or snow melt (known as meteoric water) percolated downward through the rocks (fig. 13) to high-temperature regions surrounding hot magma (plutons). There, the water was heated, became less dense and rose back to the surface along fissures and cracks. When the heated water reached the surface of the Earth, ***hot springs***, ***geysers*** and ***fumaroles*** likely formed. The downward percolation of meteoric water and subsequent heating and upward circulation of the water is collectively termed a hydrothermal system.

The Long Answer Continued ...

As the heated water made its journey back to the surface of the Earth, some of the water circulated through the surrounding volcanic deposits. The heated water, called hydrothermal fluids, caused ***hydrothermal alteration*** of the surrounding rocks by adding, removing or redistributing molecules and elements in the parent volcanic rocks. The hydrothermal alteration in the Occoneechee Mountain area likely formed deposits of kaolinite clay, zones of the mineral sericite and pods of precipitated silica (SiO_2) called ***siliceous sinter***. Sericite is a very fine-grained white ***mica*** (muscovite) mineral. Kaolinte clay and sericite along with silica (quartz) and a host of other minerals are commonly found associated with modern hydrothermal deposits.

With time, the magma that provided the heat source to the hydrothermal system cooled and solidified, thus shutting down the hydrothermal system. The kaolinite, sericite and silica deposits of Occoneechee Mountain were later buried by additional volcanic deposits. Millions of years passed, until the volcanic arc that carried the now extinct volcanic center of the Hillsborough area collided with another island or land mass. The collision caused the rocks to be folded and undergo low-grade ***metamorphism*** during the ***Virgilina deformation*** (Glover and Sinha, 1973). The heat and pressure of the low-grade metamorphism (and additional movement of silica-rich fluids), most likely changed the kaolinite deposits into the pyrophyllite-bearing rock. The sericite deposits were transformed into sericite ***phyllite***. The siliceous sinter was recrystallized into massive pods of quartz rock. The pyrophylite, sericite, and quartz rock are often white or yellowish-white in color with red mottling (iron oxide staining) common.

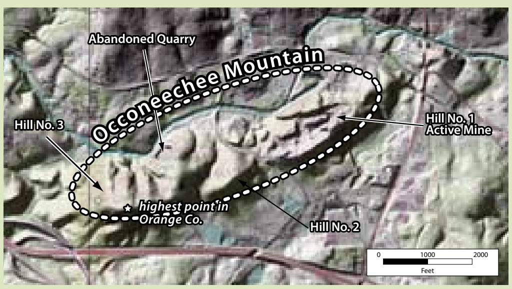


Figure 14 - *Hills number 1, 2 and 3 of Occoneechee Mountain.*

The resulting quartz rock is very hard and resistant to erosion. The central spine of Occoneechee Mountain is composed of a mixture of the quartz rock, sericite phyllite and lesser pyrophyllite. The quartz rock holds up Occoneechee Mountain (fig. 14). A generalized cross-section of Occoneechee Mountain showing the general distribution of minerals is provided as Figure 15.

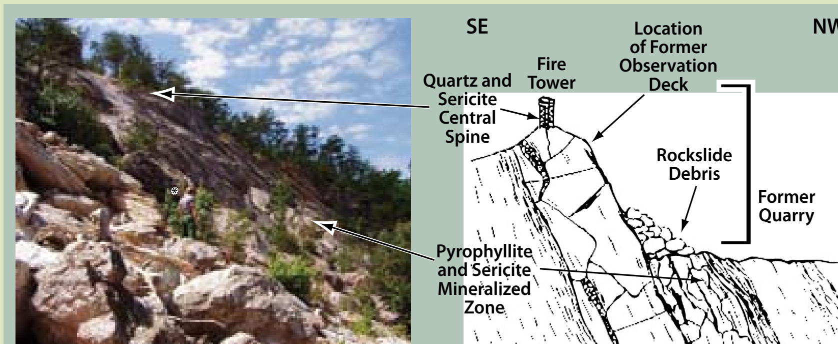


Figure 15 - *Generalized cross-section of Occoneechee Mountain showing the general distribution of minerals (after Broadhurst and Councill, 1953). *Note person for scale.*

Information about Occoneechee Mountain:

Occoneechee Mountain is composed of three hills designated from northeast to southwest as Hill Number 1, Hill Number 2 and Hill Number 3 (fig. 14). The abandoned quarry is located on the northwest side of Hill Number 3. The apex of Hill Number 3 is the highest point in Orange County at 867 feet (264 meters) above sea level. The quarry was reportedly opened before the Civil War and used for fill material during construction of nearby railroad tracks and for general fill material in the Hillsborough area. In 1906 the quarry was operating under the name of the Southern Broken Stone Company. Active quarrying ceased sometime around 1908 (Eno River Calendar for 1995, Eno River Association). The large boulders and rock debris present in the abandoned quarry are from a rockslide that occurred in February 2001 (Wooten et al., 2006). An active pyrophyllite mine is present on Hill Number 1; it has been in operation since the 1960s.

Facts about pyrophyllite:

Pyrophyllite is a hydrous aluminum silicate ($Al_2Si_4O_{10}(OH)_2$) with a structure similar to talc. It is soft, like talc, with a hardness of 1 (can be scratched with fingernail). Pyrophyllite is relatively chemically inert, has a high dielectric strength (a material that has negligible electrical or thermal conductivity) and a high melting point. Pyrophyllite is used in the ceramic industry in the production of heat resistant products such as electrical insulators. It is used in soaps, paints and in bleaching powders. The most familiar use for the mineral is as talcum powder. The pyrophyllite from the Hillsborough mine is reportedly used in the manufacture of spark plugs. North Carolina is a leading producer of raw pyrophyllite in the United States.

Sedimentary Rocks

Sedimentary Rocks in the Durham Triassic Basin

The Eno River flows into an area dominated by the sedimentary rocks of the Durham Triassic basin east of Roxboro Road (pl. 1 and figs. 3 and 4). At this point the Eno River enters the Triassic lowland. Sedimentary 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 rock. Conglomerate, sandstone, siltstone and mudstone are sedimentary rock types found within the Durham Triassic basin along the Eno River. As the names imply, sandstone is composed of ***sand-size*** sediment, siltstone is composed of ***silt-size*** sediment and mudstone is composed of mixture of silt- and ***clay-size*** sediment. Conglomerate is a sedimentary rock that is composed of rounded to partially-rounded boulder-, cobble-, gravel- and sand-size sediment. Figure 16 presents examples of sedimentary rock types found within the Triassic basin. These rocks are commonly red, maroon or brown in color and form soils of similar color. The red, often clay-rich, soil exposed in construction sites in the Durham area is typical of the Triassic sedimentary rocks. These sedimentary rocks are less resistant to erosion and rarely form outcrops compared to the crystalline rocks of the Carolina terrane. The majority of the city of Durham is relatively flat in comparison to the Hillsborough and Chapel Hill areas because the underlying sedimentary rocks are easier to erode.

Metamorphosed Sedimentary Rocks in the Carolina Terrane

Slightly-metamorphosed sedimentary rocks are interlayered with the volcanic metatuffs and metalavas of the Carolina terrane in the Piedmont upland portions of the Eno River area. These sedimentary rocks, called ***epiclastic*** rocks, are different from the sedimentary rocks in the Durham Triassic basin. The epiclastic rocks are composed of fragments of eroded volcanic and plutonic rocks and are the same age as the volcanic rocks interlayered with them. The presence of epiclastic rocks interlayered with volcanic rocks indicates that while the volcanic rocks were being deposited, erosion of those volcanic rocks was also taking place (see figs. 19 and 20).

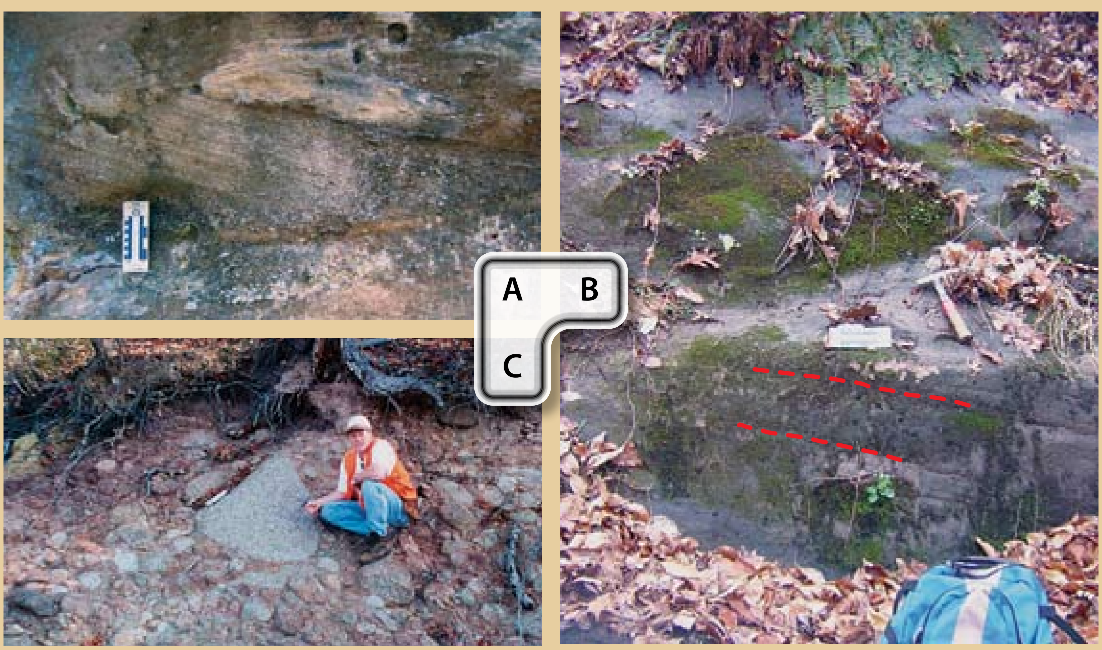


Figure 16 – *Examples of rocks found in the Triassic basin.*
A. Cross-bedded sandstone and pebbly conglomerate exposed along New Hope Creek in Duke Forest.
B. Siltstone with dipping bedding (dashed lines).
C. Triassic conglomerates from the eastern boundary of the Triassic basin on island in Falls Lake *(photograph by Tim Davis).*

IV. Genesis of the Rocks of the Eno River – The Geologic Story

Prologue

The geology presented so far has primarily been a description of the rock types encountered along the Eno River. 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 Eno River (as well as similar areas throughout the Georgia, South Carolina, North Carolina and the Virginia Piedmont), the geologic story of the Eno River was pieced together. This story combines many geologic investigations conducted within the Carolina terrane and from other locations throughout the Southeast. For a detailed review of the most recent geologic interpretation of the Carolina terrane and adjacent rocks, at the time of publication, see Hibbard et al. (2002) and references therein. A detailed review of the rocks of the Durham Triassic basin is provided in Clark et al. (2001). A detailed description of the rocks in the immediate vicinity of the Eno River is provided in Bradley et al. (2006a and b).

Much of the following geologic study has been determined through inferences and comparison of modern volcanic terranes to the rocks of the Eno River. 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 Eno River 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

Beneath the peaceful forests surrounding the Eno River lies evidence of a very old, violent and turbulent past. The geologic history of the Eno River area began more than 630 million years ago, when, far away from ancient North America, a chain of volcanic islands was forming. Multiple generations of volcanoes were actively erupting billons of tons of ash and other volcanic debris over millions of years. The islands eventually collided with, and were welded to, ancient North America. Today, some of these volcanic rocks are exposed along the Eno River from west of the town of Hillsborough to just east of Roxboro Road in the city of Durham (fig. 4 and pl. 1).

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. Millions of tons of sediment were shed off the surrounding highlands and deposited into these valleys. This sediment later lithified into the sandstones, siltstones and mudstone that are now part of the Triassic basin rocks exposed along the Eno River east of Roxboro Road. Approximately 200 million years ago, magma intruded the rocks and formed the multitude of dikes and sills of diabase all along the Eno River. Diabase sills are especially plentiful in the area east of Roxboro Road in the city of Durham (pl. 1). 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 along the Eno River.

The Early History of the Volcanic Islands Circa 630 Million Years Ago - The Island Arc Carolinia

Off the coast of the ancient African continent (called Gondwana), at the edge of a ***convergent plate boundary***, younger, more buoyant, oceanic crust collided with and rode over older and denser oceanic crust (fig. 17a and b). 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***. The island arc, named Carolinia, was likely more than 600 miles (1,000 kilometers) long. As 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. One of these coalescing masses of magma formed a large magma chamber under what is now the Eno River area 630 million years ago (fig. 18a).

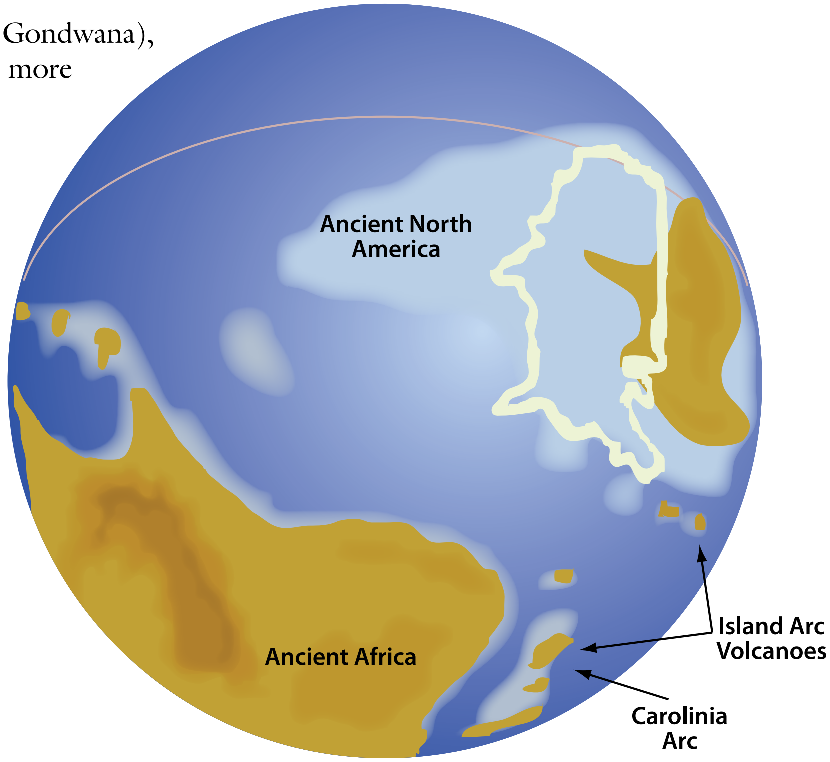


Figure 17a - *Paleo-reconstruction of the Earth approximately 630 million years ago indicating relative location of the Carolinia arc with respect to ancient North America. (Modified from USGS).*

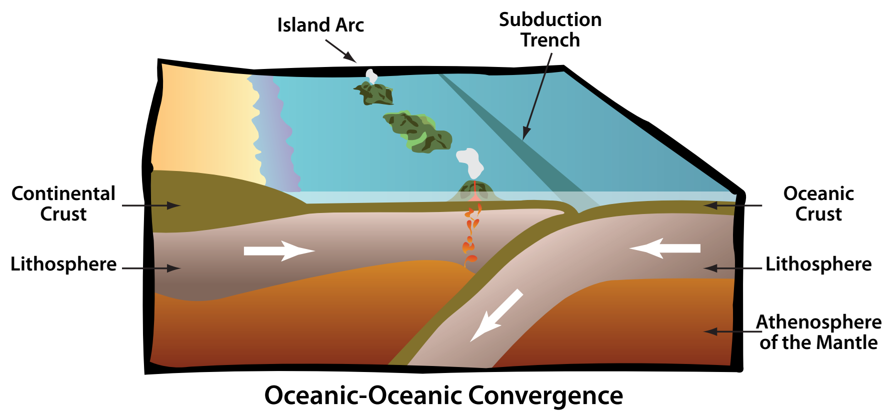


Figure 17b - *Diagram of an oceanic-oceanic plate convergence zone showing subduction trench and volcanic island arc.*

The Birth of a Volcanic Center on the Carolinia Island Arc

Above the magma chamber, the ocean floor began to bulge and swell as some of the magma began to move toward the surface along faults and fractures (fig. 18b and c). The magma eventually erupted onto the ocean floor (fig. 18c) causing underwater volcanic eruptions that discharged billions of tons of lava and tephra on the sea floor. The eruptions built enormous piles of volcanic debris many hundreds to thousands of feet thick. Evidence that many of the eruptions likely took place underwater is indicated by the presence of thinly bedded siltstone and sandstone (epiclastic rocks) interlayered with volcanic rocks, as well as the presence of ***pillow basalts*** (Wilson and Allen, 1968) in the volcanic rocks.

