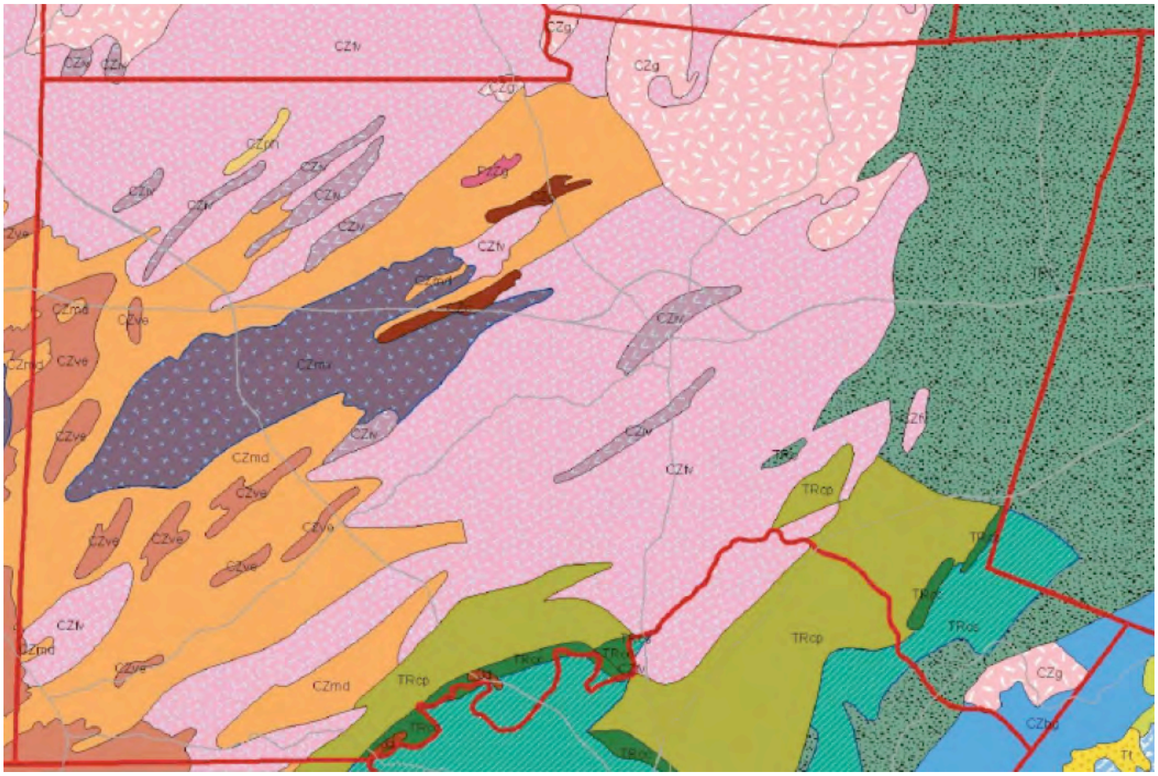
OUTLINE OF CHATHAM COUNTY GEOLOGY



Prepared for

Chatham County Historic Association

Box 93 Pittsboro, North Carolina 27312

https://chathamhistory.org

Prepared by

Christopher M. Palmer

PREFACE

Introduction

The Outline of Chatham County Geology was prepared at the request of the Chatham County Historic Association. The purpose is to introduce basic geology and its influence to County citizens and as a beginning learning aid for students. Geology forms the bedrock, landscape, soils, groundwater and mining and energy resources in the County. The County is located in the Piedmont Province and has a fascinating and complex geologic history of over 630 million years and it formed a portion of the early North American continent. Some geologic principles and processes will be introduced as background to more fully understand Chatham County geologic history.

Acknowledgments

Thanks to Cindy Schmidt at the Chatham County Historic Association who suggested preparing a geologic outline of the County. The author appreciates the opportunity to work with the Historic Association.

Phillip Bradley is the Assistant Section Chief and Senior Piedmont Geologist at the North Carolina Geological Survey (NCGS). Mr. Bradley has conducted much of the geologic study and geologic mapping in Chatham County that is used and cited in this outline. The author greatly values his help explaining field rock relationships and recommending references used in preparing this outline. The NCGS has numerous maps and publications about Chatham County and the State at their website;

https://deq.nc.gov/about/divisions/energy-mineral-land-resources/north-carolina-geological-survey

About the Author

Christopher Palmer is a retired geologist with 40 years of geological practice experience. He graduated from California State University Fresno with Bachelors and Masters degrees in Geology. His project experience includes general geology, engineering geology, and ground water and contaminant hydrogeology studies in the US. He has presented physical geology, contaminant hydrogeology and drilling and subsurface mapping seminars to the US Environmental Protection Agency Region 4, Geological Society of America National Meetings, California State University Hayward and University of California Extension, Santa Cruz. Mr. Palmer is the author of *Principles of Contaminant Hydrogeology.*

Cover: Simplified Geologic Map of Chatham County, NC (source NCGS).

December 2021

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Geologic Background

Geologic History In Chatham County

Rocks underfoot in Chatham County vary from about 630 million years before present (mybp) to present day sediments. The Piedmont Carolina crustal rock blocks emplaced by plate tectonics that formed modern day eastern North America. Geologic time, rocks and tectonics are intimately associated and intertwined to describe the story.

Geologic Time

Geologists use a worldwide standard time scale to relate time, rocks and geologic events between locations on the planet (USGS 2010). The Earth was formed about 4.56 billion years before present (bybp). Earth age is so vast it is sometimes called *"deep time."* The Geologic Time Scale was developed as geologists explored and mapped surface rocks (USGS 2010). Rock types and geographic place names classify segments of time using superposition principles. Time period names guide the reader to the eon, era and period age in years for rocks of interest spanning Earth formation to the present (see Geologic Time figure in the Appendix).

Chatham County geology spans roughly 630 million years before present (mybp). Plate tectonics moved the rocks and ancient proto-continents that were later joined into a supercontinent that included North American. This time period starts in the Neoproterozoic and continues into Phanerozoic time; the Paleozoic, Mesozoic and Cenozoic Eras (see Geologic Time Scale in Appendices). A complication in working out time and age is that rocks are eroded away or are not erupted or deposited in a region. Years of field mapping rock and understanding neighboring geology are needed to work out the time and rock gaps. Since direct rock observation is occasionally lacking, events are interpreted that could have happened resulting in what is seen today.

Rocks

The three rock types are igneous, sedimentary and metamorphic. *Igneous rocks* form from molten rock at depth and are either erupted on the surface by volcanoes, or cool at depth (plutons) and later uplifted to the surface. *Sedimentary rocks* form from eroded pre-existing rocks into gravel, sand, silt together with surface weathering that forms clay minerals. Climate and flowing water abrades and decomposes preexisting rock into sediment that is carried to a depositional environment basin. Sediments are then compacted, buried, heated and lithified forming rock. *Metamorphic rock* is formed from any rock buried under varying amounts of heat and pressure. Additional chemical changes may occur as heated water moves around and through rock. At times extreme heat and pressure have metamorphosed rock may completely melt to form new rock magma. Summaries of rock types and processes are presented in the Appendix.

The Principle of Superposition is a basic concept wherein the oldest rocks are overlain by progressively younger rocks. Rocks ages are worked out by 1) relative dating looking at the bottom to top sequence of events that formed the rocks in the field; 2) using fossils contained in rocks understanding the succession/evolution of life through time; and 3) radiometric dating that measures know radioactive elemental decay rates to calculate an "absolute" age in years. This includes age dating the sequence of events through crosscutting relationships where rock deformation and structure by folding and faulting or molten rock is injected into and through other rock.

Common Rock Groups in Chatham County

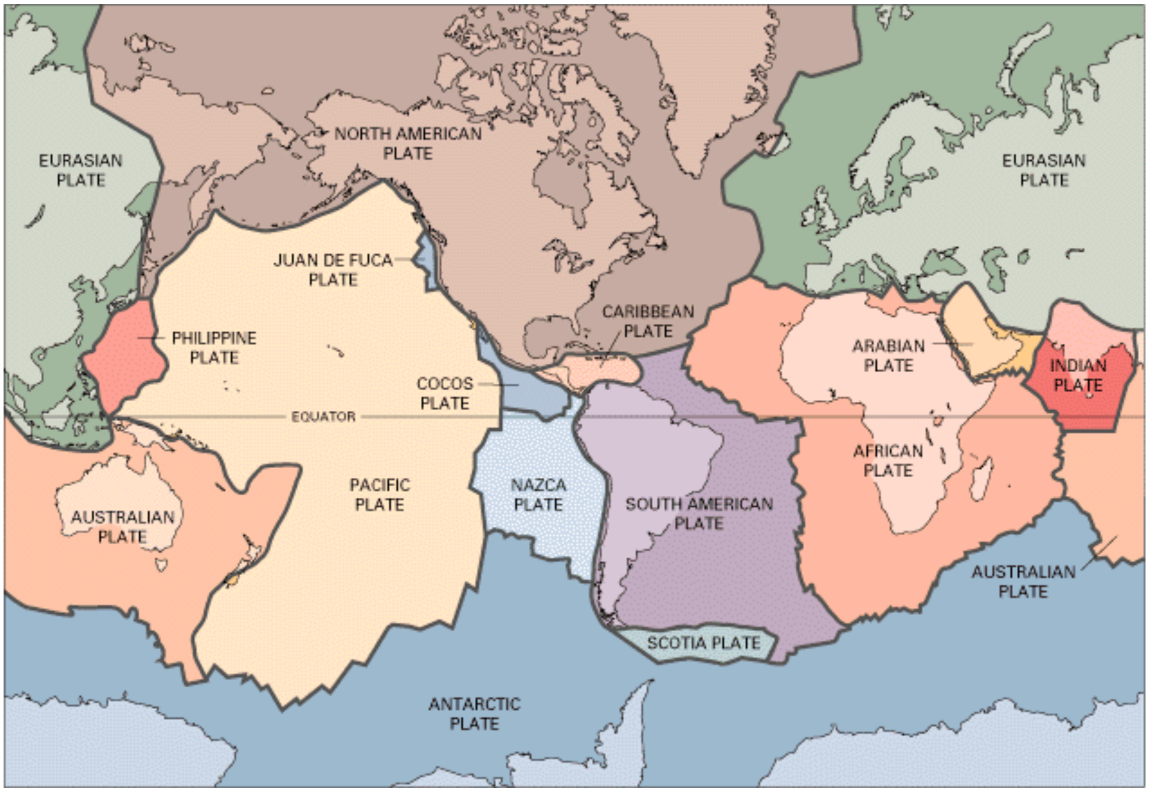
(Modified from Bradley 2021)

Rock Group	Rock Types present	Age
Diabase Dikes	Igneous Diabase-basaltic composition magma.	200 million years old.
Deep River Triassic Basin (Part of the Triassic rift basins)	Sedimentary rocks: Conglomerates, sandstone, siltstone, shale and mudstone.	220 million years old
Carolina Terrane (Part of Carolinia)	Lightly metamorphosed Igneous rocks (basalt, andesite and dacite, tuff (consolidated ash); sedimentary rocks derived from erosion of volcanoes. Also present are metamorphosed granite, granodiorite, diorite and gabbro.	630 to 540 million years old

Geologic processes have operated continuously for billions of years. Hence the tectonic, volcanic, sedimentary processes (erosion, deposition in rivers, lakes and oceans) of the past are similar to conditions observed today. In this way one can reconstruct environments back into time to describe regional geologic events and history.

Plate Tectonic Processes

Earth's surface is composed of lithospheric "plates." These rock plates include the crust and a portion of the upper mantle at depth. Plate thicknesses vary from about 6-10 miles thick in oceanic crust and continental crust may range from about 10 to as much as 30 miles. Plates can include portions of both continents and oceanic floor.