Simplified Cross-Sections of the Eno River Area During an Interval of Active Volcanism (ca. 630 million years ago)

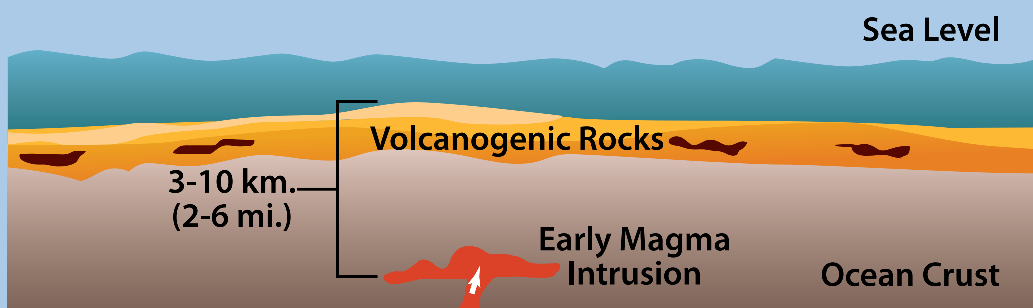


Figure 18a. - *Magma begins to settle below the ocean floor under what is now the Eno River area, forming a magma chamber.*

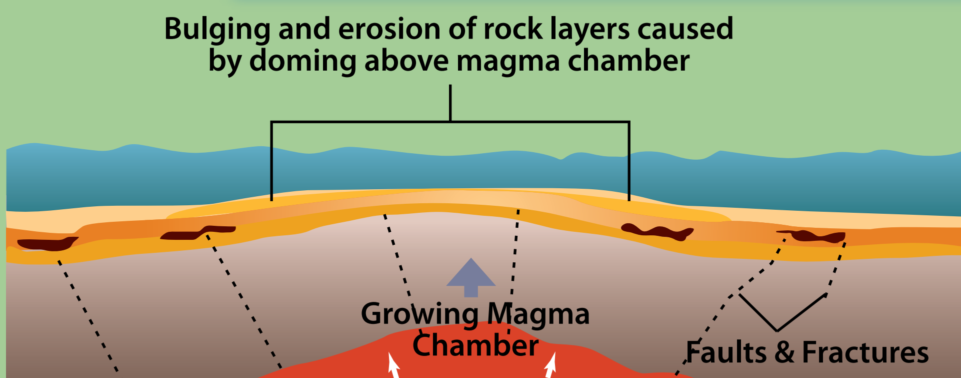


Figure 18b. - *Magma chamber continues to grow. Sea floor begins to bulge and swell causing erosion of rock layers. Faults and fractures form in sea floor from forces of growing magma chamber.*

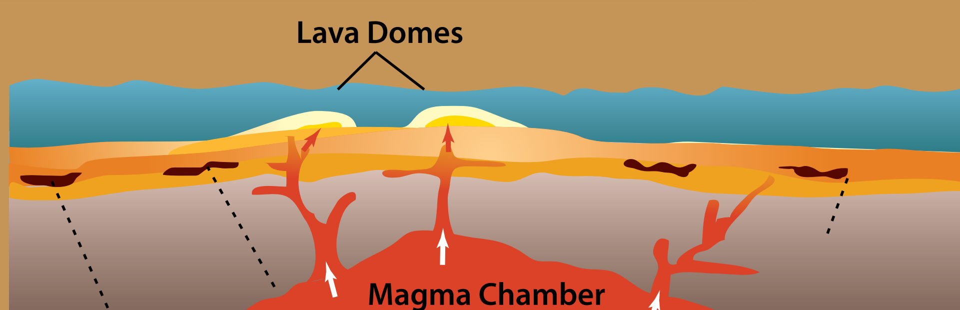


Figure 18c. - *Magma slowly follows fractures to the surface of the ocean floor and erupts billions of tons lava and ash forming under sea volcanoes.*

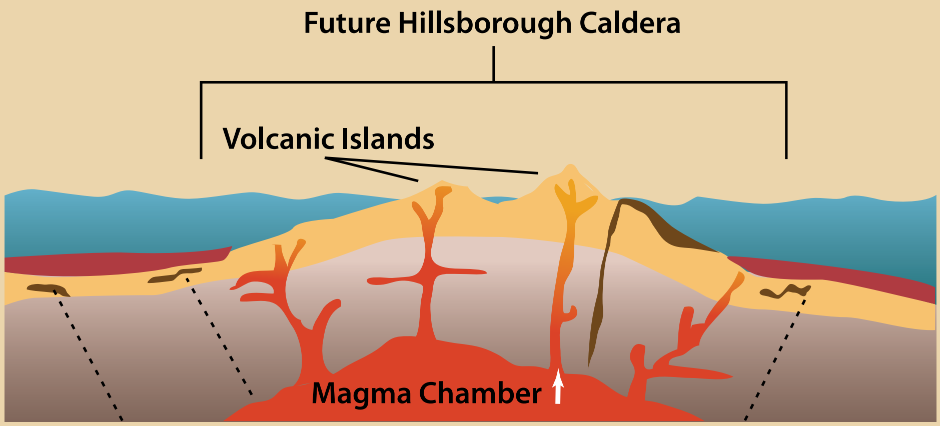


Figure 18d. - *The piles of volcanic debris build up over time until volcanic islands begin to appear above the surface of ocean.*

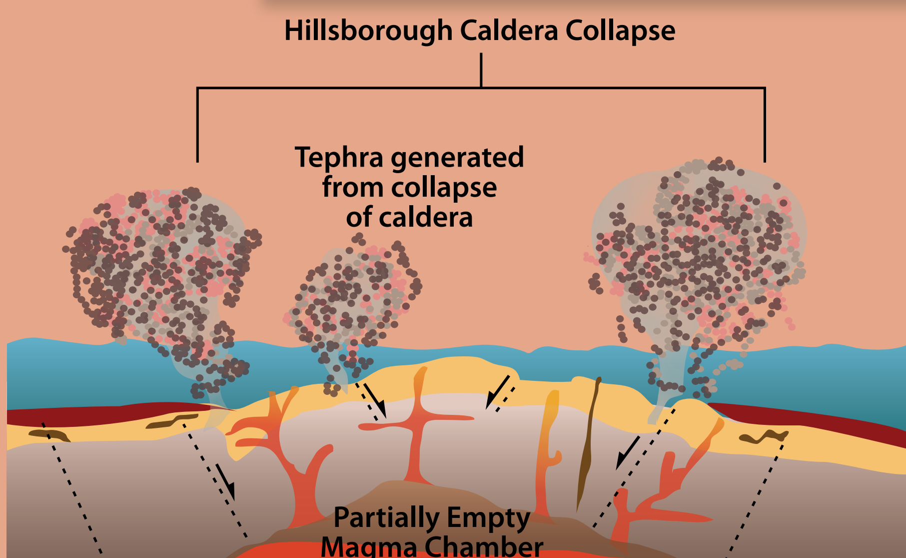


Figure 18e. - *Magma chamber explodes releasing billions of tons of tephra. Rock above magma chamber collapses into cavity formed by empty magma chamber forming a caldera.*

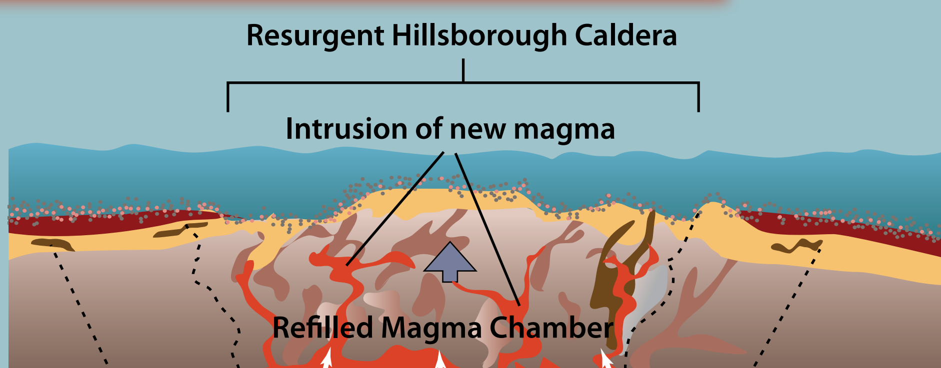


Figure 18f. - *Caldera resurges with the addition of new magma into area of former magma chamber.*

The piles of volcanic debris built up high enough that volcanic islands began to break the surface of the ocean (fig. 18d). More eruptions followed, building the islands larger and larger. As these islands emerged above the ocean 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 220 million years later during the ***Silurian*** period (410 million years ago). 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 islands probably went through many cycles of construction and destruction. Lava and ash built up small islands only to be destroyed by subsequent explosive eruptions and erosion. At times, the rate of eruptions and deposition outpaced the rate of erosion. This allowed larger volcanic islands to rise high above the surrounding ocean, forming longer-lasting ***subaerial*** (above water) conditions near the volcanic vent (fig. 18d).

Rock outcrops encountered along the Eno River helped develop the interpretation of the conditions present during volcanism. Rock outcrops of ***epiclastic rocks*** consisting of metaconglomerate (a metamorphosed sedimentary rock) with clasts of tuff, lava and granodiorite (fig. 19) and outcrops of siltstone (fig. 20) are interlayered with lavas and tephra (also known as ***primary pyroclastic rocks***). This interlayering indicates that the volcanic deposits were undergoing erosion in the same time period of active volcanism.

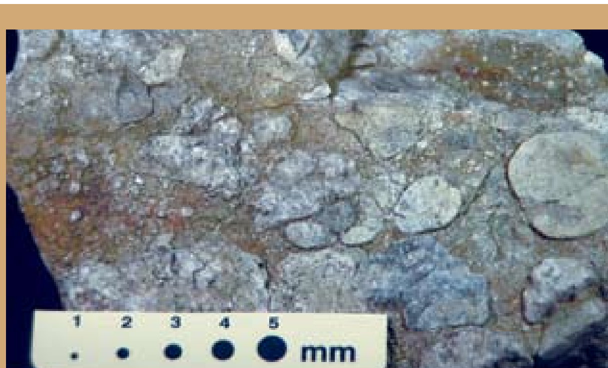


Figure 19 – *Metaconglomerate interlayered with the tuffs and lavas in the Eno River area. Sample is from Eno River State Park Wilderness Area.*

Figure 20 – *Bedded siltstone interlayered with the tuffs and lavas in the Eno River area.*

Other rock types (welded tuffs and red lavas) indicate subaerial (above water) volcanic conditions. Welded tuff is a rock that forms when hot ash is erupted from a volcano. The ash remains hot enough that when it settles down on the land the ash grains stick to each other and become welded. This produces a very hard and distinctive rock with flattened fragments of tephra called fiamme (fig. 9a). ***Fiamme*** is the Italian word for flame and is used by geologist to describe flattened and stretched ***pumice*** and glass fragments. The fragments are usually tapered on their ends like the tip of a flame – thus fiamme (flame) shaped. To become welded, the ash particles must be at a temperature of greater than 900°F (500°C). If ash is deposited underwater it is unlikely that the ash particles would remain hot enough to weld together. Welded tuffs are very resistant to erosion and sometimes form resistant ridges around the Eno River area. Welded tuffs are present on Poplar Ridge east of Hillsborough and are responsible for it being a prominent ridge today.

Lavas and welded tuffs (fig. 9b) that are red in color are common rock types in the Eno River area. Geologists interpret the red coloring as an indication that lava or ash was erupted onto land. Oxygen in the air oxidized (like rusting) the naturally occurring iron content of the lava and tuff forming the red color. Conversely, lavas erupted into water or tuffs deposited in water have not been oxidized by the air and are typically gray to green in color.

The Hillsborough Caldera

Past geologic investigations (Newton, 1983) in the Eno River area have interpreted that the volcanic debris exposed today in the Eno River area was part of a larger volcanic center on top of a large magma chamber. This magma chamber of molten rock may have been, at a minimum, 28 by 9 miles (45 by 14 kilometers) in size and may have erupted in a series of great cataclysmic eruptions as the magma chamber emptied the majority of its contents. The emptying of the magma chamber formed a large void underground and caused the ground surface to collapse into a great depression called a caldera (fig 18e).

This interpreted caldera in the Eno River area has been named the Hillsborough Caldera (Newton, 1983). The tephra ejected during the great eruptions rained back down on the land forming thick sequences of ash and volcanic debris that filled the caldera. Volcanoes that produce large calderas after huge cataclysmic eruptions are sometimes called supervolcanoes. The Hillsborough Caldera was probably too small to have been considered a supervolcano. Yellowstone National Park sits in a giant caldera that is 47 by 28 miles (75 by 45 kilometers) in diameter. Past eruptions of the Yellowstone Caldera have been considered supervolcano eruptions.

After several hundred thousand years, the Hillsborough Caldera resurged (refilled with magma). As new magma began to enter the former magma chamber, it pushed into some of the ash and other volcanic deposits from the previous eruptions (fig. 18f). Evidence of resurgence in the Eno River area is the presence of large bodies of solidified magma called granodiorite and diorite (granite-like rocks). The magma intruded the overlying volcanic rocks and cooled very slowly forming individual mineral grains that are visible with the naked eye (fig. 5). Holden Mill, The Shakori and Ridge, and Cox Mountain Trails in Eno River State Park all traverse granodiorite and diorite rocks. The rock used to construct the former dam and mill works for Holden Mill is composed of granodiorite. (See the field trip guide to the Cox Mountain and Holden Mill trails for more information.)

The Hillsborough Caldera was similar, but smaller in size, to the large Yellowstone Caldera in Yellowstone National Park. The Yellowstone Caldera is in the process of resurging. Water heated by the resurging magma is responsible for the well known ***geysers*** (e.g., Old Faithful), ***hot springs*** and ***fumaroles*** of Yellowstone. The Hillsborough Caldera, similar to modern day Yellowstone, would have had abundant hot springs where hot water, heated by the magma, circulated through the previously deposited ashes and volcanic debris. The hot spring (hydrothermal) activity extracted silica and other minerals and elements from some rock types or added silica to other rock types forming hydrothermally-altered rocks. Evidence of hydrothermally-altered rock is present in the ***sericite*** and ***pyrophyllite phyllite*** deposits of Occoneechee Mountain (figs. 12b, 13, 14 and 15).

The End of Volcanism in the Eno River Area and the Collision of the Volcanic Island Arc with Another Landmass.

Following the resurgence of the Hillsborough Caldera, volcanic activity appears to have ended approximately 610 million years ago in the Eno River area. The volcanic islands were eroded and slowly sank beneath the sea. Around 600 million years ago, the volcanic arc that carried the Hillsborough Caldera collided with another landmass that caused the rocks to be folded and undergo low-grade metamorphism (changed through heat and pressure). Known as the ***Virgilina deformation*** (Glover and Sinha, 1973), the rocks in the Eno River area were folded into a set of large ***anticlines*** and ***synclines*** (fig. 21) and developed an almost vertical ***foliation*** (Hibbard et al., 2002).

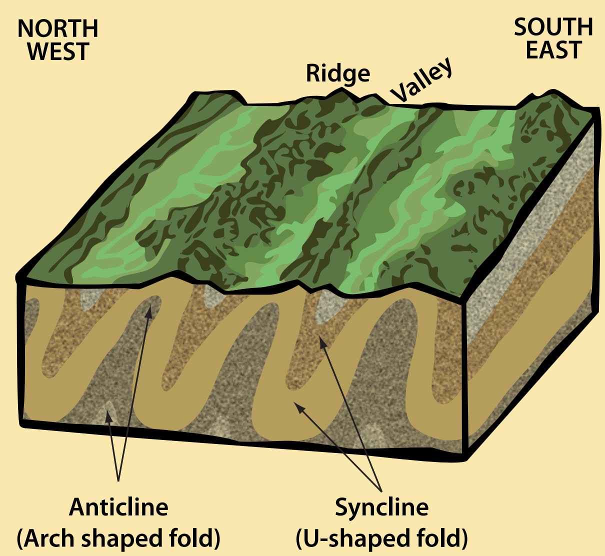


Figure 21 – *Schematic block diagram showing the folded rock layers in the Carolina terrane.* Folding produced anticlines and synclines that essentially tilted the rock layers on end.

The foliation formed during the Virgilina deformation is visible in many of the volcanic rocks in the Eno River area. During the folding, the layers of tuffs and lavas were essentially turned on their side. Many of the finned-shaped rock outcrops along the Eno River are actually the layers of tuff or lava standing on end. These folded rocks are now exposed in the Piedmont upland portions of the river west of Roxboro Road.

Renewed Volcanism on the Carolinia Arc

Following the Virgilina deformation, a new chain of volcanoes began to form on top of the now extinct and buried volcanoes of the Eno River area. Eroded away long ago from the Eno River area, the rocks of the younger volcanic island arc are now exposed near Asheboro and extend southwest into the Uwharrie Mountains which includes Morrow Mountain State Park. These rocks have been dated at about 550 and 585 million years old (Wright and Seiders, 1980; Ingle-Jenkins et al., 1999). The rocks of the Uwharrie Mountains and Morrow Mountain State Park are younger but very similar to the rocks of Eno River State Park area. These volcanoes, like the volcanoes of the Eno River area, went extinct and were eroded and sank beneath the ocean where they were covered by marine sediments. As this renewed volcanism was taking place in the Uwharrie Mountains, the entire mass of both older and younger volcanic island arcs was slowly traveling toward the ancient North American coast (fig. 22).

Collision of the Carolinia Volcanic Island Arc with Ancient North America, the Collision of Africa and the Formation of the Supercontinent Pangea

Around 450 million years ago, the Carolinia volcanic island arc, including the rocks of the Hillsborough Caldera and the Uwharrie Mountains, began colliding with ancient North America. By 440 million years ago, the collision was nearly complete forming a coastal range of mountains (fig. 22). The rocks associated with the Uwharrie Mountains volcanoes, and their eroded remains, were deformed into large anticlines and synclines and metamorphosed. The rocks in the Eno River area were essentially spared any great deformation during this collision.

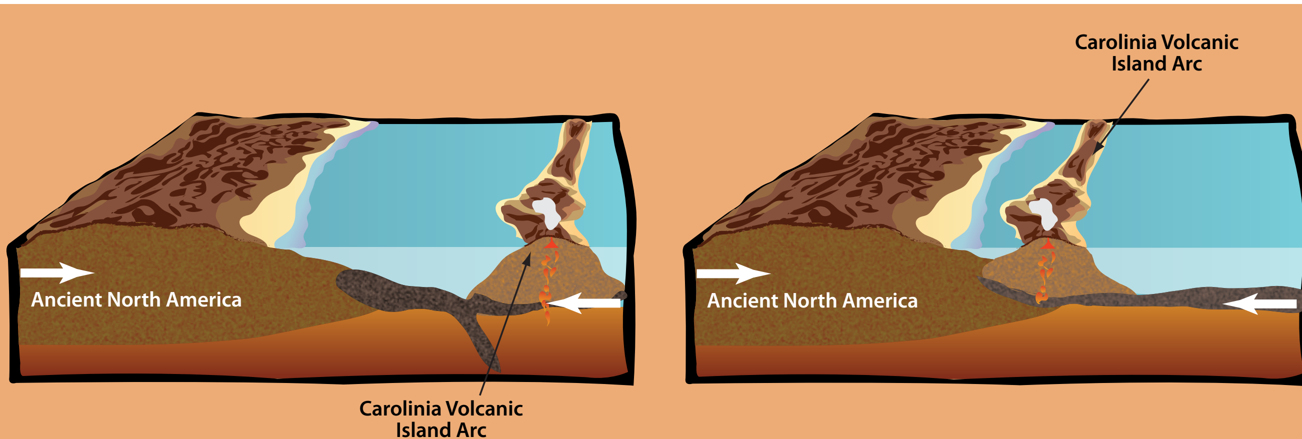


Figure 22 - *Diagrams showing volcanic island arc approaching and colliding with ancient North America* (adapted from USGS).

As Carolinia was docking with ancient North America, the ancient Atlantic Ocean (called the Iapetus Ocean by geologists) was closing and the ancient African and North American continents were headed for collision (fig. 23).