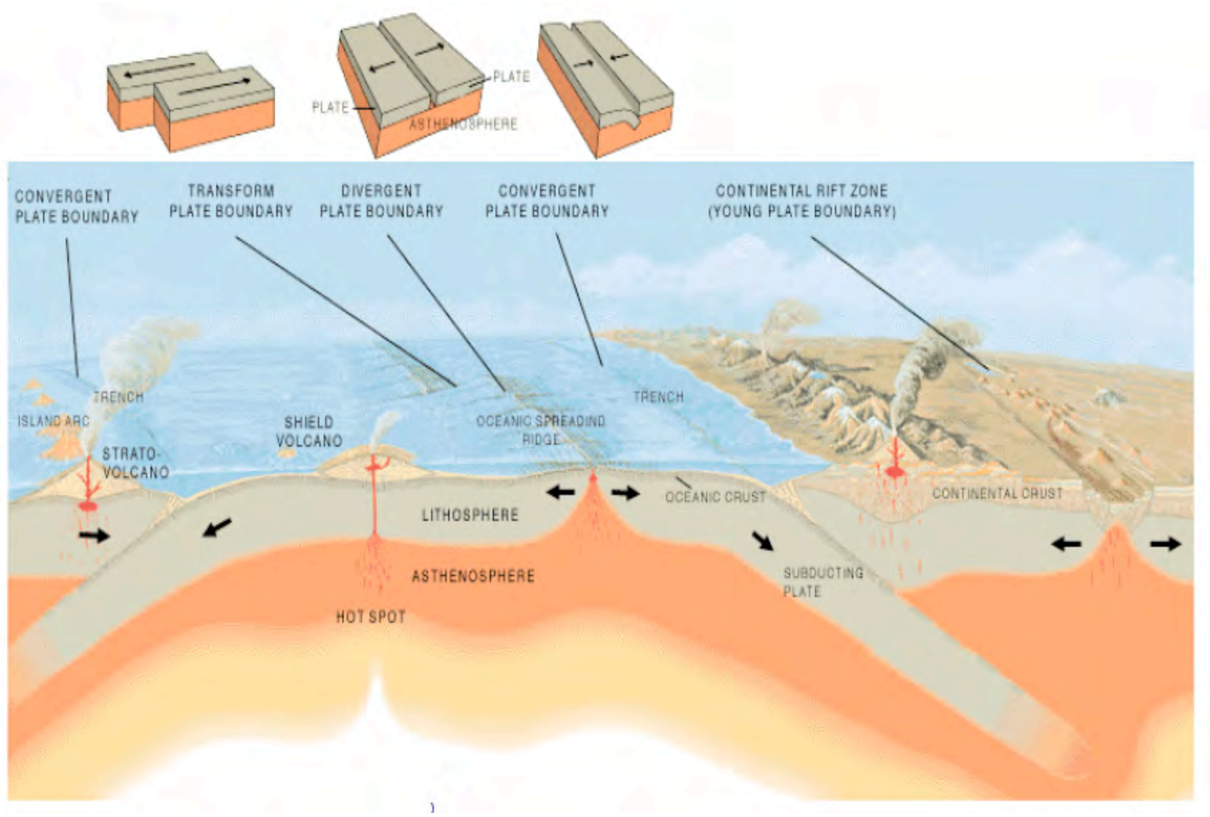


Earth's Tectonic Plates (source USGS).

Plate tectonic concepts have revolutionized geology and are the worldwide unifying geologic principles explaining rock formation, paleogeography, paleoecology, structure, mountain orogeny events and overall Earth history. Tectonic movements have operated for billions of years. Ancient continents have separated and rejoined as "supercontinents" at various times and locations on the planet.

Deep mantle (Asthenosphere) molten rock under high heat and pressure rises into the upper crust where basalt lava is erupted along oceanic ridge volcanoes. The erupted rock forms new sea floor and crust and moves laterally away from the spreading ridge center (see diagram below). These sea floor spreading rifts in ocean basins form the longest mountain range (about 40,000 miles) on Earth. Continental plates also move along the ductile Mantle and at times are rifted apart similar to the sea floor.

Plate boundaries are very seismically active causing thousands of earthquakes per year. Very large earthquakes tend to occur at subduction zones. Movements occur at centimeter per year rates over hundreds of millions of years. Plate tectonics and interactions at plate boundaries operate in four basic ways (Lindeberg, 2002):



Basic Plate Tectonic Motions (Lindeberg USGS, 2002)

Divergent Boundaries where new crust is generated/formed as the plates pull away from each other, for example sea floor spreading ridges. Extension forms basins and volcanic activity erupting basalt rock can form curvilinear mountain ranges on land and in the ocean. Examples are Mid-Atlantic Ridge System, Iceland.

Convergent Boundaries where crust is destroyed as one plate dives under another plate, for example oceanic crust subducted under a continent or other sea floor. Compression deforms, uplifts rocks and can cause large rock masses to move over other rock, and create mountain building events. Examples are the Alps, Himalayas, Aleutian Islands, Andes, and Japanese Islands.

Transform Boundaries where crust is neither formed nor destroyed since plates slide past each other and lateral fault movements predominate. Examples are the ocean rift basin floors and the San Andreas Fault Zone on land.

Plate Boundary Zones where broad belt boundaries are not well defined and the effects of plate interaction are unclear. Examples are in the Indian Ocean and Indonesia.

New magma can rise through the old ocean floor and/or under and into continental crust to form new volcanic island arc chains and emplace plutonic rock. These volcanic arcs may form in ocean basins or on land. Eruptions may also occur as large flood basalts on land such as the Deccan Traps in India, Siberia and northwest U. S. These can deposit huge volcanic rock volumes hundreds to thousands of feet thick over tens to hundreds of thousands of square miles.

“Hotspots” occur where magma rises through sea floor or continental crust at one location. These creating large volcanic complexes that can be tracked over the eruption history; examples are Yellowstone and the Hawaiian Islands.

Sea floor crustal basalts lose heat and buoyancy while moving away from hot erupting ridges toward subduction zones. These zones may occur in sea floors or along continental edges. The oceanic crust cools moving away from the rifts. As these cooler and denser rocks approach the subduction zone they are and are forced downward under the hotter continent or other sea floor rock. Subduction zones are very deep trenches that occur in the “Ring of Fire” around the Pacific Ocean as well as along the west coast of North and South America and other locations.

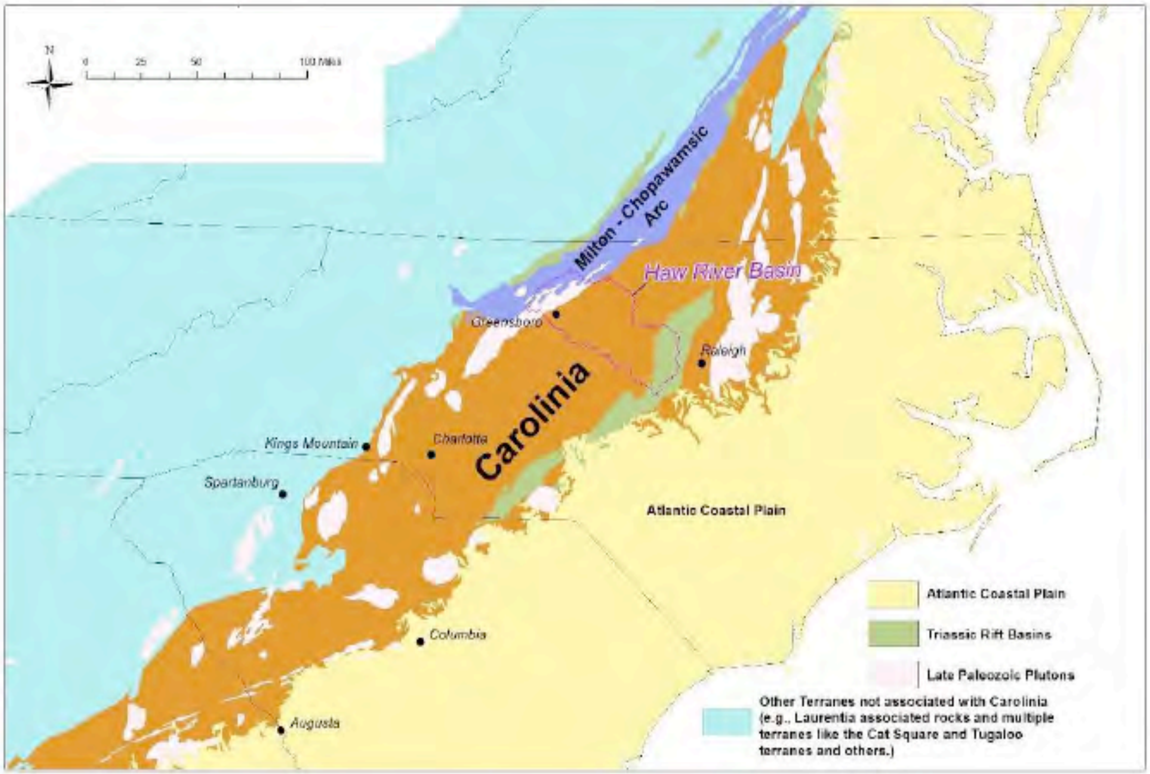
Continents are less dense and more buoyant that ocean crust. At the same time crust is subducted it carries ocean water with it compressing and deforming rock. This can create increase the heat melting rock generating magma for new volcanoes, and compress rock welding it to a continent. In this way continents enlarge by this accretion process.

Geologic mapping and studies over the last 150 years have located and worked out types, ages and sequences of rock formation and emplacement. Remnants of these same processes (rock formation, rifting, faults, folds, etc.) can be observed in ancient rocks. By using aforementioned geologic concepts with field data, geologists can work out the interpretations of the last 630 million years geologic history of Chatham County.

Chatham County Geology Highlights

Plate Tectonics, Proterozoic and Paleozoic Geologic History

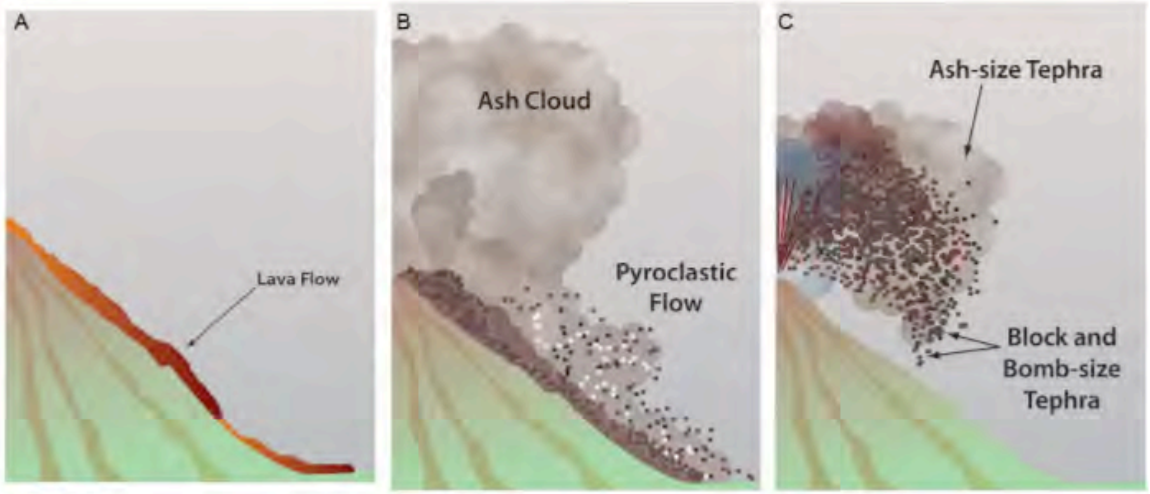
Plate tectonics move island arcs and continents around Earth. These volcanic rocks were magmas erupted to form basalt, dacite, andesite, tuffs and pyroclastic rocks. Violent pyroclastic clouds eruptions of superheated gas and rock fragments incinerate and bury anything in their paths. Eruptions expelled millions of tons of lava, volcanic ash and rock fragments into the atmosphere then dropped to the surface. These volcanic rocks occur over large areas of North Carolina.



Carolinia Crustal Block in the Piedmont
(Source, NCGS)

The Carolinia Crustal block forms a large portion of the Piedmont and Chatham County and the following discussion is summarized from Bradley (2021). The Carolinia crustal block is a remnant of a volcanic island arc. The rocks compose the Neoproterozoic-Cambrian aged Carolina Volcanic Arc Hyco Formation (see Geologic Map in Appendix). Igneous volcanic andesite and dacite rocks are deposited by lava flows, pyroclastic clouds and air fall tephra about 633-612 mybp. The “Carolinia Terrane” was once an island arc near to or a part of ancestral South America and African Gondwana continents.

The Hyco formation includes metamorphosed volcanic basalt, tuffs and dacite, and andesite. Later granite plutons deep below the surface formed the West and East Farrington Plutons about 579 mybp that intruded the Hyco. These plutons are composed of meta-granite and meta-diorite rocks. Both older Hyco volcanic and younger plutonic rocks were later metamorphosed to limited extent together.



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.

Diagram of erupted volcanic rock deposition processes interpreted to have formed the Hyco Formation (source NCGS 2021).