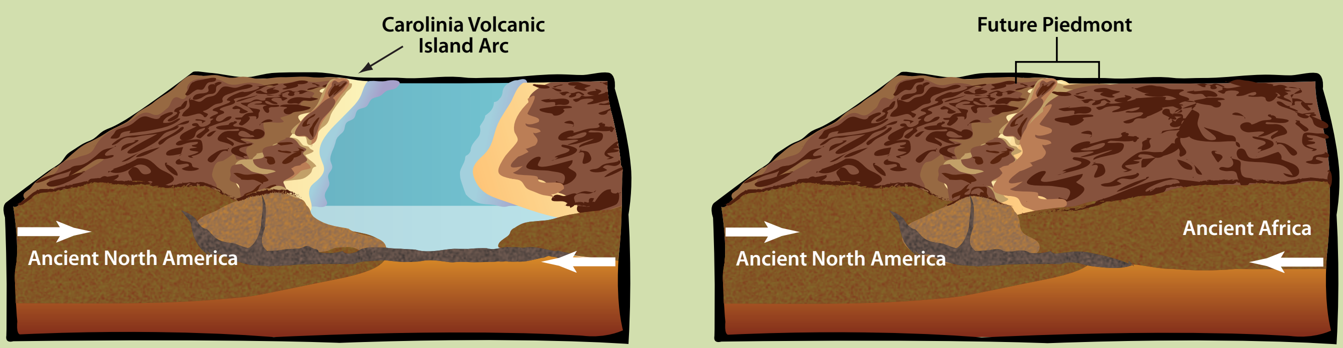


Figure 23 - *Diagrams showing volcanic island arc accreted to ancient North America and collision of ancient Africa with ancient North America.* (adapted from USGS).

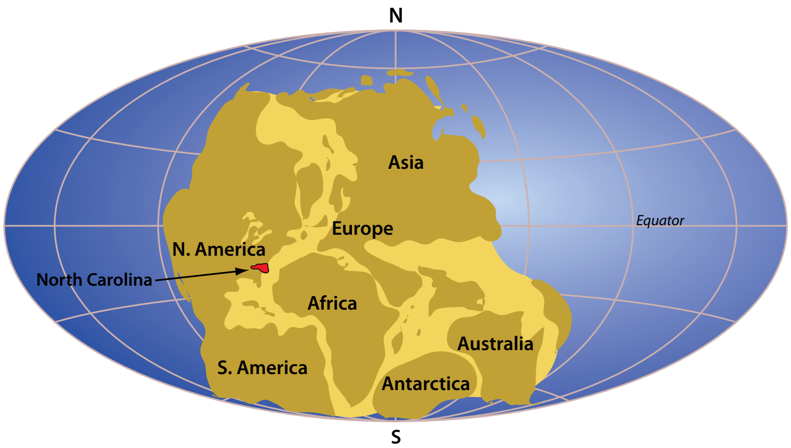


Figure 24 - *Supercontinent Pangea at end of Paleozoic era* (NCGS).

Approximately 300 million years ago, ancient Africa slammed into ancient North America. 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. 24). 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

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 progressed up the continent toward New England and the Canadian Maritime Provinces.

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. 25). The rift basins are similar to the modern day East African Rift system. The city of Durham sits within one of these rift basins, called the Durham Triassic basin. The sand, silt and clay deposited within the Durham Triassic basin later turned into the red to maroon colored sandstones, siltstones and mudstones common in the Durham area. Rocks of the Durham Triassic basin are exposed along the Eno River east of Roxboro Road (pl. 1 and fig. 4). The Durham Triassic basin and other similar-aged basins form the Triassic lowland of the Piedmont (fig. 3).

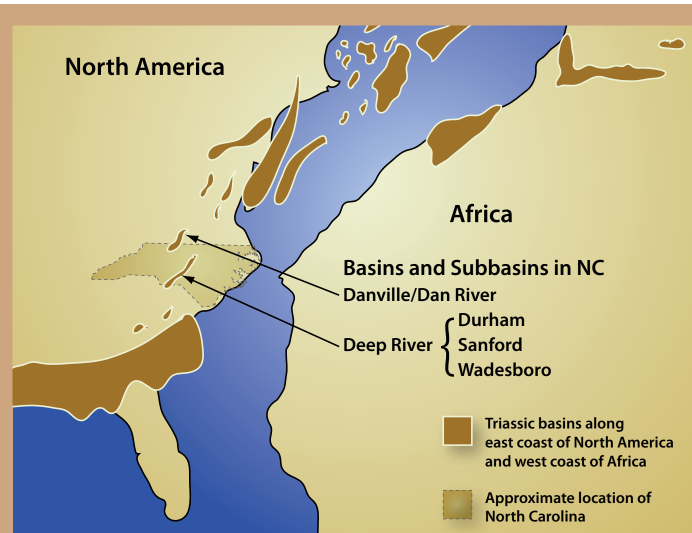


Figure 25 - *Generalized map of the major exposed buried and Triassic rift basins of the Newark Supergroup in North America and similar aged basins in Africa.* (Modified from Ralph Lewis, Connecticut Geological Survey, www.wesleyan.edu/ctgeology/CtLandscapes/).

The faulting that occurred during the breakup of Pangea formed many large and small faults. Often the faults were zones where silica rich fluids traveled. With time, the silica in the fault zones precipitated out and formed thick quartz-lined fault zones or fractures. One of these thick quartz zones runs through Cox Mountain in Eno River State Park and is evident by the presence of opaque, white quartz boulders and cobbles strewn along the ground in a northwest trend (See geologic trail guide for Cox Mountain for more details). This faulting (commonly referred to as Mesozoic faulting by geologists) is also speculated to be responsible for the multitude of ***lineaments*** visible on Plate 2. A prominent north-south trending lineament coincides with the north-south segment of the Eno River from Few's Mill to Borland-McCauley Mill (pl. 2). This lineament and therefore the course of the Eno River are controlled by faulting that occurred more than 200 million years ago! The flow directions of many of the streams and tributaries of the Eno may be controlled by the presence of faults originally formed during the breakup of Pangea.

The Eno River area during the late Triassic was full of life. North Carolina was located near the equator and had a semi-arid tropical climate. Situated between rugged mountains, the Durham Triassic basin was dominated by lakes, swamps and meandering rivers and streams that would periodically dry-up. Crocodile-like animals called phytosaurs, early dinosaur ancestors, and primitive mammals roamed the land of the Triassic basin; fish, clams and various crustaceans lived in the lakes and rivers; insects crawled on the ground and flew through the air; and abundant conifer trees and *cycads* grew. Evidence of this abundant life is seen by the common occurrence of petrified wood in Triassic sediments, the occasional discovery of fossilized bones of reptiles and the footprints of early dinosaurs (fig. 26 and 27) in Triassic basin sediments throughout North Carolina.

Figure 26 - *Achisauripus sp.* an ichnogenus of a theropod dinosaur, known only from fossilized bipedal, 3-toed footprints, Late Triassic period, Mt. Tom Formation, Holyoke, Massachusetts *(Courtesy of Brian Gay)*. Scale bar is 5 cm.
Inset - Dinosaurian footprints from the Sanford Triassic basin, NC from Olsen and Huber 1998.

Figure 27 - *Artist rendition of flora and fauna of the Triassic basins.*
From the News and Observer Newspaper - Triassic Triangle poster *(reproduced with permission)*.

The North-South Segment of the Eno River

Why does the course of the Eno River change direction and begin flowing in a north-south direction just east of Cox Mountain?

The short answer:

The Eno River flows into an extinct geologic fault that formed more than 200 million years ago during the break-up of Pangea. The faulted rock is weaker and easier to erode causing that north-south segment to be the preferred flow path of the river.

The long answer:

Rivers and streams typically follow the geologic structure or grain (like the grain in wood) of the rocks that they flow over. Some of these geologic structures include ***joints, layering, faults, fractures*** and ***foliations.*** Geologic structures commonly control the orientations, patterns and local gradients of streams and rivers. Zones where pre-existing fractures, joints and faults are present within rock may be more easily eroded. Running water likes to take the "path of least resistance" and will flow into zones that are easier to erode. When geologic structures like joints and faults intersect, the flow path of rivers and streams may form kinks or abrupt bends at sharp angles. A close examination of the course of the Eno River reveals many kinks and abrupt bends.

In the Eno River area, most geologic structures (such as layering, joints and foliation) are oriented in a northeast-southwest trend – parallel to the trend of the entire Appalachian Mountains. The section of the Eno River from the town of Hillsborough to just west of the Few's Mill area flows in a general northeast direction with many small-scale kinks and bends. This section of the Eno appears to follow the dominant structure of the underlying rock parallel to the major trend (northeast-southwest trend) of the rocks, with minor deflections as the river follows small-scale fractures and joints. However, at Few's Mill in Eno River State Park, the Eno River abruptly bends toward the south at a sharp angle. This sharp angle bend coincides with the Eno encountering a prominent linear feature (a ***lineament***) visible on the raised relief map (pl. 2). The same prominent north-south lineament extends toward the north and is occupied by Buckquarter Creek.

Lineaments may reflect the trace of faults and fractures or the orientation of rock features such as layering and foliations. Several prominent lineaments (several miles long) are present on the raised relief map (pl. 2) of the Eno River area. Many of these lineaments are parallel to the known direction of faulting associated with the split-up of Pangea and the formation of the Triassic basins. At many locations, portions of the Eno River and its tributaries occupy the trace of these lineaments.

Outcrops of fractured rock, off-set map patterns of geologic units and the presence of other features consistent with faulting have been observed within the trace of the prominent north-south lineament. These observations have led to the interpretation that the flow of the Eno River in this section is controlled by faults that formed during the breakup of Pangea and the formation of the Triassic basin more than 200 million years ago (pl. 1).

Dikes and Sills Intrude the Triassic Basin and into Carolina Terrane Rocks

Mafic magma from deep in the Earth welled up through fractures in the crust at the beginning of the Jurassic period (approximately 195-205 million years ago). This magma intruded the sediments of the Triassic basin and surrounding crystalline rocks of the Carolina terrane. At this same time, to the east of the Durham Triassic basin, 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. In the Durham Triassic basin, the magma solidified into rock known as diabase (fig. 6). Diabase is a mafic rock with a composition similar to ocean floor basalts.

In the Durham Triassic basin, diabase is more resistant than the surrounding sandstones and siltstones it intrudes and often forms resistant ridges in the Durham area. Penny's Bend on the Eno River is underlain by diabase. Diabase is composed of minerals that contain abundant iron and magnesium in comparison to the Triassic sediments. Because of the abundance of iron and magnesium, unique plant communities sometimes develop on top of areas underlain by diabase (e.g. The Diabase Glades).

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 beginning of the Triassic to the end of the Cretaceous periods (66 to 245 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 Modern Floodplain Deposits

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.

During times of relatively slow and gradual uplift, streams and rivers meander through their floodplain and erode the land surface into broad valleys. During times of relatively rapid uplift, streams and rivers become entrenched in their floodplains. This entrenchment of the rivers causes them to down-cut and incise their channels as the land surface is uplifted. The Eno River is an incised river with steep banks in many places. Additional evidence for stream incision is the presence of floodplain deposits within the Durham Triassic basin that are no longer subjected to flooding by the river. Old floodplain deposits that are now elevated above the active floodplain are referred to as ***terrace deposits***. (See the geologic trial guide to West Point on the Eno Park Stop 3 for an example of a terrace deposit.)

The timing of the uplift and erosion of the Piedmont is not well understood by geomorphologists (scientists who study landforms). Generally, it is believed that the Piedmont was uplifted differentially (some parts uplifted faster than others) and entered a period of relatively rapid uplift and subsequent erosion about 5 million years ago. Recent research along the Potomac River in northern Virginia indicates that the deep incision of some Piedmont rivers may be geologically recent and have incised 30 to 60 feet (10 to 20 meters) gorges beginning as recently as 35,000 years ago (Reusser et al., 2004).

The Earth was in the last Ice Age 12,000 to 35,000 years ago. During this time the northern portion of the North American continent was covered in ice. Global sea level was much lower. North Carolina had a climate wetter than today with abundant rainfall and snow. A wetter climate, coupled with lower global sea level, may have caused the gradients of Piedmont rivers and streams to greatly increase. The increased gradients subsequently increased the erosive power allowing the rivers to carve deep stream valleys in a geologically short period.

The sand, silt and clay deposits present in the river bed of the Eno River 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 river banks and are deposited. These deposits are known as ***alluvium*** or floodplain deposits. Alluvium is the youngest geologic unit within the Eno River. Someday the sand, silt and clay material that composes the alluvium will be deposited at the mouth of the Neuse River near the coast. If buried deep enough and long enough, it will become sandstone, siltstone and mudstone.

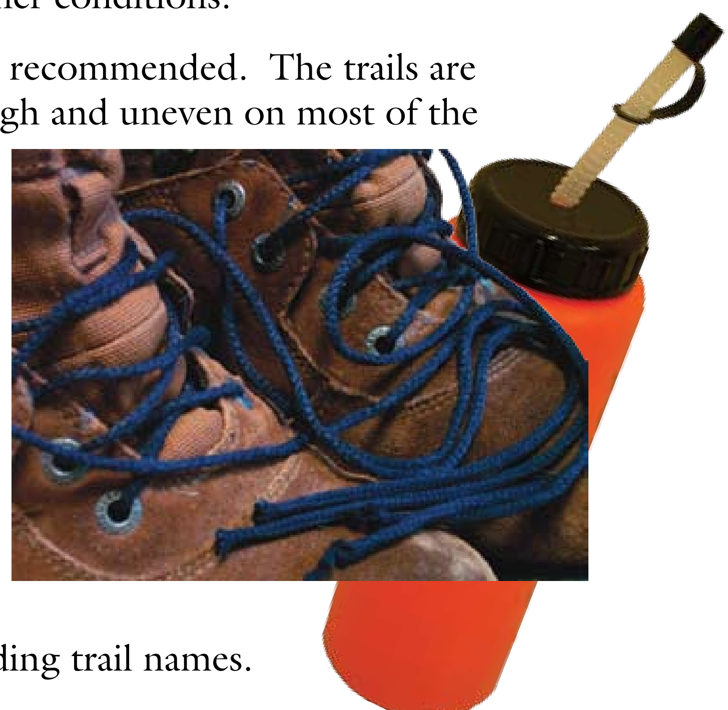
V. GEOLOGIC TRAIL GUIDES

The following sections of this Information Circular include interpretive geologic guides to select trails in Eno River State Park and West Point on the Eno Park. The preceding portions of this publication provide the geologic background for the terminology and concepts discussed in the trail guides. You may find it helpful to read through the trail guide prior to the hike and refer back to the main portions of the publication to familiarize yourself with the geologic terms and concepts.

As with all outdoor activities there are certain possible hazards. Proper planning will minimize most hazards to ensure an enjoyable geologic adventure. Before beginning a hike please consider and be aware of the following:

Hiking Checklist

- ✔ Check the weather before starting the hike and make sure that you are appropriately dressed for changing weather conditions.
- ✔ Wear sturdy footwear. Hiking boots are recommended. The trails are often slippery when wet. Footing is rough and uneven on most of the trails.



- ✔ Make sure you have enough time to complete the hike and return to your vehicle before sundown. Don't get stuck on the trail in the dark. The park gates close at sundown.
- ✔ Acquire the park maps for the trail areas. Many of the maps can be downloaded from the internet. The park maps have specific park rules and regulations and other information including trail names.
- ✔ Several of the hikes are relatively strenuous (more than 4 miles). Please be sure your level of physical fitness is appropriate for the hike.
- ✔ Carry water and food on the hike especially during the summer months and on the longer hikes.
- ✔ Follow all park rules and regulations.

Trail Guide Locator

Please remember that rock and mineral collecting is **STRICTLY PROHIBITED** in Eno River State Park as well as land operated by the city of Durham Parks and Recreation Department. The location of the selected trails with geological trail guides is provided in Figure 28. Geologic trail guides are provided for the following trails:

- **Cox Mountain and Fanny's Ford trails** – Eno River State Park – Few's Ford Access.
- **Holden Mill trail –** Eno River State Park – Few's Ford Access.
- **Cabe Lands and Eno Quarry trails** – Eno River State Park – Cabe Lands Access.
- **West Point on the Eno Park trails** – city of Durham Park.

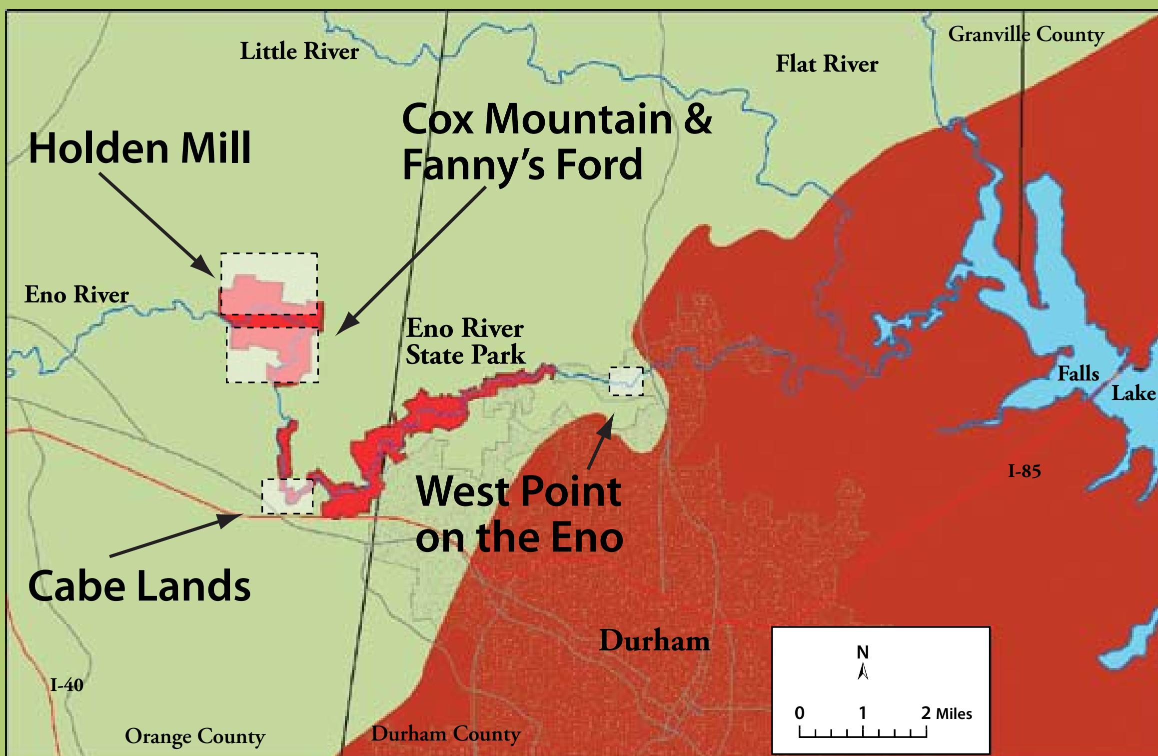


Figure 28 - *Locations of geologic trail guides in Eno River State Park and West Point on the Eno Park.*
Green area of map is underlain by crystalline rock of the Carolina terrane.
Brown area of map is underlain by Triassic basin sediments and diabase.