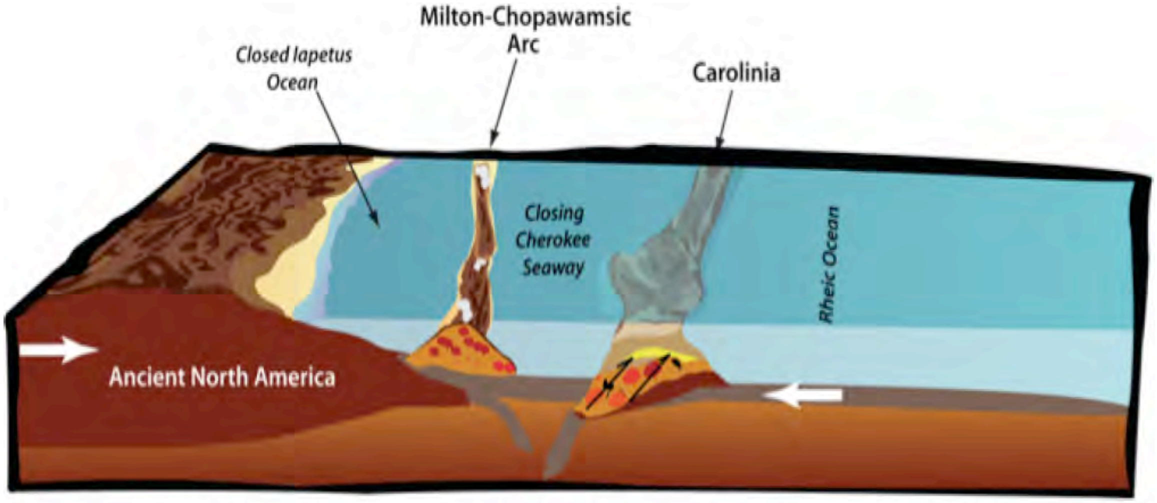
An interesting sidelight is that about 725 to 640 mybp the entire Earth partially or totally froze over due to glaciations. This created "Ice-ball or Slush-ball Earth" formed during the Cryogenic period time (Hoffman 2012; Wikipedia 2017). This might have happened several times prior to and during Carolinia arc igneous rock formation time.

Later planetary warming (primarily attributed to increased volcanic activity) aided in creating a large greenhouse effect ending "ice-ball" episodes. The beginning of the Paleozoic and the Cambrian "explosion of life" about 530 mybp followed the Cryogenic period. Glacial events have occurred repeatedly in Earth geologic history with the most recent glacier retreat about 16-12,000 years ago.

Tectonics of Carolinia and Pangea Continent Formation

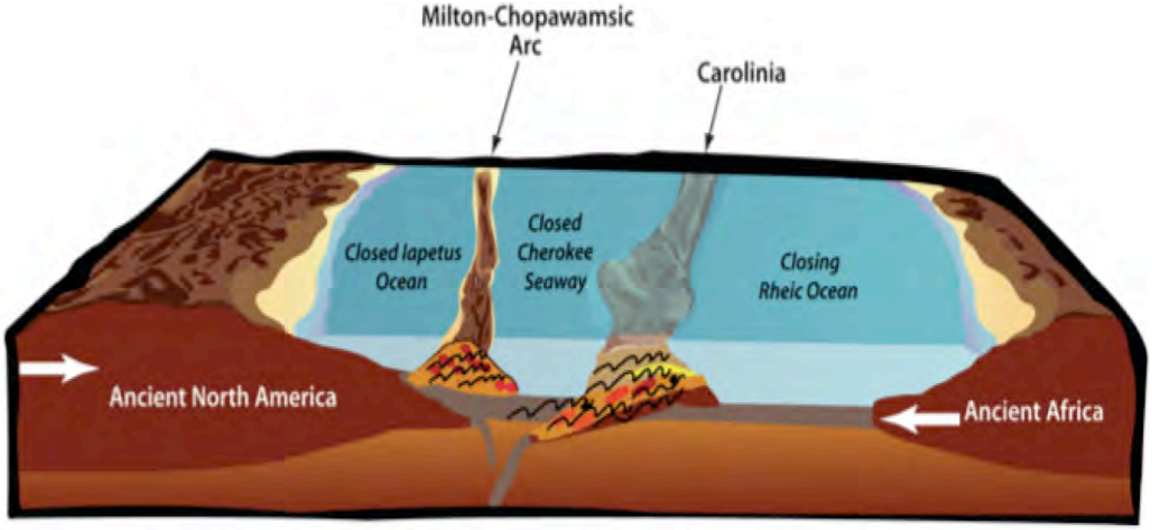
Carolinia rocks were a part of, or near to, the ancient Gondwana continent that contained portions of ancestral Africa and South America continents. About 520 mybp Carolina rifted away from Gondwana with the birth of the Rheic Ocean. Plate tectonics moved, deformed, compressed and metamorphosed the Carolinia rock crustal block that was accreted to the ancestral Laurentia (later to become the North American) continent (Nance and Linnemann 2008). About 300 mybp Gondwana ancestral continents collided forming the Appalachian Mountains as part of the "super continent" Pangaea.

The following block-diagram figures show the interpreted events sequence as the Carolinia island arc terrane moved toward ancestral North America. Tectonic motion moved ancient Africa and South America toward North American closing Rheic Ocean.



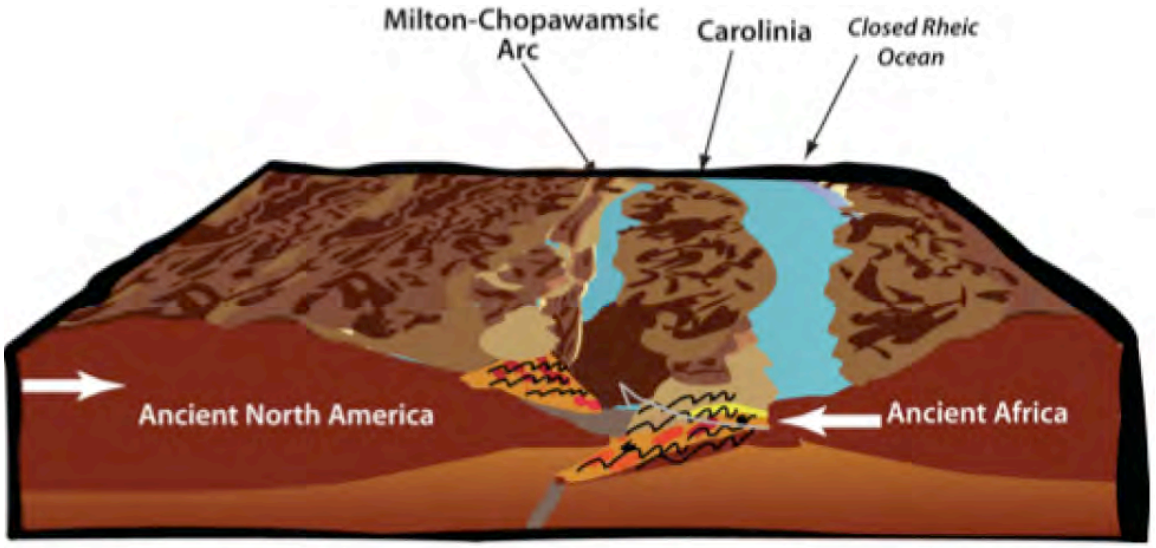
1. Carolinia starts to collide with Laurentia about 450 mybp, source NCGS.

As ancestral Africa approaches Laurentia (ancient North America) the ancient Iapetus and Rheic Oceans close as the island arcs move toward each other. The convergent continents compress at the subduction zone, deforming, folding, faulting and uplifting the rocks. At the same time some rock is metamorphosed due to subduction heat and pressure.



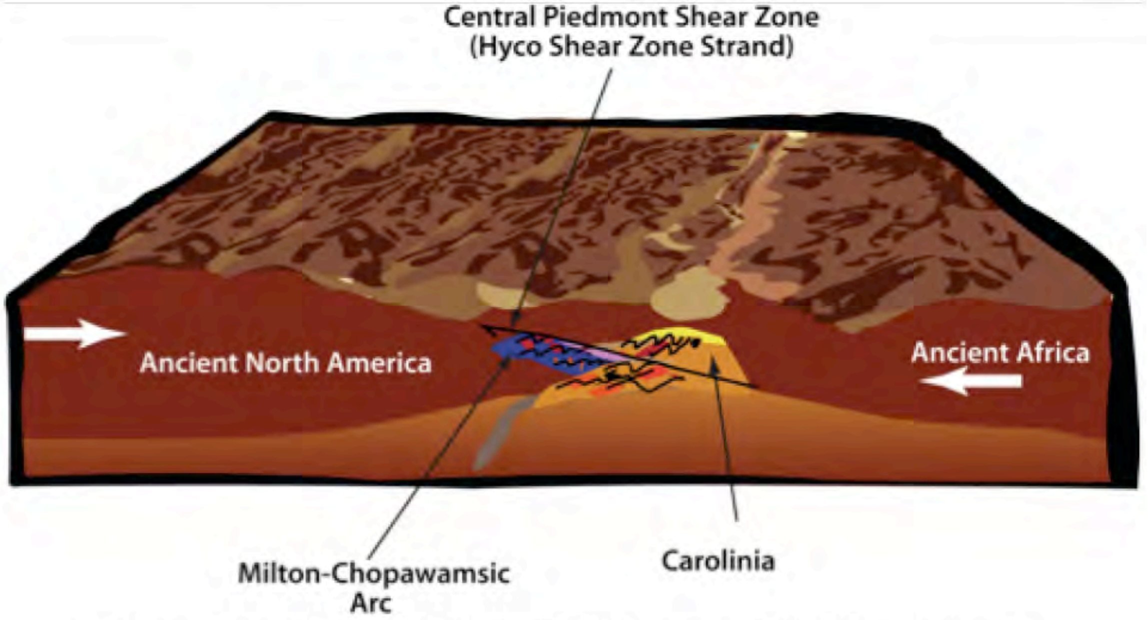
2. Gondwana continent approaching Laurentia about 340 mybp, source NCGS.

Carolinia is deformed as the ancient Rheic Ocean closes. The Milton-Chopawamsic island arc (adjacent to and slightly northeast of Carolina) that formed 475-460 mybp begins to converge with Carolina closing the ancient Iapetus Ocean. Ancient Africa in turn continues to close the Rheic Ocean.

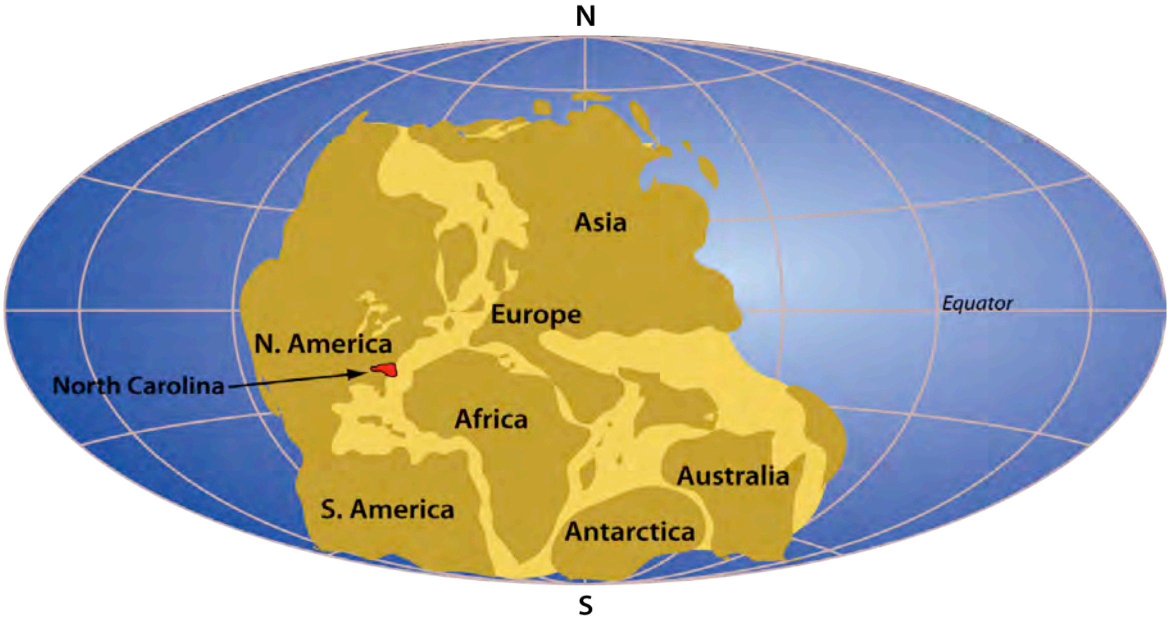


3. Start of Alleghanian deformation and thrust faulting about 330 mybp, source NCGS.

The colliding continents result in the Alleghanian Mountain building episode as a part of the Appalachian Mountains. The Carolina, Hyco Formation and Hyco Shear Zone island arc rocks are folded and emplaced as continental masses converging into the Pangea "supercontinent." Pangea was composed of most of the continental landmasses with the "super ocean" Panthalassa covering the rest of Earth.



4. Culmination of Alleghanian Deformation and Pangea formation about 300 mybp, source NCGS



PANGEA SUPERCONTINENT
Pangea formed about 300 mybp; North Carolina located in red (source NCGS).