Geologic Trail Guide to the Cox Mountain and Fanny's Ford Trails

Eno River State Park – Few's Ford Access

Distance and difficulty of hike: Approximately 4 miles of relatively strenuous hiking.

What you will see:

- Outcrops of volcanic tuffs near the swinging bridge crossing the Eno River
- A geologic contact separating volcanic tuffs from intrusive granodiorite
- Boulders and cobbles of quartz associated with a Triassic-age brittle fault
- Outcrop of jointed granodiorite
- Outcrops of granodiorite with examples of fine- and medium-grained textures
- Outcrop of xenolith of volcanic rock within granodiorite pluton
- Outcrops of tuff breccia formed from a lahar

Introduction

The geologic trail guide of the Cox Mountain and Fanny's Ford trails begins at the parking lot for the picnic area associated with the Few's Ford access area of Eno River State Park. As you follow this trail guide, you will traverse from a topographic low of about 400 feet above sea level at the Eno River to a topographic high at about 680 feet near the top of Cox Mountain. A topographic map with stop locations is provided in Figure 29. It is recommended that you acquire a park map indicating the locations and names of the trails before starting your trip. To avoid becoming lost or disoriented it is recommended that the companion map (fig. 29) and the park map be referenced frequently during the hike.

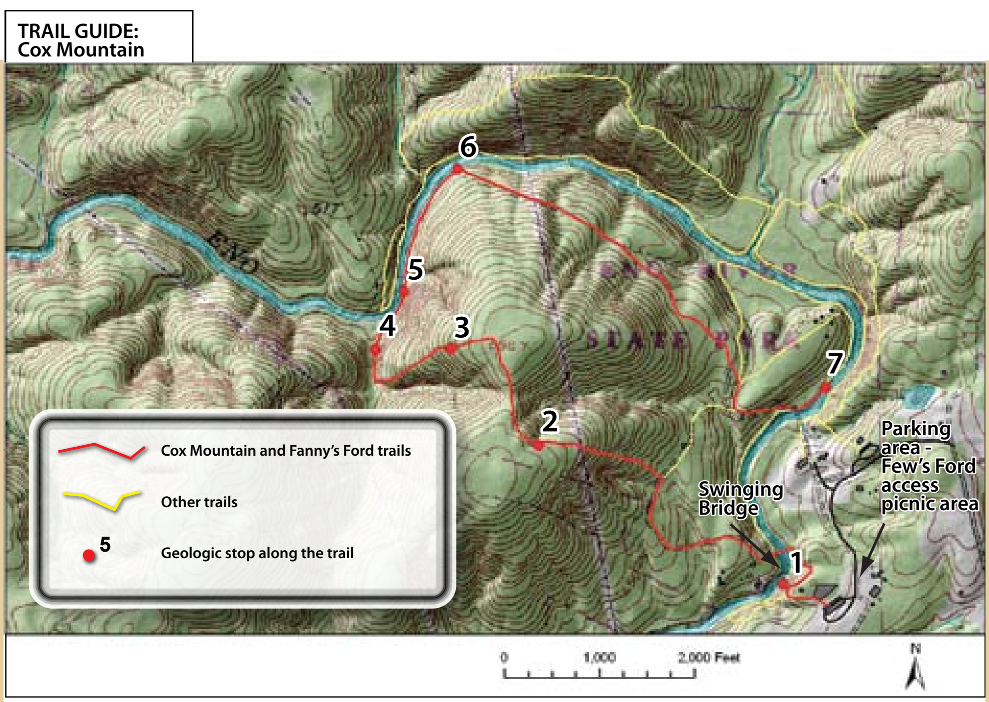


Figure 29 - *Map of geologic stops along the Cox Mountain and Fanny's Ford trails.*

Trail Guide and Points of Interest

From the parking and picnic areas, follow the trail towards the swinging bridge over the Eno River. After descending the stairs into the floodplain of the river – stop and take a moment to refer to your maps. You should see the swinging bridge toward the north crossing the Eno River. Stop 1 is located a short walk of about 100 feet toward the south along a small footpath that parallels the river and appears to dead-end at a large outcrop of rock.

Stop 1: Lichen and moss-covered outcrop of lithic tuff near the swinging bridge

At this location, the large outcrop (fig. 30a) and the outcrops in the Eno River are volcanic rocks called lithic tuffs. Lichen and moss hide the true beauty of the rock. A cut slab of the rock (fig. 30b) reveals that the rock is composed of black angular fragments of solidified lava in a green, fine-grained ash matrix. The black angular fragments of lava and ash were blown out of a nearby volcano 630 million years ago and deposited in relatively horizontal layers. Today, the rock layers are tilted on end because they were folded into ***synclines*** and ***anticlines*** (fig. 21). The layers are now inclined at an angle of about 60 degrees from the present-day ground surface. If you examine the surface of the rock closely, you may notice numerous intersecting fractures that are filled with quartz and other minerals. This fracturing of the rock may be related to brittle faulting (breaking of the rock) during the breakup of Pangea in the Triassic period. Quartz-filled veins are best seen as you retrace your steps to the stairs. Look for the quartz veins on the surface of the rock that you crawl over.

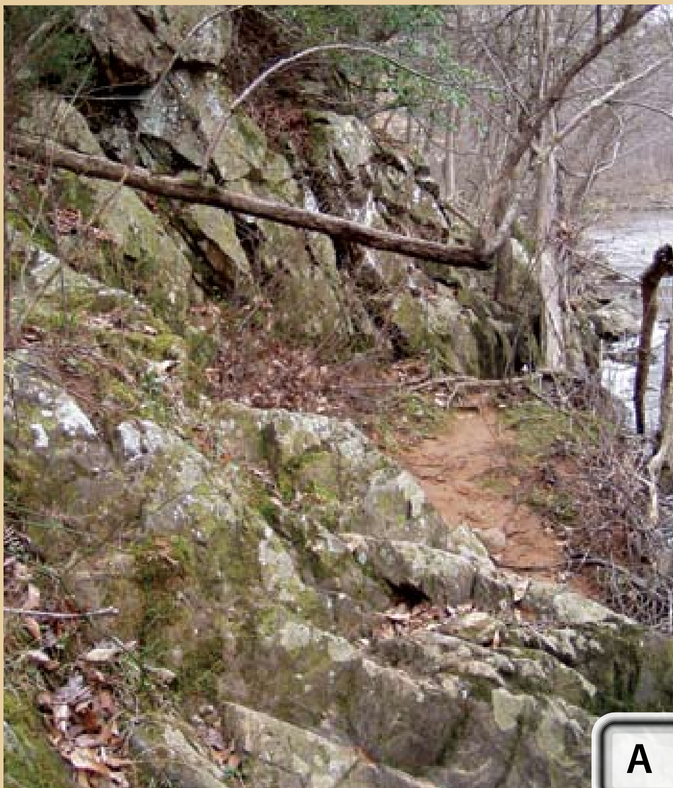


Figure 30
A. Outcrop of lithic tuff at Stop 1 on banks of Eno River.
B. Cut slab of lithic tuff showing black clasts of lava in green ash matrix.

To reach Stop 2, cross the Eno River on the swinging bridge and continue along the connector trail to the Cox Mountain trailhead (about 1,700 feet away). Pay attention to the signs indicating the way to the Cox Mountain trailhead and refer to your maps. Do NOT take the unmarked trail heading west before the signage for the Cox Mountain trail (This unmarked trail leads to the Wilderness section of the park and is not the Cox Mountain trail.) Along the entire trail from the Eno River to the Cox Mountain trailhead and beyond, you are walking on volcanic tuffs similar to the rocks of Stop 1.

Once you enter the trailhead on the Cox Mountain trail you should notice numerous boulders lining the path. If any fresh surfaces of the boulders are visible, notice the color of the rock. The fresh surfaces should be black to dark gray in color, indicating the volcanic tuffs. Continue walking west (uphill) toward the top of Cox Mountain.

While walking under the of high voltage power lines, again note the color of fresh surfaces of the boulders and cobbles. You are still walking over the volcanic tuffs. Continue to look at the cobbles and boulders along the trail and see if you can tell when the rock changes from the tuffs to spheroidally (round-shaped) weathered boulders and cobbles of granodiorite. When you reach the first gully in the trail and see the round-shaped boulders, stop. You have reached Stop 2.

Stop 2: Contact zone of granodiorite and tuff unit

The contact (location where the rock type changes) between the granodiorite and the tuff parallels the gully that crosses the trail (fig. 31). Rounded boulders of granodiorite can be seen on the west side of the gully and volcanic tuffs on the east side. Fresh granodiorite in this area is gray in color and fine-grained. The granodiorite intruded the tuffs as a blob of melted magma, then cooled slowly and formed the granodiorite.

Continue along the trail and keep climbing. As you walk, look for cobbles and small boulders of quartz (white, milky rock). You will cross a small swale as you continue to climb, eventually reaching an elevation of approximately 680 feet near the top of Cox Mountain. A short distance after beginning to descend Cox Mountain, you should again notice white cobbles and boulders of quartz strewn along the trail and in the woods. Many of the quartz boulders have been moved from the woods to the edge of the trail to help mark the path and to prevent erosion.

Figure 31 - *View looking toward west along Cox Mountain trail at location were trail crosses first gully after powerlines.* The photograph was taken standing on the green tuffs while looking across the geologic contact toward the granodiorite. Red line designates approximate trace of geologic contact. Presence of a change of rock type is subtle and evident in the composition of cobble and boulders in and around the trail.

Stop 3: Quartz boulders and quartz-veined altered rock strewn along trail

Stop 3 is a zone of quartz boulders strewn along the trail. The quartz is the white to yellowy-white boulders and cobbles on the ground. This portion of the trail crosses an area interpreted to be a fault with abundant quartz precipitation along the fault. Notice that the rock type abruptly changes from the spheroidally weathered granodiorite cobbles and boulders to angular white quartz cobbles and boulders (figs. 32a and b). Continuing downhill, the trail turns toward the north and parallels a small stream that drains toward the Eno River. This stream has eroded through the same zone of abundant quartz seen at Stop 3. After entering the stream valley, follow the trail and walk about 250 feet toward the north and look for abundant quartz boulders on the slope on the east side of the trail. In the winter, when the leaves have fallen, quartz boulders can also be seen on the west side of the drainage.

Figure 32 -
A. View looking southwest at Stop 3 on the Cox Mountain trail, where it crosses an area of numerous quartz cobbles and boulders.
B. Close-up view of quartz rock along trail.

Stop 4: Zone of quartz boulders extending up both sides of stream

At Stop 4, quartz boulders and cobbles extend up the hills on both sides of the stream. The quartz extends to the northwest and back toward the southeast. The quartz boulders of Stop 3 are part of the same trend. Try to visualize the linear nature of the fault as it cuts across the land. You are standing in the center of an ancient geologic fault that was active in the Mesozoic era (66 to 245 million years ago).

Continue the hike by following the trail to the Eno River. This segment of the Eno River has abundant boulders and outcrops of granodiorite. Many of the outcrops display a geologic feature called jointing or ***joints***. Joints are planar fractures in rock in which no appreciable movement has occurred. As you walk, try to find rock outcrops that have flat sides. The flat sides are the joint surfaces.

The granodiorite was formed when magma cooled very slowly deep in the earth. When deep in the earth, the rock was under great pressure from the weight of the overlying rock. Over many millions of years, as the land surface uplifted and the rock above was eroded away, the pressure on the rock mass was greatly reduced allowing the rock to expand and crack. These expansion cracks are what geologists call joints. Some joints may also be formed from the faulting of rock.

Joints often occur in sets perpendicular to one another. Streams and rivers often flow along zones of weakness caused by joints (or faults) in rocks. Examine the topographic map of the Cox Mountain area (fig. 29) and notice how the path of the Eno River flows in a straight line for a distance then abruptly changes course into another straight line segment. The river is following the grain of the rock probably controlled by joints and/or faults. See if you can pick out the sets of nearly vertical and perpendicular joints in the outcrop. Are some of the joint sets similar to the flow direction of the Eno River?

Stop 5: Jointed outcrop of granodiorite

A large outcrop of jointed granodiorite can be observed a few feet down the trail after passing a set of wooden stairs. If you look with care at the outcrop, where lichen and moss are absent, the texture of the rock can be seen. The granodiorite ranges from a fine-grained to medium-grained texture. In many locations, the medium-grained (lighter-colored) granodiorite can be seen intruding the finer-grained (darker-colored) granodiorite (figs. 33 and 34). The ruins of the dam for Holden Mill are visible on the other side of the Eno River. The large outcrop of Stop 5 may have been used to anchor the dam to this side of the river. For a brief history of Holden Mill see the geologic trail guide for the Holden Mill trail.

Figure 33 - *Photograph of jointed outcrop of granodiorite at Stop 5 on the bank of Eno River.* Dashed red lines indicate joints.

There are additional outcrops of granodiorite along this section of the Cox Mountain trail. Stop at a few of them along your way and try to identify the joints and see if you can find other locations where the medium-grained granodiorite intrudes into the finer-grained granodiorite.

After leaving Stop 5, continue to follow the Cox Mountain trail along the river. When the trail turns east and leaves the banks of the Eno River, the trail crosses over a rock that looks like it is filled with cracks. This is Stop 6 and is an example of a ***xenolith***.

Figure 34 - *Sample of fresh granodiorite showing both medium and fine-grained varieties in same sample. Minerals in granodiorite include:*
Black = amphibole (hornblende variety)
White = feldspar (plagioclase variety)

Stop 6: Xenolith of ash tuff in granodiorite

A xenolith is a piece of foreign rock enclosed within an igneous rock. When the granodiorite pluton intruded the surrounding rocks, a piece of ash tuff was incorporated into the hot magma and "frozen in place" (preserved) before it has a chance to melt. Xenoliths can be sedimentary, metamorphic or igneous rocks. Figure 35a shows the exposed xenolith in the middle of the trail. Figure 35b shows a fresh surface of the xenolith rock. The rock is green and fine-grained. Look closely at the surface of the xenolith in the trail. You will see abundant intersecting fractures in the large block (identified with red lines in Figure 35a) that likely formed when the rock was fractured as it was being forcefully intruded by the hot magma of the granodiorite.

This is the end of points of geologic interest along the Cox Mountain trail. The next stop is a relatively long distance away (see map) on the Fanny's Ford trail. As you walk out the rest of the Cox Mountain trail, notice the rounded boulders of granodiorite at the powerline crossing. After exiting the Cox Mountain trail, refer to your maps.

Figure 35 -
A. Xenolith of tuff in granodiorite. Red lines indicate fractures in the large block. These fractures likely formed when the rock was intruded by the hot granodiorite magma.
B. Freshly exposed surface of the green tuff from figure 35A.

Locations of Interest along the Fanny's Ford Trail

The next stop is accessed via the Fanny's Ford trail. When you leave the Cox Mountain trail and enter the Fanny's Ford trail you cross-out of the granodiorite body and back into the tuffs of Stop 1. When you begin your descent toward the Eno River, look at the rock fragments in the old roadbed of the Fanny's Ford trail. See if you can spot the fine-grained texture of the green tuffs on fresh surfaces of rocks.

Stop 7: Tuff breccia outcrops at Few's Ford

Stop 7 is located off of the Fanny's Ford trail near the ruins of Few's Mill along the Eno River (fig. 36). Stop 7 can also be reached by parking at the Few's Ford parking area adjacent to the Piper-Cox house and crossing the river on foot - if you don't mind getting your feet a little wet. The best exposures are observed from the west side of the river. At times of low water, it is possible to walk out onto the rocks. ***At times of high water the rocks at Few's Ford can be dangerous and should not be climbed.***

The rocks are best viewed by leaving the trail and carefully climbing on the rocks. These are volcanic rocks known as tuff breccia. Breccia is an Italian word for broken stones or rubble. The tuff breccia is composed of pieces of different rock types suspended in a green, finer-grained background (similar to a chocolate chip cookie with the rock fragments representing the chocolate chips and the finer-grained background material representing the cookie dough). You will notice the rock is made-up of sand to boulder-sized clasts of other rocks (some clasts are up to 3 feet long). Use a cup or your hands to splash water on the outcrop to help see the texture. These rocks are interpreted to have been formed by lahars (volcanic mudflows) that rapidly traveled down the steep slopes of a nearby volcano soon after an eruption. A general discussion of lahars is provided in section III of this publication titled **The Rocks of the Eno River**. See figures 11a and 11b in that section for photographs of a modern day lahar and a photograph of the Few's Ford lahar deposit.

Figure 36 - *Stop 7 - Tuff-breccia outcrop at Few's Ford.*

History of Few's Mill

Information on the history of Few's Mill was acquired from The Historic Mills of Eno River State Park pamphlet and the Eno River Association Calendars for 1978 and 1988.

To the west of Stop 7, a portion of the Fanny's Ford trail follows the mill race of the former Few's Mill (fig. 37). Stone ruins are visible just west of the ford on the west bank of the River. Few's Mill, built by the brothers William and James Few, was in operation from approximately 1758 to 1908.

The Fews played important roles in the colonial history of the area and the birth of the United States. William Few's son, James Few, participated in the Battle of Alamance in 1771. He was captured and later hanged by the order of the royal governor William Tryon. The Fews, having lost public favor in the colonial town of Hillsborough, moved to Georgia. In Georgia, William Few Jr., distinguished himself as a patriot during the Revolutionary War and went on to sign the Constitution.

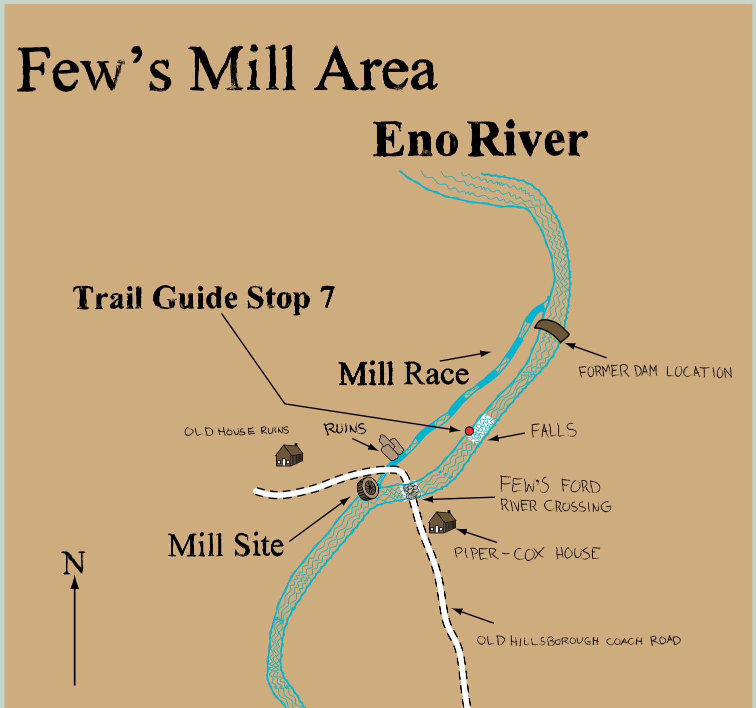


Figure 37 - *Sketch of Few's Ford area.*

After the Fews, the mill property changed owners many times. In 1831, the mill site was owned by the W. Piper Company and included a blacksmith shop, oil mill, grist mill, saw mill, wheat thrasher and wool-carding machine. In the 1840s, the mill site was remodeled into a manufacturing company of various goods. The mill was abandoned in 1908 after being badly damaged by flooding.