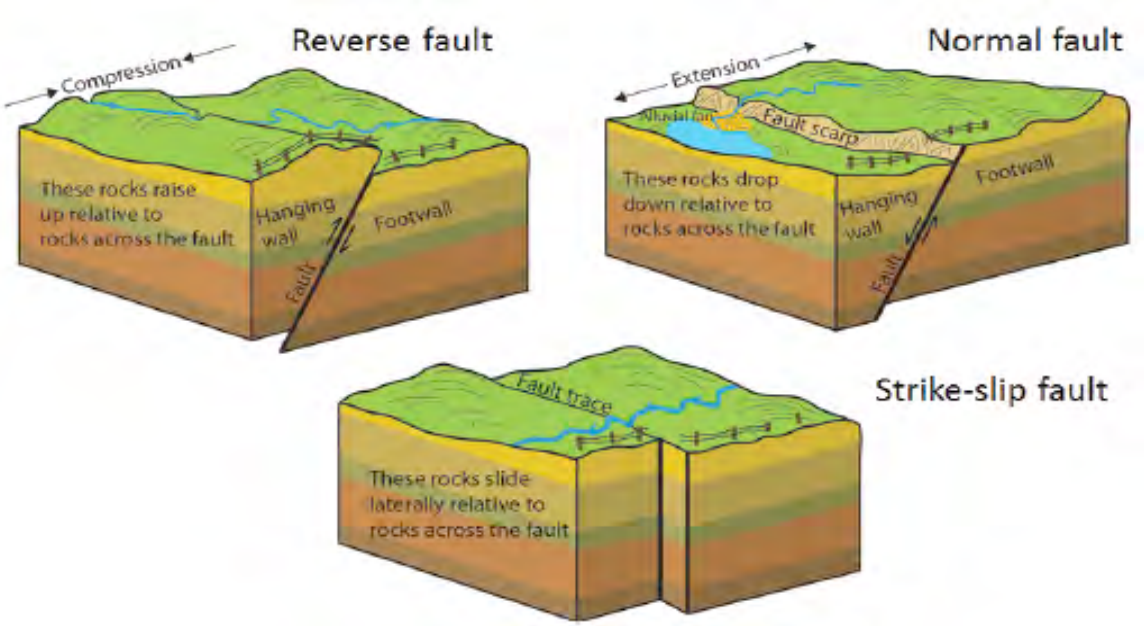
Pangea Breakup, Triassic Basins Formation and Atlantic Ocean Opening

Pangea existed for roughly 90 mybp until renewed continental rifting started a break up. Continental rifting began about 220 mybp (early Mesozoic) Triassic time (Marzoli et al 1999; Marzoli 2011). Continental breakup rifting extension and separation caused normal faulting that created basins. As this continued sediments were deposited into the deepening basins.

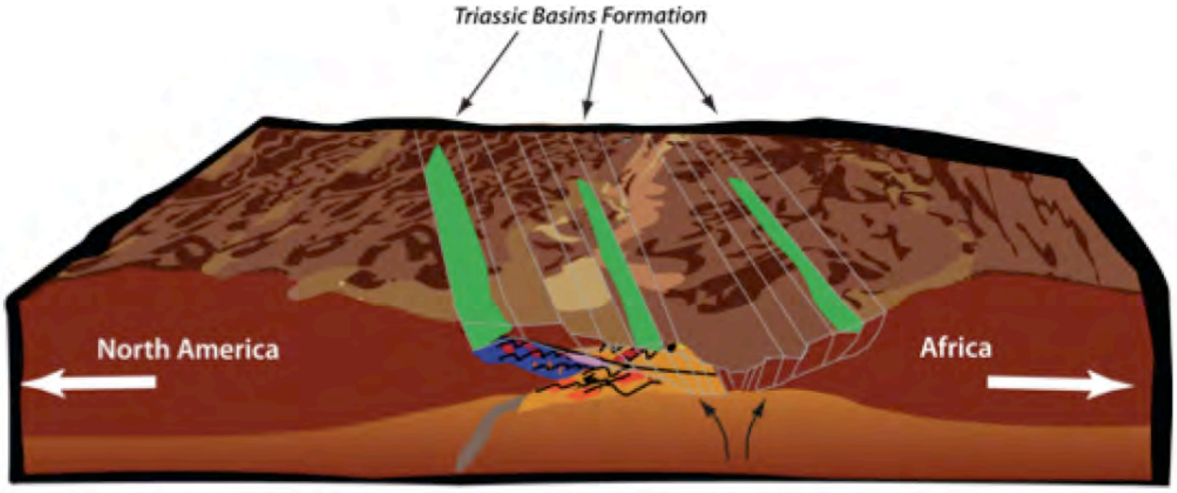
This process continued as the ancestral Atlantic Ocean rifting began to form about 200 mybp. Renewed widespread volcanic activity caused very large eruptions between North America Europe South America and Africa. This included diabase dikes injected into existing rock on a regional scale. North and South America and Africa and Europe have continued to separate away from the Mid Atlantic Ridge to the present.

Faulting and folding deforms rock during continental rifting or collision. Numerous faults occur on sea floors, continental mountain building and along plate boundaries during this process. These earthquake faults basically move in three ways – *Normal, Reverse or Thrust, and Strike Slip*. The three fault movements are shown below where rock blocks may move down, up, or laterally in relation to each other.

The Triassic Deep River Basin in southern Chatham County is a result of extension normal faulting as continents rifted. This extension caused blocks (called “grabens”) to tilt downward forming parallel fault valley basins. These ancient fault remnants can be seen in other Triassic/Mesozoic basins in the eastern United States. Geologic mapping of fault structural relationships help interpret basin development, periods of erosion and sediment deposition. Extension normal faulting from separating continents caused repeated down dropping of rock slab blocks causing basin subsidence. Crustal stretching and associated volcanic diabase dike activity magma that was injected through pre-existing rock as dikes.



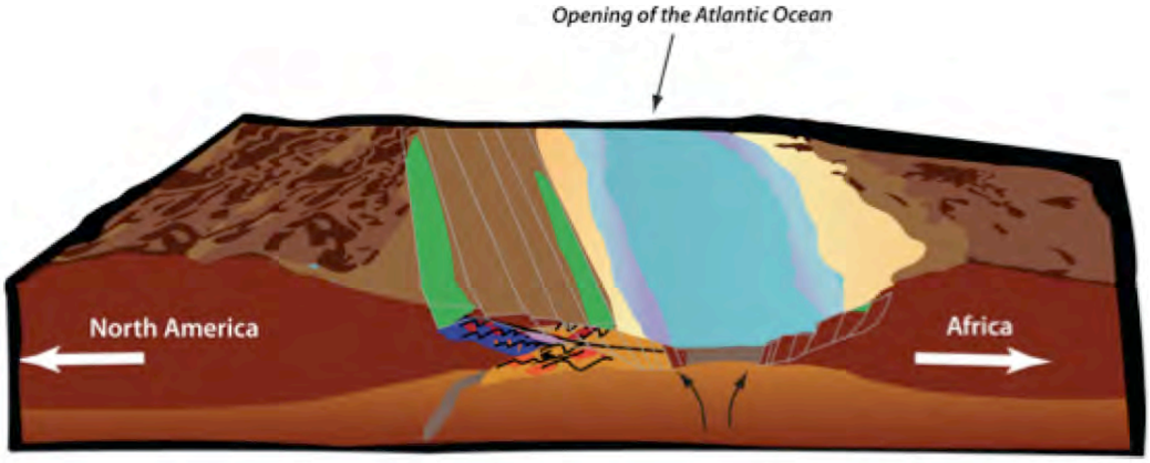
The three fault types (source Earle 2015)