Geologic Trail Guide to the Holden Mill Trail

Eno River State Park – Few's Ford Access

Distance and difficulty of hike: From the Few's Ford access parking area, adjacent to the Piper-Cox house, the round-trip is 4.1 miles. The Holden Mill trail is accessed via the Buckquarter Creek Trail. The Holden Mill trail includes moderate to strenuous hiking with a few locations where you will have to walk on bare rock that may be slippery.

What you will see:

- Alluvium deposits in Buckquarter Creek floodplain
- Fine- and medium-grained granodiorite and diorite
- Excellent example of the process of exfoliation at Onion Rock
- The ruins of Holden Mill

Introduction

The geologic field trip of the Holden Mill trail begins at the Few's Ford access parking lot adjacent to the Piper-Cox house. The Holden Mill trail is accessed from the Buckquarter Creek trail. A topographic map with stop locations is provided as Figure 38. It is recommended that you acquire a park map indicating the locations and names of the trails before starting your trip. To avoid becoming lost or disoriented, it is recommended that the companion map (fig. 38) and the park map be referenced frequently during the hike.

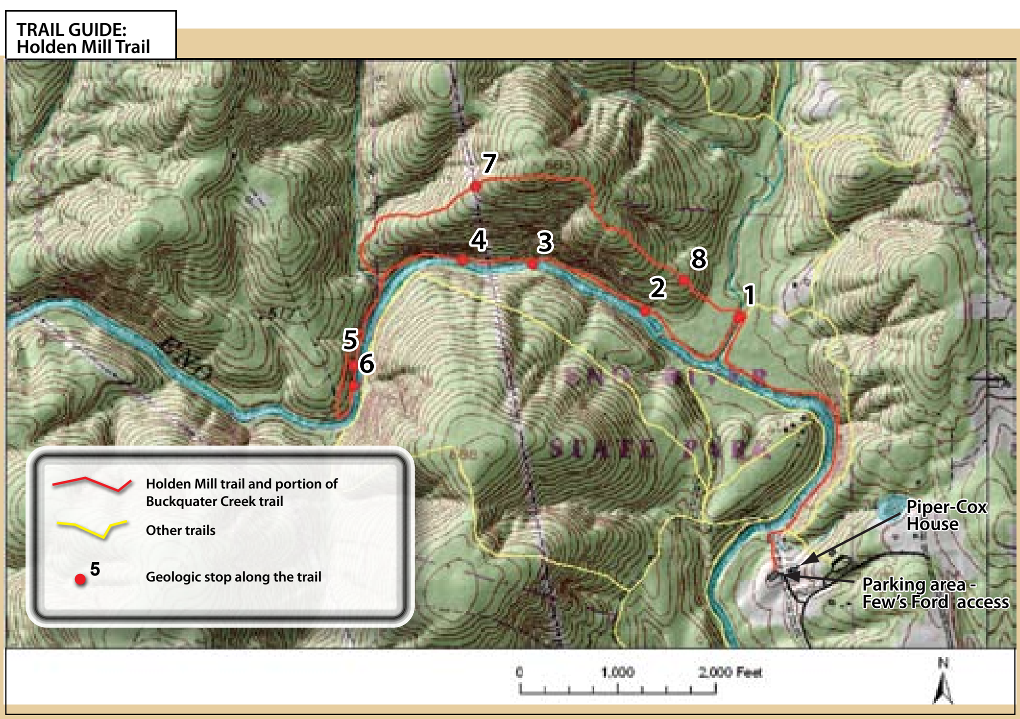


Figure 38 - *Map of geologic stops along the Holden Mill trail.*

Trail Guide and Points of Interest

Begin the tour by hiking the Buckquarter Creek trail. The trail passes Few's Ford and goes over a large outcrop area via a staircase. The parking area and the majority of the Buckquarter Creek trail traverse volcanic tuffs which include a body of tuff breccia in the vicinity of the staircase. A discussion of the significance of the tuff breccia is provided in the geologic trail guide to the Cox Mountain and Fanny's Ford trails at Stop 7.

The trail follows the Eno River as it bends to the west (left). The Buckquarter Creek trail turns away from the river and follows Buckquarter Creek.

This area of the trail is located within the floodplain of Buckquarter Creek. The floodplain is characterized by an area of relatively flat topography with no rock outcrops. If you were to dig down through the floodplain deposits, you would find a layer of clay- to boulder-sized sediments that range from just a few feet thick to over 10 to 15 feet (3 to 5 meters) thick in places. Once you have dug through the clay- to boulder-sized sediments you would hit hard crystalline rock. Geologists call the sediment deposited in the floodplain ***alluvium***. Alluvium deposits typically occupy flat lowland areas that may be swampy.

Stop 1: Floodplain of Buckquarter Creek with alluvium overlying exposed crystalline rock

A good place to see exposed alluvium is located to the south of the bridge crossing over Buckquarter Creek (Stop 1). A small area of crystalline rock (granodiorite) is exposed underneath alluvium deposits at this location (fig. 39).

Figure 39 - *View looking south from bridge over Buckquarter Creek.*
Floodplain deposits (alluvium) overlying exposed granodiorite. Arrow indicates outcrop of granodiorite.

To continue the tour, cross the bridge over Buckquarter Creek. Take a moment and refer to your maps. You are now on the Holden Mill trail. Follow the trail to the south, back toward the Eno River (left after crossing the creek). This portion of the trail will take you along Buckquarter Creek to its intersection with the Eno River. Follow the trail as it turns toward the west (right). As you walk along the Eno River, notice that the land surface to your right is gradually building into a ridge. After a short distance along the Eno, the trail exits the floodplain of Buckquarter Creek and enters the narrow floodplain of the Eno with numerous boulders and rock outcrops on your right (Stop 2).

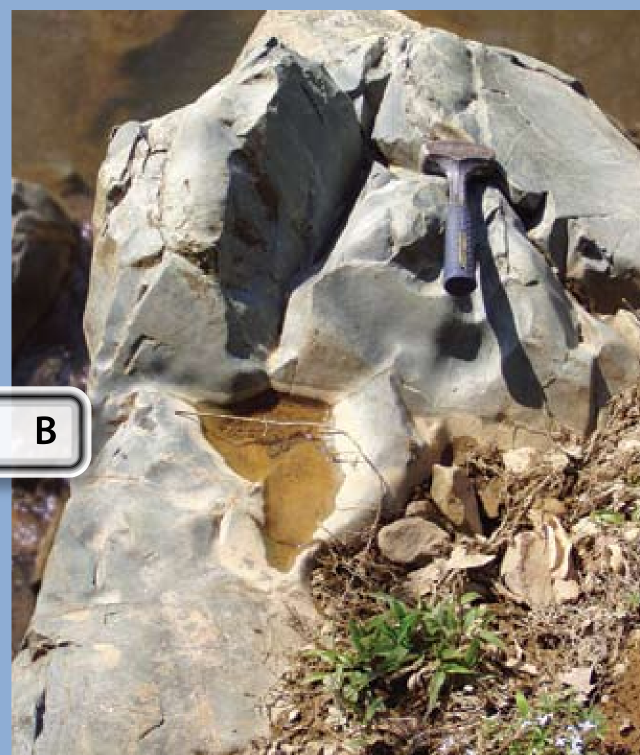
Stop 2: Outcrop and boulders of granodiorite

Outcrops and boulders along the river section of the Holden Mill trail are of a rock type called granodiorite. Granodiorite is an igneous rock that intruded the volcanic rocks of the area as a blob of melted magma. The magma cooled slowly and formed the granodiorite. The granodiorite ranges from a fine-grained to medium-grained texture. Many of the rock outcrops are covered with lichen, causing the texture of the rock to be visible only under close examination (you need to be standing within 1 or 2 feet of the rock). In many locations the medium-grained (lighter-colored) granodiorite can be seen intruding the finer-grained (darker-colored) granodiorite. This texture (see fig. 34) is visible in many locations along the trail. See if you can spot other locations where the two textures are visible on your walk.

The granodiorite is part of a larger igneous intrusive body called a pluton. The magma that formed the pluton intruded the tuffs of the Eno River area around 630 million years ago. The granodiorite rocks traversed by the Holden Mill Trail are part of the same pluton as the rocks on Cox Mountain Trail (pl. 1).

A particularly good exposure of medium-grained granodiorite intruding the fine-grained granodiorite is present just before Stop 3 where the trail winds around some large (car-sized) outcrops. After winding around the large outcrops, pay close attention to the rocks in the Eno River. Notice that there is an area of rapids defined by a ledge of rock crossing the river rather than a bunch of separate boulders (fig. 40a). The ledge is composed of a fine-grained granodiorite ***dike*** oriented approximately north-south, crossing the river and is the destination for Stop 3.

Figure 40 -
A. View looking upstream toward rapids at Stop 3. The rapids are created by a ledge forming dike of resistant fine-grained granodiorite. Arrows indicate ledge.
B. Outcrop on bank of river polished, green-colored, fine-grained granodiorite.



Stop 3: Rapids in river created by resistant fine-grained granodiorite dike

The fine-grained granodiorite of the dike is more resistant to weathering than the medium-grained granodiorite and forms the rapids consisting of a ledge with a small drop (2 to 3 feet / 0.5 to 1 meters) in the river (fig. 40a). The fine-grained granodiorite is green in this location because it has a slightly different chemical composition compared to the other granodiorite along the trail. The surface of outcrops in the river have been polished by running water and show the green color of the rock (fig. 40b).

The next stop is located a few hundred feet west of the powerline crossing of the trail.

Stop 4: Onion Rock

Onion Rock (also known as Lunch Rock) is an excellent example of the weathering process known as exfoliation (fig. 41). Exfoliation is sometimes described as "onion-skin" weathering. Onion Rock received its name because it looks like the peeling skin of a giant onion.

Figure 41 - *View of Onion Rock looking west.*
Onion Rock exhibits an excellent example of exfoliation or "onion-skin" weathering. Red lines indicate exfoliation sheet (onion-skin).

Exfoliation is the process in which concentric layers of rock separate and peel from a large rock mass. The rock mass forming the pluton of granodiorite exposed on the trail was originally many miles beneath the surface. When buried, Onion Rock was under great pressure from the overlying rock. Uplift of the land surface and subsequent erosion reduced the thickness of the overlying rock. Less overlying rock reduced the downward pressure and the rock expanded primarily in an upward direction. At shallow depth, the expansion caused the rock to crack into sheets separated by joints parallel to the overlying surface. With continued erosion, Onion Rock was exposed on the surface and now looks as if it is peeled like an onion. A spectacular example of exfoliation is seen in the erosion of the giant granitic masses of rock named Half Dome in Yosemite National Park. Half Dome is peeling like a giant onion similar to Onion Rock. In North Carolina, an example of exfoliation on a scale similar to Half Dome is found at Stone Mountain State Park in western North Carolina.

Continue the tour by following the river as the Eno begins to bend toward the south. Be on the lookout for a sign indicating the spur trail to the ruins of Holden Mill. At the spur trail, cross the creek, and take a moment to refer to your maps.

While walking toward the mill ruins, the keen observer may notice several boulders of quartz strewn along the ground. When the leaves are off the trees during the winter, a vein of quartz may be observed in an outcrop of granodiorite along the route. The quartz is likely related to quartz precipitation along a fault active during the split-up of the supercontinent Pangea in the Mesozoic era. The quartz present on the trail has similar origins as the abundant quartz boulders present along a portion of the Cox Mountain trail. Refer to Stop 3 and 4 in the geologic trail guide for the Cox Mountain trail for additional information about the origin of the quartz.

The trail to the ruins of Holden Mill is a loop, follow the trail adjacent to the river to reach the ruins of the mill house (Stop 5).

Stop 5: Ruins of mill house of Holden Mill

The ruins of the mill house consist of a wall of stacked boulders and foundation stones composed of granodiorite. Look closely at some of the boulders (but do not move or disturb them). See if you can identify the fine- and medium-grained textures of the granodiorite. Continue walking south along the loop trail to the ruins of Holden Mill dam.

Stop 6: Ruins of Holden Mill dam

Like the mill house, the early settlers used the native granodiorite to construct the mill dam (fig. 42). While at the dam, take a few moments to look around. Notice that that there is outcrop in the middle of the river extending all the way to the far side. In this location the banks of the river are steep and form a relatively narrow valley. The narrow valley with hard outcrop on the banks and in the middle of the river provided a naturally favorable location to build a dam. Follow the trail as it goes over the former dam. See if you can identify the mill race where water was diverted from the Eno River to the mill house to turn the grinding wheels.

Figure 42 - *Ruins of Holden Mill dam constructed of granodiorte blocks.*

History of Holden Mill

Information on the history of Holden Mill was acquired from The Historic Mills of Eno River State Park pamphlet and the Eno River Association Calendar for 1978. Holden Mill was in operation from approximately 1811 to 1908. Built by Isaac Holden, the mill was inherited by his son, Thomas W. Holden, in 1820. In 1844, the daughter of Thomas Holden married John Fleming Lyon forming the Holden-Lyon Mill partnership. The mill site was used for corn and wheat grinding and handled cotton, oil, wool and lumber. The Holden-Lyon Mill was such a substantial operation that it supported a local schoolhouse. John Fleming Lyon operated the mill until 1868. In 1882, the mill was reopened by Samuel Cole and later closed in 1893 upon his death. The mill dam was destroyed in the flood of 1908.

After leaving the dam, follow the trail along the Eno River. Refer to the trail maps and be sure to follow the trail as it makes a sharp loop back toward the mill ruins. This portion of the trail traverses land just out of the floodplain on higher ground. From the trail, you can look down into the Eno River and see the dam ruins and former mill race.

To reach the next location of interest on the geologic tour, follow the trail back to the north, cross back over the small creek and pick up the portion of the Holden Mill trail that traverses the higher elevations. Take a moment to refer to your maps.

The next stop is approximately a half-mile walk from the dam ruins. The stop, located on the eastern edge of the powerline right-of-way, consists of an outcrop and boulders of diorite.

Stop 7: Outcrop of diorite along powerline right-of-way

Diorite is an intrusive igneous rock similar to granodiorite. This outcrop of diorite exhibits flat sides called jointing. A discussion of jointing and joints is provided in Stop 4 of the Cox Mountain trail guide. Of particular interest at this location is a single boulder about 2 feet (0.6 meters) in diameter with 0.5 to 1 inch (1 to 2 centimeters) long accicular (needle shaped) amphiboles (probably the amphibole type named actinolite) (figs. 43a and b). You will have to inspect the rock boulders carefully to find the boulder with the accicular amphiboles. **Please remember, the collection of rocks and minerals or the breaking of rocks on state park land is prohibited**.

Continuing on the trail, the next point of interest is approximately a half-mile walk from the powerlines.

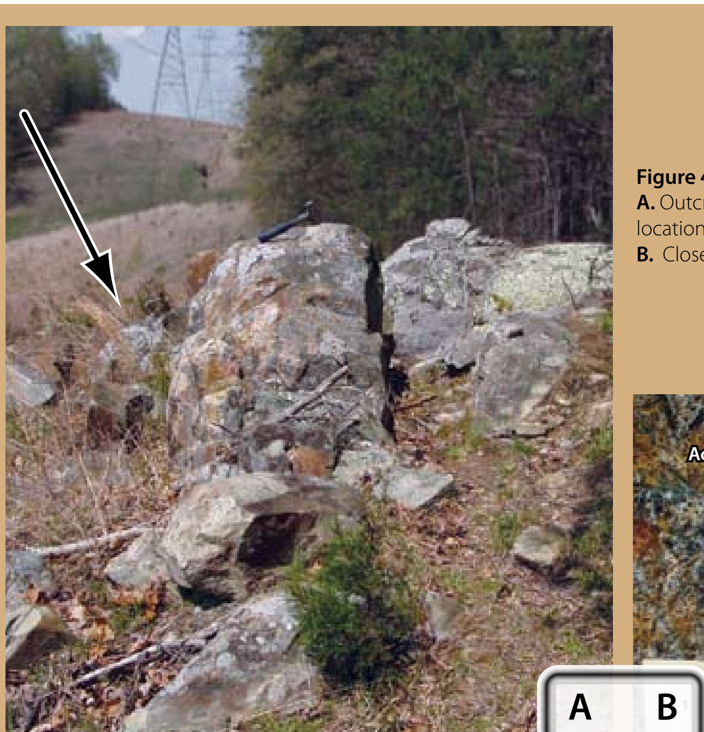


Figure 43
A. Outcrop of diorite along powerline right-of-way. Arrow indicates location of boulder with needle-shaped (accicular) amphiboles.
B. Close-up of boulder with needle-shaped (accicular) amphiboles.

Stop 8: Boulder piles of granodiorite along trail

Near the end of the Holden Mill trail, there are several piles of lichen- and moss-covered boulders of granodiorite. The boulders were probably placed in piles during past land clearing activities during the mid-1800s. The boulders are usually lichen-covered, making identification difficult. If you look closely you can find a few boulders without lichen and moss that show the texture of the granodiorite.

A few hundred feet to the east, the trail again enters the floodplain of Buckquarter Creek and leads back to the bridge crossing. Follow the Buckquarter Creek trail back to the parking area.

Geologic Trail Guide to the Cabe Lands and Eno Quarry Trails

Eno River State Park – Cabe Lands Access

Distance and difficulty of hike: 2 miles of relatively easy to moderate hiking.

What you will see:

- Topographic transition into the floodplain and floodplain deposits
- Volcanic rocks interpreted to have been deposited from a lahar
- An island in the middle of the Eno River formed from the buildup of sediment downstream of the former mill pond associated with Cabe Mill
- A portion of the mill race of former Cabe Mill excavated into alluvium
- Abandoned segments of the former Fish Dam Road
- The abandoned Eno Quarry and associated volcanic rocks

Introduction

A topographic map with stop locations is provided as Figure 44. A sketch of the Cabe Mill area, based on a drawing from the Eno River Association Calendar for 1978, is provided as Figure 45. It is recommended that you acquire a park map indicating the locations and names of the trails before starting your trip. To avoid becoming lost or disoriented it is recommended that the companion map (fig. 44) and the park map be referenced frequently during the tour.

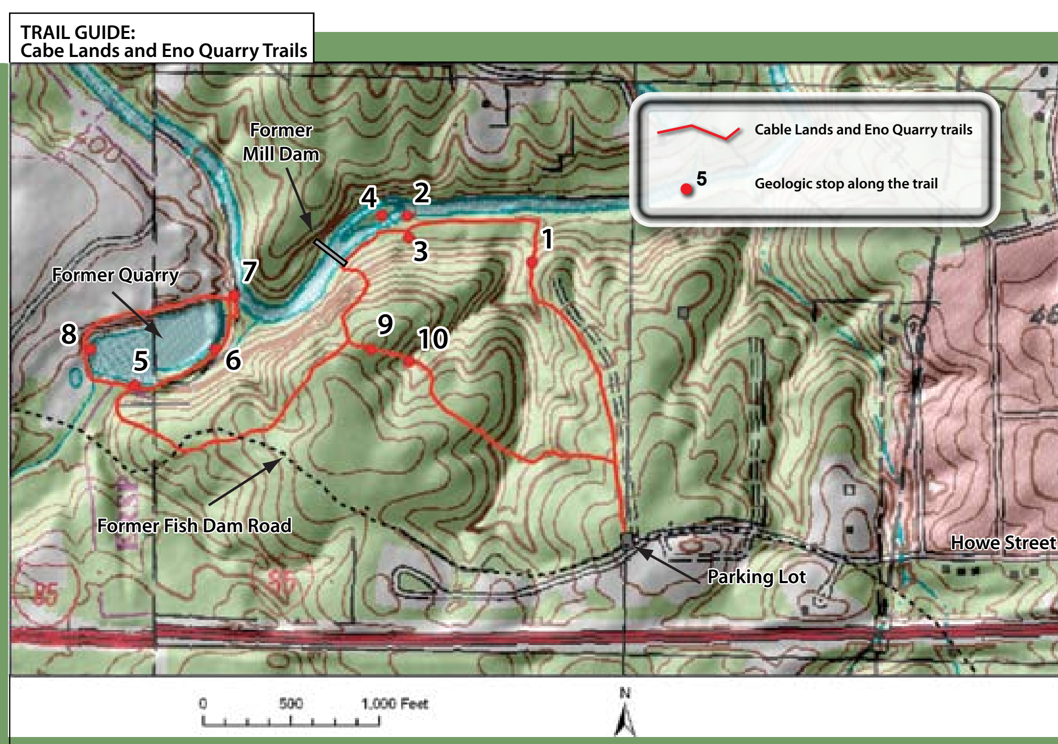


Figure 44 - *Map of geologic stops along the Cabe Lands and Eno Quarry trails.*

You will start your journey on the Cabe Lands trail at the parking area underlain by a granodiorite (granite-like rock) body. You will find little evidence of the granodiorite body on the first section of the trial from the parking area. The first rocks exposed in the trail are volcanic rock called tuffs. You will be walking from the upland topography on top of the granodiorite into the lowland of the floodplain, underlain by volcanic rocks. On your walk toward the river, notice how the land surface descends gradually. As you make the transition into the floodplain, also notice the change in vegetation. The upland is occupied by pine and cedar trees, where the floodplain is dominated by hardwoods.

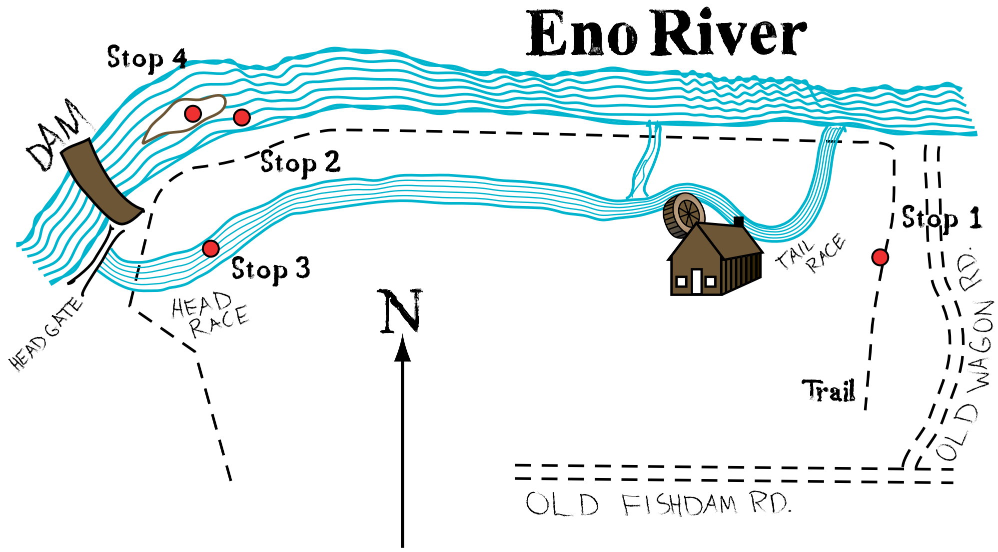


Figure 45 - *Sketch of Cabe Mill area during period of operation (circa 1799-1880s).*

Trail Guide and Points of Interest

Stop 1: Transition into the floodplain of the Eno River

As you walk north toward the Eno River, notice that the land surface is gradually descending. The trail traverses down an abrupt slope with a 15 to 20 foot (5 to 7 meter) drop in elevation as the trail enters the floodplain of the river (Stop 1). At Stop 1, turn around and face south (toward the parking area). Notice the steep slope and rock debris on the slope. This slope marks the topographic break between the upland portion of the trail and the lowland portion of the trail in the floodplain. The rock on the slope is a volcanic rock called tuff. Tuff is hardened volcanic ash that erupted out of nearby volcanoes 630 million years ago.

The floodplain is characterized by an area of flat topography with no rock outcrops exposed on the surface. If you were to dig down through the floodplain deposits you would find a layer of clay- to boulder-sized sediments that range from just a few feet thick to more than 10 to 15 feet (3 to 5 meters) thick in places. Once you have dug through the clay- to boulder-sized sediments you would hit hard crystalline rock.

To get an idea of the material of the floodplain below your feet, walk over to the west a few feet (toward the left if you are facing the river) and look into the channel carved by a small tributary that parallels the trail. Notice the cobbles and boulders at the base of the tributary and the clay- to sand-sized sediment in the walls of the tributary. You are looking at a cross-section of the floodplain deposits. During major flood events, this portion of the trail is likely under water. Geologists call the sediment deposited in the floodplain ***alluvium***.

Continue with the tour by following the trail toward the river. Cross the narrow footbridge and follow the trail to the west for about 850 feet along the Eno River. The next point of interest (Stop 2) is where a large rock is exposed in the center of the river, opposite a large outcrop on the north bank, immediately downstream of an island (figs. 44 and 45).

Stop 2: Outcrop and boulders of tuff breccia

The rocks of Stop 2 are best viewed by leaving the trail and looking closely at the outcrops and boulders in the river. These are volcanic rocks known as tuff breccia. Breccia is an Italian word for broken stones or rubble. The tuff breccia is composed of pieces of different rock types suspended in a green, finer-grained background (similar to a chocolate chip cookie - the rock fragments represent the chocolate chips and the finer-grained background material is the cookie dough). If these textures in the rock are not easy to see, try wetting the rock using handfuls of water from the river. A close inspection of the rock reveals that the rock is made up of fragments of other rocks ranging from the pea-size to football-sized pieces. See Figure 11b for an excellent example of a tuff breccia with a similar texture.

These rocks may have been formed from lahars (volcanic mudflows) that rapidly traveled down the steep slopes of a nearby volcano soon after an eruption. The tuff breccia at this location is similar to the tuff breccia exposed at the Few's Ford area and is interpreted to have formed in the same way.

If the water is low enough, see if you can find the holes drilled into the rock outcrop closer to the center of the river. The former dam location for Cabe Mill is located further upstream from these rocks. The holes drilled into the rocks may have been used to anchor some type of structure into the bedrock outcrop.

Stop 3: Headrace of former Cabe Mill

The ***headrace*** to former Cabe Mill was dug into the soft sediment of the alluvium and is visible a short distance to the south from Stop 2. To see remnants of the headrace (Stop 3), walk toward the south from Stop 2, cross the trail and enter the forested area. The headrace looks like a long ditch with small trees growing in it. Water from the mill pond traveled in the headrace to the mill house (fig. 45) and was used to turn the grinding wheel in the mill.

History of Cabe Mill

Information on the history of Cabe Mill was acquired from The Historic Mills of Eno River State Park pamphlet and the Eno River Association Calendar for 1978. Cabe Mill was in operation from approximately 1799 to the 1880s. John Cabe founded and operated the mill until 1818. John Cabe was an important local figure; as a member of the North Carolina General Assembly, he helped pass the N.C. Bill of Rights. At his death in 1818, the mill, considered to be very productive, was valued at $9,000. The mill was left to three of his nine daughters. In the 1830s the mill was put back into operation by William T. Shields, the husband of John Cabe's youngest daughter, Jane Cabe. The Shield's family operated the mill until the 1880s when the mill was destroyed by a fire.

Stop 4: Island in Eno River immediately downstream of former Cabe Mill dam location

The small wooded island located immediately upstream of Stop 2, and downstream of the former Cabe Mill dam, is composed of boulder- to clay-sized sediment. The island's origins are a result of the construction of Cabe Mill dam. After Cabe Mill dam was constructed, water from the Eno was impounded against the dam, the velocity of the water slowed, allowing the river's sediment load to settle out and be deposited upstream of the mill dam beneath the quiet mill pond. After many years, the sediment would have become relatively thick and the mill operator would have to wash out the mill pond periodically or it would fill with sediment. As part of normal mill maintenance, the dam gates would be opened, allowing the sediments to be flushed out. The lighter sediment (clay and silt) would have been transported far downstream while the heaver sediment (sand and cobbles) would travel only a short distance downstream. Over the life of the mill, enough sediment piled up downstream of the dam to form a small island.

Reworking of the sediments on the island and the addition of sediment to the island has also occurred over the years. Cabe Mill was in operation until the 1880s. After the 1880s the dam likely fell into disrepair but was probably still impounding water and sediment. Because of decay, the dam likely failed during a flood event, causing the impounded sediment to "let loose" and be transported downstream, likely adding additional sediment to the island. The shape of the island on the topographic map (fig. 44) hints that the island itself may be migrating downstream. The island is skinny on the upstream side and wider on the downstream end. This shape suggests that sediment from the upstream side is being transported downstream and being deposited on the downstream end of the island. Some day the island may be many hundreds of feet downstream of the former mill dam site.

Continue the tour by following the trail toward the west. As you approach the location where the trail takes an abrupt turn to the south and climbs out of the floodplain, see if you can spot the entrance to the headrace south of the trail. Take a moment to look at your maps.

Be careful to take the trail to the south; if you mistakenly continue toward the west (straight), the trail quickly becomes inaccessible. As you continue on the trail to the south, you will be climbing out of the floodplain and be walking on rock debris of the volcanic tuffs. Once you reach the top of the slope, look for the trailhead to the Eno Quarry.

Eno Quarry Trail

Stops 5-8: Former Eno Quarry

Part of the Eno Quarry trail traverses over white-colored soil formed from the breakdown of granodiorite rock beneath your feet. Closer to the quarry, the trail traverses over volcanic rocks. The Eno Quarry trail crosses the former Fish Dam Road in two places (fig. 44). Fish Dam road was originally a Native American trail that ran from the Neuse River to the Native American village of Occoneechee Town, on the Eno River, in the present day town of Hillsborough. The road is evident by a linear excavated area with trees growing in the middle. Settlers modified the road for use by horse-and-wagon traffic in the 1700s. In the 1920s, parts of the road were paved and became city streets, while other segments were abandoned and are now overgrown with trees.

In 1960, the Eno Quarry began operations to supply crushed stone for the construction of Interstate 85. The quarry was opened by Coleman Contracting Company after leasing the land from the Coile family. In 1961, Superior Stone Company bought the lease and moved its crushing facilities to the site. The company produced crushed aggregate until 1964 when the lease was relinquished to the Coile family. The quarry, now full of water, is reported to be 60 to 80 feet (18 to 25 meters) deep, making the bottom of the quarry lower than the river bottom. The eastern edge of the quarry is about 20 feet (6 meters) higher than the river and is so close to the river that if one stands on the eastern berm one can see both the quarry and the river (especially in the winter with no leaves). Water in the quarry comes mostly from groundwater; little of the water in the quarry is from runoff. During operation, the groundwater entering the quarry would have been pumped out. After termination of quarry activities in 1964, the pumps were turned off and the quarry filled with water over several years. In 1968, the water level had filled the quarry with 15 to 20 feet (3 to 4 meters) of water. The former Eno Quarry became part of Eno River State Park in 2002. (Information from Allen and Wilson, 1968 and News from the *Eno River Association* newsletter, Spring 2003.)

The rocks exposed in and around the quarry are composed of volcanic rocks called tuff. Tuff is a rock name for hardened volcanic ash. The ash was erupted out of area volcanoes about 630 million years ago. The quarry contains tuffs of three different color varieties: green, white and gray. Each variety of tuff tells a slightly different geologic story.

Note: *Although the Eno Quarry has a long tradition of being used as a swimming hole,* ***swimming is not recommended****. The water in the quarry is deep and the quarry walls are steep, making egress from the water difficult. Low bank is very limited, and a gently sloping bottom exists in only one area. One drowning occurred in 1993.*

Stop 5: Outcrop area of green-colored tuff

The Eno Quarry trail crosses Rhodes Creek and climbs a berm onto the edge of the water-filled quarry. While standing on the edge of the quarry, carefully look over the edge and notice the green-colored rock. This rock is a tuff formed from hardened volcanic ash. Around the quarry, there are also many cobbles and boulders of the green-colored tuff lying on the ground. The green-colored tuff varies from a rock that is fine-grained with no visible minerals or rock fragments (fig. 46) to rock with abundant rock fragments, similar to the tuff breccia at stop 2.

Figure 46 - *Example of green fine-grained tuff from the former Eno Quarry.*

Figure 47 - *Example of light gray to white, hydrothermally altered tuff from the former Eno Quarry.*

Stop 6: Outcrop area and boulders of light-gray to white hydrothermally altered tuff

The southeast corner of the quarry has outcroppings and boulders that have a red- to brown-colored weathering rind. If you can locate a fresh surface on the rock, you will see that the rock is light-gray to white in color. These rocks are hydrothermally altered tuffs (fig. 47). Hydrothermal alteration occurs when water, heated by magma, permeates through rocks or deposits and changes their composition by adding, removing or redistributing chemical elements. The rocks have been leached of many elements, leaving behind quartz and changing some minerals into the mineral sericite. Sericite is a fine-grained, white mica mineral. Together the quartz and sericite typically give the hydrothermally altered rock its white color. The mineral pyrite (also known as fool's gold) is sometimes present in the altered tuffs. This rock is probably the altered equivalent of the green tuffs in the quarry. The rock was likely altered from the migration of hot fluids during the intrusion of the magma associated with the nearby granodiorite body (the same granodiorite body under the parking area and under part of the Cabe Lands trail).

Stop 7: Boulder of green tuff with calcite veining on the bank of the Eno River

Caution - this stop is located on an unmaintained section of a footpath down to the Eno River with many rocks. The footpath is steep and may be slippery. This stop is not recommended for small children. In the summer when vegetation is thick, long pants are recommended to avoid contact with poison ivy.

Continue the tour by walking around the eastern end of the former quarry. During quarry activities, numerous large boulders of green colored tuffs were dumped next to the Eno River. When these boulders come into view, look for a small footpath down to the river. Stop 7 is accessed by taking this small footpath off the eastern end of the quarry berm down into the floodplain of the Eno. Follow this footpath toward the north until a large green boulder with white streaks blocks the trail (fig. 48). The white-colored streaks are a vein of the mineral calcite (see inset of fig. 48). Calcite is a mineral composed of calcium carbonate with a chemical formula of $CaCO_3$; it has a rhombohedral crystal structure (like a crooked square -▱); and when broken will break into little rhombus shapes. The reddish-brown mineral intergrown with the calcite is likely an iron carbonate mineral (e.g., siderite). **Please remember that collecting rock samples and using hammers is strictly prohibited in the state park.**

Turn back around and begin to retrace your steps. As you walk back toward the quarry berm, examine the large boulders near the top of the boulder pile. In one large boulder, dark-green and light-green alternating layers are visible (fig. 49). The layers represent volcanic ash deposited from different volcanic eruptions 630 million years ago.

Figure 48 - Large boulder with calcite veining at Stop 7. Inset shows close-up of calcite vein with typical rhombohedral cleavage.

Figure 49 - Boulder of green tuff with dark-green and light-green alternating layers. Each layer represents a deposit from a volcanic eruption.

Return to the quarry berm and follow the trail around the north side of the quarry to Stop 8. As you walk around the north side of the quarry, notice the rocks lining the trail and the areas of abundant loose rock. This is “leftover” crushed stone removed from the quarry and is the type that would have been used in the construction of I-85.

Stop 8: Outcrop of crystal tuff

The outcrop of Stop 8 is on the western edge of the quarry and next to the water. The rock is a gray tuff and contains abundant white crystals of the mineral ***plagioclase*** (fig. 10b). The rock is made of hardened volcanic ash, like the green tuff, but is different in that it contains abundant plagioclase crystals. Geologists call tuff with lots of mineral crystals a crystal tuff.

Like the other rocks in the quarry area, these rocks have been slightly metamorphosed. When a rock is metamorphosed, new minerals grow due to heat and pressure. These new minerals often grow in planes and form something called a ***foliation***. A foliation causes the rock to look like it is made up of many hundreds of very thin sheets like the pages of a book (folio = page of a book). Examine the sides of some of the fin-shaped rocks and try to see the foliation. The foliation formed when these rocks were metamorphosed as they were being folded into synclines and anticlines. The folding causes the rock layers to be tilted on end forming the fin-shaped outcrops.

Stop 8 is the final stop in the former Eno Quarry area. Continue the tour by completing the loop around the quarry and retrace your steps along the Eno Quarry trail to the main Cabe Lands trail. Take a moment to refer to your maps.

Stop 9: Altered volcanic rocks - Evidence of contact zone of volcanic rocks with intrusive granodiorite

At the intersection of the Eno Quarry trail and the main Cabe Lands trail, you will turn to the right and follow the trail toward the southeast. Recall that the tuffs near the river and at the quarry are green or gray in color. As you walk toward the parking area, you will walk through a transition zone of hydrothermally altered rock into the granodiorite. The color of the rock found in boulders and cobbles in the trail is white to yellowy-white (similar to fig. 47). These rocks are additional examples of hydrothermally altered rocks and were originally similar to the green rocks exposed along the river and the quarry, but have been altered by the hot magma of the granodiorite.

Stop 10: Boulders and cobbles of granodiorite and quartz

As you continue walking back toward the parking area you will descend down and up two small drainages. The first drainage marks the approximate contact (place where the rock types changes) between the hydrothermally altered volcanic rock and the granodiorite. After crossing the first drainage, start looking carefully at the rocks on the side of the trail. These rocks are boulders of the granodiorite and white opaque quartz (fig. 50). The quartz is likely related to the precipitation of silica in the form of quartz from hydrothermal fluids.

This is the last location of geologic interest on the trail. Refer to your maps to return to the parking area.

Figure 50 - *Boulders and cobbles of granodiorte (G) and quartz (Q) at Stop 10.*

West Point on the Eno - City of Durham Park

Distance and difficulty of hike: Approximately 1.5 miles of relatively easy to moderate hiking.

What you will see:

- Outcrop of tuff at "Turtle Rock"
- Rounded cobbles and gravel located high above the present day Eno River floodplain
- Outcrops of granodiorite
- Alluvium deposits from the Eno River and tributaries
- Granodiorite porphyry of Sennett Hole
- Diabase

Introduction

The geologic trail guide of West Point on the Eno Park begins at the West Point Mill. A topographic map with approximate stop locations is provided as Figure 51. It is recommended that you acquire a park map indicating the locations and names of the trails before starting your trip. To avoid becoming lost or disoriented it is recommended that the companion map (fig. 51) and the park map be referenced frequently during the tour.

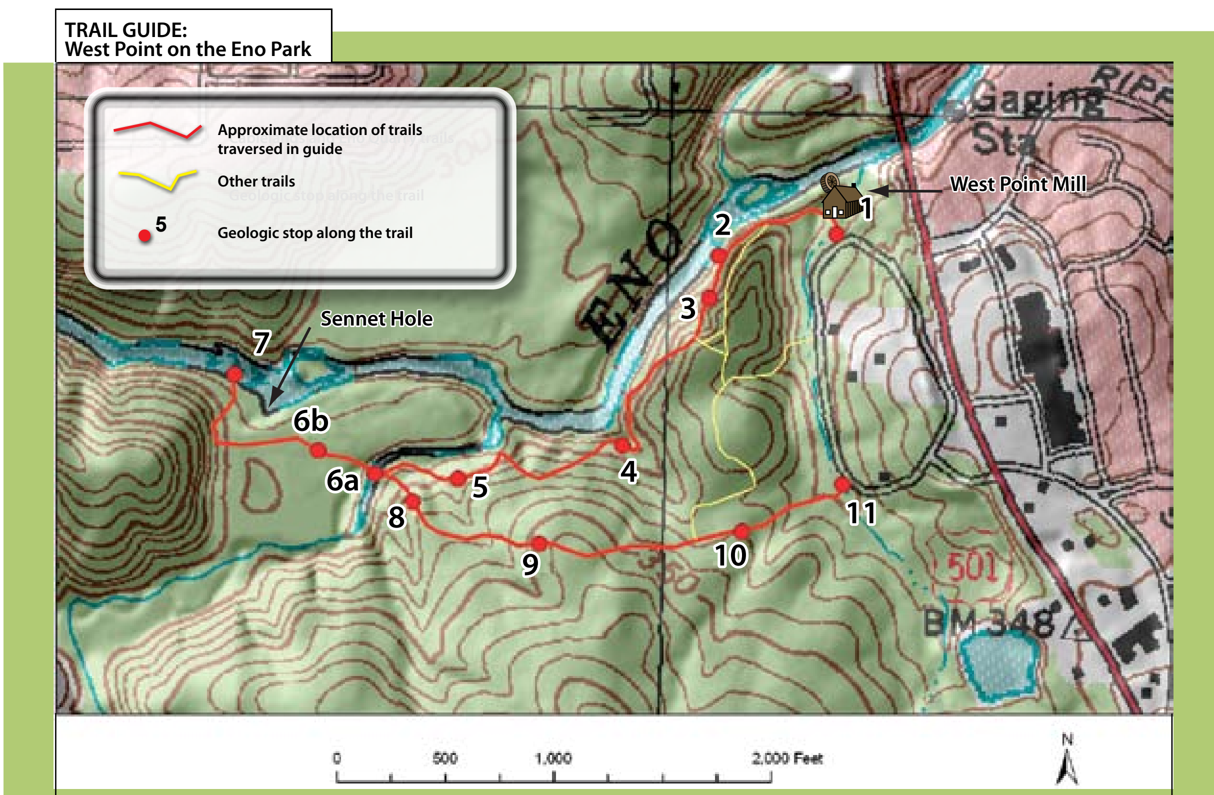


Figure 51 - *Map of geologic stops along the West Point on the Eno Park trails.*

Trail Guide and Points of Interest

Stop 1: Boulder of Triassic sandstone located near West Point Mill house

While standing in the mill yard of the West Point Mill house, look around and notice the boulders of rock and millstones. The largest boulder in the mill yard (Stop 1) is composed of reddish-brown Triassic age sandstone (fig. 52). The boulder has a bowl-shaped indention that was probably carved into the rock. This block of sandstone was likely transported to the park for use in mill operations. Touch the surface of the boulder and feel the rough sandpaper-like texture. What you are feeling are the small sand grains in the rock.

Figure 52 - *Yard area of West Point Mill with large boulder of Triassic age sandstone of Stop 1.*

This boulder does not represent the rock type beneath the park, but is still a good example of some of the Triassic age sedimentary rocks present in the Durham Triassic basin. The closest naturally-occurring outcrops of Triassic age sandstone occur to the north and south of the park (Plate 1). Triassic sandstones and siltstones underlie large portions of the Durham area further to the east.

To continue the tour, cross the bridge over Meadow Branch Creek. This bridge crosses the mill dam. The mill pond with its impounded water is located on the upstream side of the dam. The mill wheel and water pouring over the mill dam can be seen on the downstream side of the dam. After crossing over the bridge, walk toward the trailhead for the South River trail. The relatively flat area you are walking on is part of the floodplain of the Eno River. You will walk over another small bridge that crosses the larger dam in the Eno River that diverts water into the headrace for the mill. Follow the path up the stairs toward Stop 2. When the trail splits; take the trail to the right. You will know you are going in the correct direction when you see a trail marker with "#14" (These numbered markers are part of the park interpretive trail system.). After a short distance you will encounter a short spur trail at park trail marker "#13". This short spur trail leads to Turtle Rock (Stop 2).

Stop 2: Outcrop of felsic tuff located at Turtle Rock

Stop 2 is a rock outcrop located on a perch high above the Eno River known as Turtle Rock (fig. 53a). Turtle Rock receives its name because it is a good spot to view turtles in the river. Turtle Rock is composed of rock called tuff. Tuff is the rock formed from consolidated volcanic ash (fig. 53b). The ash that composes the tuff erupted from nearby volcanoes 630 million years ago. The ash was deposited in layers and later buried by subsequent eruptions. Millions of years later (ca. 600 million years ago) the layers of tuff were folded into ***synclines*** and ***anticlines*** causing the layers to be turned on end (fig. 21). Since entering the trail, hidden below the soil under your feet, you have been walking over numerous (possibly hundreds) of different layers of tuff that record just as many volcanic eruptions over many hundreds to thousands of years.

Figure 53 - *Turtle Rock.*
A. View looking northwest at outcrop located at Turtle Rock. The Eno River is located just past the trees.
B. Close-up of fresh surface of tuff (rock composed of consolidated volcanic ash) of Turtle Rock.

From Turtle Rock, look toward the river and notice that the river is 20 to 30 feet (6 to 9 meters) below where you are standing. This relatively steep elevation difference is a good example of how the Eno has incised (cut down) into its river valley. Usually, over time, rivers like to meander across the land, forming wide floodplains.
As the Piedmont land began to slowly uplift during the Cenozoic era, the erosive power of the Eno kept pace with the rising land. Instead of forming great meanders in the Piedmont upland portion, the Eno was restricted to its narrow valley and cut down into the land forming the steep-sided valley we see today.

Continuing along the South River trail, the next area of interest starts soon after leaving Turtle Rock.

Stop 3: Area of rounded cobbles and gravel – Possible older elevated floodplain of the Eno River or remnants of Triassic sediments

As you continue along the South River trail, pay attention to the color and composition of the soil and the presence/absence of outcrop in or near the trail. You should notice a relatively sudden change from a trail with small low outcrops and angular rock fragments to a portion of the trail with no outcrop, sandier soil and a few rock fragments with rounded edges (Stop 3). A rock fragment that shows rounded edges usually indicates that the rock has been worn by water – so how did a rock apparently rounded (smoothed) by water get up here?

As with many things in geology, the origin of these rounded rock fragments high above the river could be interpreted in two ways:

1) The fragments could represent sediment from an ancient (1-5 million years ago) floodplain of the Eno River. Before the Eno was so incised in its valley, it deposited sediment as alluvium in its floodplain. Later the river may have cut down through its floodplain and incised itself deep in the Eno River valley, leaving some of its floodplain deposits behind at higher elevations. Geologists call these deposits ***terrace deposits***.

2) Another possible explanation of the origin of rounded rock fragments high above the river is that this area could represent a deflation surface. A deflation surface is a residual deposit of sediment produced by the continual removal of the finer-grain portions of soil leaving a surface covered with cobbles and gravel. As the finer-grained portions of the deposit are washed away, the land surface is deflated (like deflating a tire), leaving only the heavy portions of the deposit behind. Rounded rock fragments similar to those on the trail are found in the coarser-grained layers of the Triassic sediments – yet there are no known exposures of Triassic sediments nearby. It is speculated that the rock fragments with rounding may be the remnants of Triassic sediments long eroded away. Triassic sediments were likely present on top of the tuffs now exposed along the trail (see fig. 56).

Stop 4: Cobbles and boulders of quartz and granodiorite

Continuing along the South River trail (yellow blaze marker), the trail traverses an area where larger boulders and outcrops of rock are once again visible. The first rocks encountered are white- and red-colored cobbles of quartz along the trail. The quartz is interpreted to be associated with the contact zone (zone where the rock type changes from tuff to granodiorite) of a nearby granodiorite (a granite-like rock) body. After passing the quartz cobbles you will encounter white-colored soils, a few boulders and outcrop of granodiorite (Stop 4). The granodiorite body formed when hot molten magma intruded the tuffs, cooled and solidified. When the granodiorite intruded the tuffs, it heated local groundwater that, in turn, dissolved large amounts of silica (SiO_2). The dissolved silica latter precipitated along the outer edges of the granodiorite body forming the quartz.

The trail continues for several hundred feet to the west over the white-colored soils and outcrop of rock associated with the granodiorite body. The trail then traverses an area of tuffs (similar to stop 2) that have been slightly "cooked" by the intruding granodiorite magma and show signs of ***hydrothermal alteration***.

As you continue to walk along the trail, see if you can spot the dark-brown rounded boulders that cross the trail and extend into the woods on either side of the trail. The line of boulders is relatively thin, only a few feet wide, so you will have to pay close attention. This line of boulders is Stop 5.

Stop 5: Boulders of a diabase dike

The boulders are a type of rock called diabase. Diabase typically occurs as rounded boulders with a dark-brown rust-colored weathering surface. Diabase is a mafic igneous rock that is composed of abundant iron and magnesium minerals. The rust-colored surface of the diabase is from the oxidation (rusting) of the abundant iron-containing minerals. Diabase intruded the rocks of the Eno River area during the Jurassic period (approximately 200 million years ago) after the supercontinent Pangea began to split apart. The Earth's crust became so thin in places that magma was able to intrude towards the surface. Diabase occurs as ***dikes*** and ***sills*** throughout the Durham area. In the Triassic basin, diabase is more resistant than the surrounding sandstones and siltstones it intrudes and often forms resistant ridges in the Durham area. Penny's Bend on the Eno River is underlain by a diabase sill. Soil derived from diabase is rich in iron and magnesium and is a basic soil (soil with a pH above 7) compared to the more acidic soils more commonly found in the Triassic basin. The basic soils of the diabase sometime host unique plant communities like those present at Penny's Bend.

Leaving the diabase boulders, the South River trail descends into the floodplain of Warren Creek, a tributary of the Eno. The South River trail intersects the Buffalo trail. Follow the Buffalo trail to the west to Warren Creek. Refer to the park map for extra assistance.

Stop 6a and 6b: Floodplain deposits

Notice that Warren Creek has a few large boulders and cobbles in its middle and is flanked by soft sand and silt (fig. 54a) on the banks of the creek (Stop 6a). This is called alluvium by geologists and is loose material deposited in a floodplain.

Figure 54 - *Floodplain deposits (Alluvium).*
A. Example of sand sized floodplain deposits present along Warren Creek,
B. Photograph of trail approaching Sennett Hole. Notice flat topography of floodplain,
C. Example of cobble and boulder sized floodplain deposits near Sennett Hole.

To reach stops 6b and 7, cross Warren Creek and pick up the Sennett Hole trail. The trail to Sennett Hole is poorly marked. Look for a worn footpath through the woods and refer to your Park map for assistance. The trail continues to Sennett Hole and traverses into the floodplain of the Eno River (Stop 6b). This portion of the floodplain is characterized by an area of flat topography with no rock outcrops (fig. 54b). During major flood events, this portion of the trail is likely under water. Sediment ranging from clay to boulder size clasts are mobilized and deposited within the floodplain of the Eno River during major flood events (fig. 54c).

Stop 7: Sennett Hole area

The trail to Sennett Hole remains within the flat floodplain for about 600 feet. Pay attention, the trail will leave the floodplain for a short distance. The trail will continue uphill toward the west then abruptly turn to the north (right) back into the floodplain of the Eno River and lead to the rocky portion (Stop 7) of Sennett Hole (see maps).

Sennett Hole was the location of a mill in the mid-1700s. Explore the rock outcrops on the banks and in the river. See if you can find several drilled holes in the rock. These holes were likely anchor points for wooden posts used for construction of the old mill. The main rock type exposed at Sennott Hole is called granodiorite ***porphyry*** (fig. 55a). A porphyry is an igneous rock that has conspicuous crystals (known as ***phenocrysts***) suspended in a fine-grained background or ***groundmass*** (fig. 55b). To better see the texture of the rock, wet the rock face with handfuls of water from the river. Phenocrysts and the enclosing background minerals are similar to a chocolate chip cookie, with the phenocrysts representing the chocolate chips and the finer-grained background material representing the cookie dough.

The granodiorite porphyry is very similar to, and is probably related to, the granodiorite body traversed on the South River trail. Like all granodiorites, the rock was formed when molten granodiorite magma cooled and solidified. Another rock type present in the Sennett Hole area (you will have to look around closely) is a green, fine-grained rock known as a mafic dike. The mafic dike does not have any phenocrysts and is more uniform in appearance. The mafic dike intrudes (cuts) the granodiorite porphyry (fig. 55c). Geologists can

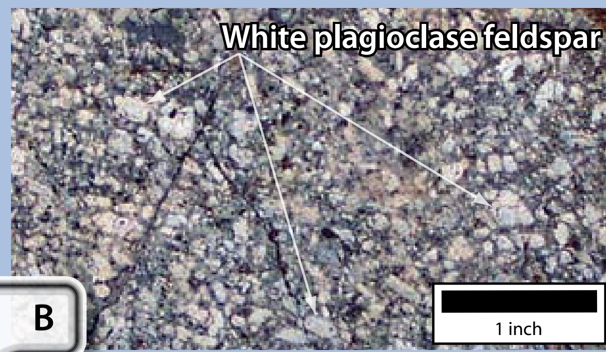


Figure 55 - *Sennett Hole Area*
A. Photograph of outcrop surface of granodiorite porphyry exposed at Sennett Hole area.
B. Close-up of outcrop of granodiorite porphyry. Phototgraph shows plagioclase feldspars suspended in a fine-grained matrix.
C. Photograph of fine-grain mafic dike intruding granodiorite porphyry.

determine the relative age of rocks based on cross-cutting relationships (which rock cuts the other rock). If you examine the mafic dike, you will notice that it cuts the granodiorite porphyry, therefore, we know that the granodiorite porphyry is older than the mafic dike (the granodiorite was there first and was intruded by the mafic dike, therefore, the granodiorite is older than the mafic dike). The granodiorite porphyry at Sennett hole is approximately 630 million years old.

Another easily seen geologic feature associated with the outcrops at Sennett Hole are joints. Joints are naturally occurring planar fractures present in outcrops. The jointing at Sennett Hole give the rock a blocky appearance in places.

Sennett Hole is reportedly very deep and was likely formed when fast moving water eroded away part of the river bed and bank. A close look at the geologic map of the vicinity of Sennett Hole indicates that Triassic sediments are present a short distance to the north and south from the Eno River (fig. 56). Triassic sediments were likely present at this location along the Eno River, but have long since been eroded away. It can never be known for certain, but it is hypothesized that Sennett Hole may have been the location of a grand waterfall where water cascaded off of the hard crystalline rocks of the Piedmont upland into

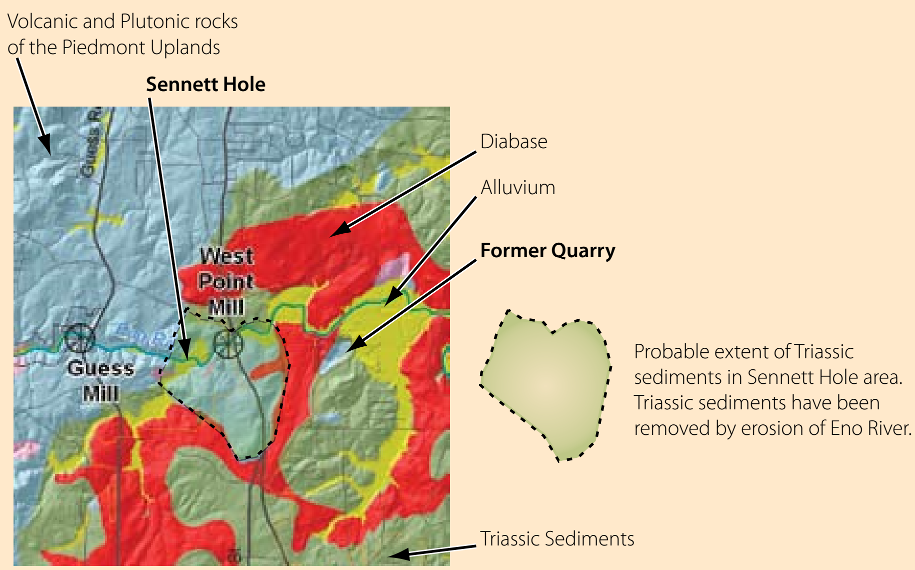


Figure 56 - *Generalized geologic map of West Point on the Eno area.*
Green transparent area indicates probable extent of Triassic sediments that the Eno River eroded away.

the softer Triassic sedimentary rocks. This hypothetical waterfall may have scoured through the Triassic sediments and into the crystalline rocks below forming a deep pool. Later, this pool may have filled with alluvium sediment. This alluvium may have later eroded out forming the Sennett Hole of today.

Retrace your steps along the Sennett Hole trail and cross back over Warren Creek. Follow the Buffalo trail to the East. As you start climbing out of the floodplain, look at the rock exposed in the trail.

Stop 8: Contact zone of granodiorite and tuffs

This segment of the Buffalo trail traverses over a different portion of the contact zone between the granodiorite body and the volcanic tuffs previously crossed after Stop 4. The contact coincides with the trail leaving the floodplain. Several weathered outcrops and many boulders of hydrothermally altered rock are present in this contact area. The presence of the contact between the tuffs and the granodiorite coinciding with the slope break out of the floodplain is probably due to differences in rock hardness. Granodiorite is typically a more resistant rock that weathers slower than some of the surrounding volcanic rocks. The granodiorite, being more resistant, forms the higher-elevation areas of the Buffalo trail.

There are additional boulders of diabase located on the north side of the trail at the top of the slope. These boulders are likely associated with the same diabase dike of Stop 5.

Stop 9: Different textures of the granodiorite body along the Buffalo trail

Continuing east on the Buffalo trail you will start noticing outcrops and boulders of rock (Stop 9). These outcrops are associated with the granodiorite body that intrudes the volcanic tuffs and are part of the same granodiorite body seen on the South River trail. The rocks from Stop 8 to Stop 9 are all part of the same solidified mass of magma, but show different grain-size textures due to different rates of cooling. The outcrops closer to Stop 8 have a fine-grained matrix with visible plagioclase feldspar mineral grains. Geologically, this rock is more appropriately called a dacite and the fine-grained matrix indicates that the magma in this location cooled relatively quickly. The minerals in the matrix of the rock were not able to cool slowly enough so as to organize themselves into larger more visible crystals. As you walk toward Stop 9, the rock takes on a different texture of visible interlocking mineral grains. Visible interlocking mineral grains are typical of intrusive igneous rocks that cooled slowly enough that the minerals had sufficient time to organize themselves into visible grains. The finer-grained margin of the granodiorite body near Stop 8 (the contact with the tuffs) is called a chill margin. The magma chilled relatively quickly, making the mineral grains of the rock matrix small.

As you continue your walk toward the east, the granodiorite body is still present beneath your feet all the way to the intersection of the Buffalo trail and the Buffalo spur.

Stop 10: Boulders of hydrothermal quartz associated with contact zone of the granodiorite body

Immediately east of the Buffalo trail and Buffalo spur intersection (approximately 200 feet to the east) are several boulders of white- and red-colored quartz. You will have to look very closely for the quartz, especially in the fall when leaves may be covering the rocks.

The red coloring is probably from iron impurities within the crystal-lattice of the quartz. Like the quartz observed in the vicinity of Stop 4, this quartz is interpreted to have been from the precipitation of silica from heated groundwater associated with the intrusion of the hot granodiorite body. After passing the quartz boulders, you are walking over volcanic tuffs similar to the rocks of Turtle Rock (Stop 2).

Follow the Buffalo trail to the east and cross the bridge over Meadow Branch Creek.

Stop 11: Large diabase boulders immediately east of the Buffalo trail bridge over Meadow Branch Creek

Immediately after crossing over the wooden bridge leading to the trailhead for the Buffalo trail are several boulders of Jurassic age (approximately 200 million years old) diabase. Identical in origin to the diabase at Stop 5, these boulders have relatively fresh surfaces that are dark in color.

These boulders likely were transported to the park from a nearby quarry. Crushed stone (diabase, volcanic tuff and lava rock) were removed from the now inactive quarry located less than one mile to the east from Roxboro Road. Crushed stone from this quarry was used in the construction of almost every road and building in the Durham area during the operational period of the quarry. The topographic depression of this quarry can be easily seen on Plates 1 and 2 and Figure 56.

This is the end of the geologic trail guide; refer to the park map to return to the mill and your vehicle.

Glossary

The following is a geologic glossary of terms and concepts used in this Information Circular. 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.

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 contains the oldest section of rock.

Aphanitic - An igneous rock texture in which individual mineral grains are too small to be distinguished with the naked eye or under 10x magnification.

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

Basaltic lava - 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.

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.

Clay-size - any particle smaller than 1/256 of a millimeter in diameter

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.

Cycads - Cycads are an ancient group of seed plants with a crown of large compound leaves and a stout trunk. They are a minor component of the flora in tropical and subtropical regions today, but during the Jurassic Period, they were a common sight in many parts of the world. For this reason, the Jurassic is often referred to as the "Age of Cycads." Definition from http://www.ucmp.berkeley.edu/seedplants/cycadophyta/cycads.html Web Site.

Dacitic lava - A fine-grained, extrusive (volcanic) igneous rock with a silica content ranging from 63 to 74%, contains less iron, magnesium and calcium than basalt. Dacitic lava is a common rock type associated with subduction zone volcanism.

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.

Enclave - An enclave is a xenolith of intrusive rock present as an inclusion in an igneous rock (e.g. fine-grained granodiorite inclusions in a medium-grained granodiorite). Sometimes considered synonymous with xenolith.

Epiclastic rocks – Sedimentary rocks formed from the erosion of older rocks. In the Eno River area, epiclastic rocks refer to sedimentary rocks formed from the erosion of older volcanic rocks during or a relatively short time after active volcanism.

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 rocks 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, that are 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.

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.

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

Fumaroles - A volcanic vent that emits hydrogen sulfide or other gases.

Geyser – A spring associated with areas of active volcanism that periodically erupts in a shower of water and steam.

Gradient – The change in elevation of a river per distance traveled by the river. Gradient is usually expressed in feet per mile. (e.g. The river has a gradient of 15 feet per mile. This means that for every mile of river traveled the elevation decreases by 15 feet.)

Groundmass - The groundmass of a rock is the fine-grained mass of material in which larger grains or crystals are embedded.

Head – A term used to describe the hydraulic force developed by water due to impoundment, temporary storage or a difference in elevation. This hydraulic force is what allows the water to travel quickly down the headrace of the mill.

Headrace – A headrace is a waterway that feeds water to a mill, water wheel or turbine.

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.

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

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.

Layering – Layering refers to the layers formed when sedimentary or extrusive volcanic rocks are originally deposited. These deposits form layers often referred to as original sedimentary or volcanic layering.

LiDAR elevation data – LiDAR is an abbreviation for **Li**ght **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.

Lineament - A linear (relatively straight) topographic feature or features such as a fault, line of dense vegetation, or a chain of aligned volcanoes. A lineament can be interpreted to reflect characteristics of the underlying rocks.

Local base level - The level (elevation) at which a stream or river can erode no more. The ultimate base level is sea level.

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.

Meander – A meander is a sinuous curve or loop in the course of a river. If a river meanders, its course is characterized by many smooth loops and curves. Can also be used as a verb to denote a river that flows via meanders.

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).

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.

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

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 200 million years ago to form today's continents.

Phenocryst - A phenocryst is a relatively large and usually conspicuous crystal distinctly larger than the grains of the rock groundmass of a porphyritic igneous rock.

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 muscovite).

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.

Piedmont upland – The portion of the Piedmont that is underlain by igneous and metamorphic rocks. The Piedmont upland is typically higher in elevation than areas of the Piedmont underlain by the sedimentary rocks of the Triassic basins.

Pillow basalts – Basaltic lava that forms spherical structures (like pillows) when suddenly cooled under water. The presence of pillow lavas indicate that the lava was extruded under water.

Plagioclase – Plagioclase is a common rock-forming mineral of the feldspar group. Plagioclase is often white in color.

Primary pryroclastic rocks - Igneous rocks that are produced from the consolidation of fragmented volcanic material ejected during an eruption. Ancient primary pyroclastic rocks display textures of similar to modern day volcanic rocks.

Porphyry - Porphyry is an igneous rock consisting of large-grained crystals, such as feldspar or quartz, dispersed in a fine-grained groundmass. The larger crystals are called phenocrysts.

Pumice – A porous form of solidified magma. Pumice contains abundant air pockets that are called vesicles. The air pockets cause the pumice to be less dense than typical rock. Pumice may float on water if the air pockets are sufficiently abundant. Because of the air pockets pumice can be easily flattened.

Pyrophyllite – Typically a white mineral with a chemical composition of $Al_2Si_4O_{10}(OH)_2$. Pyrophyllite resembles the mineral talc and is used in various industrial applications, mainly in high temperature ceramics.

Rift-valley – A rift-valley is a elongated valley (usually >15 miles / 25 kilometers wide) 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 0.0625 - 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.

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. Sericite may be considered the fine-grained variety of muscovite mica.

Siliceous sinter – Silica rich deposits formed from hot springs. Formed from the precipitation of silica from hot water associated with hot springs.

Sill – An igneous rock mass that intruded between older, parallel rock beds. Sills form horizontal sheet-like or tabular bodies.

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 410 to 440 million years ago.

Subaerial – Pertains to a volcanic environment in which deposition of volcanic deposits occurred on land. Opposite of submarine volcanism.

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

Terrace deposits - Terrace deposits are composed of river deposits such as gravel, sand and silt that are located on a level or near-level area of land, generally above a river and separated from it by a steeper slope. Terrace deposits indicate that at some time in the past the river flowed at a higher level.

Tuff - Volcanic rock made up of rock and mineral fragments in a volcanic ash matrix.

Triassic lowland – The portion of the Piedmont that is underlain by sediments of the Triassic basin. The area is generally lower in elevation than surrounding areas underlain by crystalline rocks.

Vesiculated – In geology, vesiculated pertains to the formation of tiny gas bubbles in magma.

Virgilina deformation – The name given to a geologic event that faulted and folded the rocks of the Eno River area into large scale synclines and anticlines approximately 600 million years ago. First defined in the Virgilina, VA, area by Glover and Sinha (1973).

Viscous – Pertains to a liquid-like lava or magma that has a high resistance to flow. A viscous lava moves slower than a less viscous lava.

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.

Xenolith - Foreign rock; an inclusion of a pre-existing rock into an igneous rock.

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North Carolina Standard Course of Study Correlation

This publication is aligned with the following Competency Goals and Objectives of the NC Standard Course of Study in Science:

This publication contains appropriate subject matter, in regards to the NCSCOS, for middle to high school level education and higher. In addition, this publication (especially in the trail guide sections) would be very useful background information for a 5th grade teacher studying landforms. The information can easily be correlated for use with a 5th grade class on a field trip to Eno River State Park if hiking some of those trails.

Grade 5 Science

Competency Goal 2: The learner will make observations and conduct investigations to build an understanding of landforms.

OBJECTIVES

2.03 Discuss and consider the wearing away and movement of rock and soil in erosion and its importance in forming:

- Valleys.
- Meanders.

2.04 Describe the deposition of eroded material and its importance in establishing landforms including:

- Floodplains.

2.06 Identify and use models, maps, and aerial photographs as ways of representing landforms.

2.07 Discuss and analyze how humans influence erosion and deposition in local communities, including school grounds, as a result of:

- Building dams.

Grade 6 Science

Competency Goal 1: The learner will design and conduct investigations to demonstrate an understanding of scientific inquiry.

OBJECTIVES

1.06 Use mathematics to gather, organize and present quantitative data resulting from scientific investigations:

- Measurement.
- Analysis of data.

Competency Goal 3: The learner will build an understanding of the geological cycles, forces, processes and agents which shape the lithosphere.

OBJECTIVES

3.01 Evaluate the forces that shape the lithosphere including:

- Crustal plate movement.
- Folding and faulting.
- Deposition.
- Volcanic Activity.

3.04 Describe the processes which form and the uses of earth materials.

- Rock cycle.
- Minerals.
- Characteristics of rocks.
- Economic use of rocks and minerals.
- Common gems, minerals, precious metals and rocks found in N.C.

Grade 8 Science

Competency Goal 1: The learner will design and conduct investigations to demonstrate an understanding of scientific inquiry.

OBJECTIVES

1.06 Use mathematics to gather, organize and present quantitative data resulting from scientific investigations:

- Measurement.
- Analysis of data.

Competency Goal 3: The learner will conduct investigations and utilize appropriate technologies and information systems to build an understanding of the hydrosphere.

OBJECTIVES

3.02 Explain the structure of the hydrosphere including:

- Local river basin.
- Local water availability.

Competency Goal 5: The learner will conduct investigations and utilize appropriate technologies and information systems to build an understanding of evidence of evolution in organisms and landforms.

OBJECTIVES

5.01 Interpret ways in which rocks, fossils, and ice cores record Earth's geologic history and the evolution of life including:

- Geologic Time Scale.
- Index Fossils.
- Unconformity.

Earth/Environmental Science

Competency Goal 1: The learner will develop abilities necessary to do and understand scientific inquiry in the earth and environmental sciences.

OBJECTIVES

1.03 Evaluate the uses of satellite images and imaging techniques in the earth and environmental sciences.
1.04 Apply safety procedures in the laboratory and in field studies:

- Recognize and avoid potential hazards.

Competency Goal 2: The learner will build an understanding of lithospheric materials, tectonic processes, and the human and environmental impacts of natural and human-induced changes in the lithosphere.

OBJECTIVES

2.03 Investigate and analyze the processes responsible for the rock cycle:
- Analyze the origin, texture and mineral composition of rocks.
- Trace the path of elements through the rock cycle.
- Relate rock formation to plate tectonics.
- Identify forms of energy that drive the rock cycle.

2.05 Create and interpret topographic, soil and geologic maps using scale and legends.

2.06 Investigate and analyze the importance and impact of the economic development of earth's finite rock, mineral, soil, fossil fuel and other natural resources to society and our daily lives:
- Availability.
- Geographic distribution.

Competency Goal 3: The learner will build an understanding of the origin and evolution of the earth system.

OBJECTIVES

3.01 Assess evidence to interpret the order and impact of events in the geologic past:
- Relative and absolute dating techniques.
- Fossil evidence of past life.
- Divisions of Geologic Time

3.02 Evaluate the geologic history of North Carolina.

Competency Goal 4: The learner will build an understanding of the hydrosphere and its interactions and influences on the lithosphere, the atmosphere and environmental quality.

OBJECTIVES

4.01 Evaluate erosion and depositional processes:
- Formation of stream channels with respect to the work being done by the stream (i.e. down-cutting, lateral erosion, and transportation).
- Nature and characteristics of sediments.
- Effect of human choices on the rate of erosion.

AP Environmental Science

Competency Goal 1: The learner will develop abilities necessary to do and understand scientific inquiry.

OBJECTIVES

1.04 Apply safety procedures in the laboratory and in field studies:
- Recognize and avoid potential hazards.

Competency Goal 2: The learner will build an understanding of the interdependence of Earth's systems.

OBJECTIVES

2.03 Investigate the solid Earth.
- Earth history and the geologic time scale.
- Volcanism.
- The rock cycle.
- Soil formation.

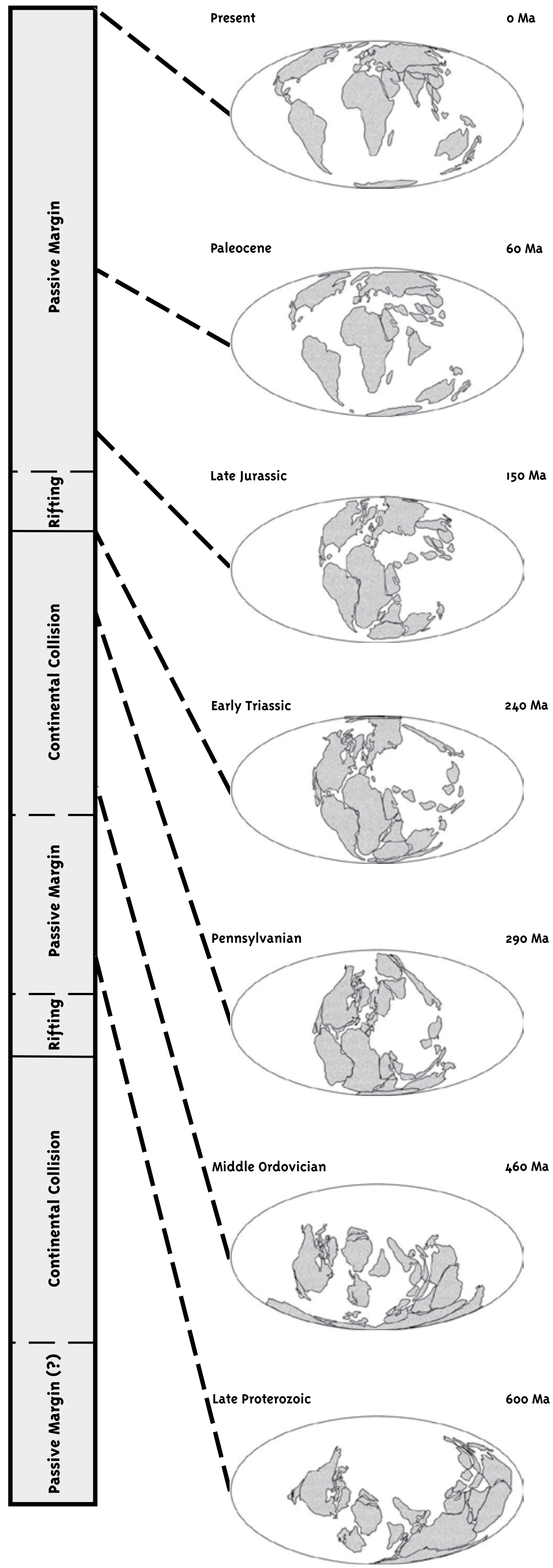
NOTES

EON	ERA	PERIOD	EPOCH	AGE millions of years before present
PHANEROZOIC	Cenozoic	Quaternary	Holocene	0.008
			Pleistocene	1.8
		Tertiary — Neogene	Pliocene	5.3
			Miocene	23.8
		Tertiary — Paleogene	Oligocene	33.7
			Eocene	55.5
			Paleocene	65
	Mesozoic	Cretaceous		145
		Jurassic		213
		Triassic		248
	Paleozoic	Permian		286
		Pennsylvanian		325
		Mississippian		360
		Devonian		410
		Silurian		440
		Ordovician		505
		Cambrian		544
PROTEROZOIC (Precambrian*)	Late Proterozoic			900
	Middle Proterozoic			1600
	Early Proterozioc			

* Rocks older than 544 Ma are also called Precambrian, a time term without specific rank.

WILSON CYCLES

INFERRED LOCATION OF EARTH'S TECTONIC PLATES



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