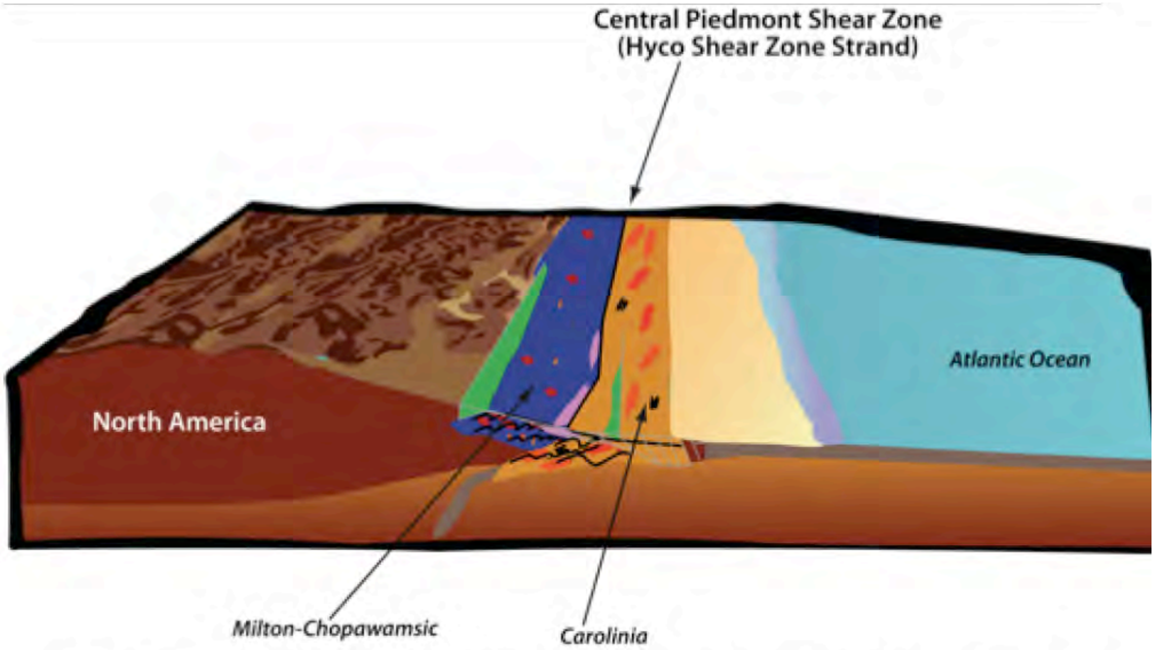
4. Start of Pangea breakup and Triassic basins formation about 220 mybp, source NCGS.

Jurassic-aged diabase dikes (red lines) are ribbon-like volcanic rock bodies intruding into and cross cutting through pre-existing rock. They are associated with rifting and numerous dikes occur in Chatham County. Similar igneous dike activity occurred along the U. S. East Coast from the regional continental rifting and breakup.

An extinction event occurred at the end of the Triassic about 201.3 mybp (Olsen et al 2004; Wikipedia 2021). A primary cause is interpreted due in large part to Pangea wide Atlantic Ocean opening and associated large-scale volcanism about 200 mybp. This volcanism erupted about 5 million square miles of rock in a few million years (Marzoli et al 1999; Marzoli et al 2010). The result was a world wide oceanic and atmospheric disruption with catastrophic biological effects.



5. Continued Pangea breakup,Triassic basins formation and Diabase intrusions (red) about 200 mybp, source NCGS.



6. Continued erosion of the Appalachian Mountains and formation of the Atlantic Coastal Plain about 66 mybp, source NCGS.

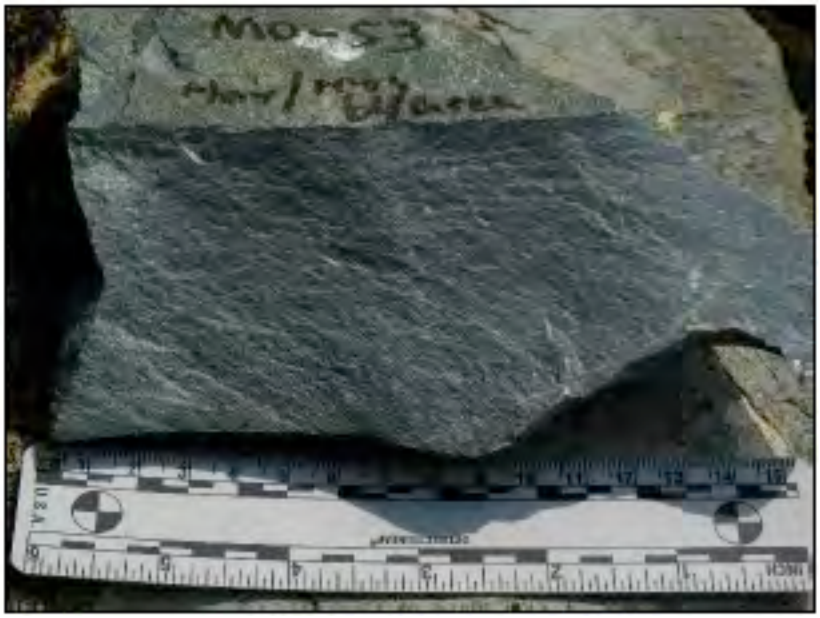
As the North American and European continents separated the Atlantic Ocean widened and the U. S. east coastal plain began to form. Sediments were deposited along the plain and into the new oceanic basin on North America's trailing (eastern) plate edge. The shoreline moved ocean ward (or transgressed) to the east ultimately creating the North Carolina Coastal Plain and similar eastern U. S. coastal plains.

The Mid-Atlantic Ocean floor volcanic spreading ridges continue to separate North and South America from Europe and Africa to the present. Erosion of the Appalachians and sediment deposition on the North American trailing plate edge Atlantic coastal plains and continental shelf has continued to the present.

Neoproterozoic-Cambrian and Triassic Basin Rock Example Photographs

The Neoproterozoic-Cambrian Hyco Formation volcanic eruptions that formed the island arcs generated huge quantities of rock that built the Carolinia terrane. Some representative rocks remain from the ancient volcanoes that one may view in Chatham County are presented below.

Dacite Hyco volcanic rock sample collected from the Haw River Vicinity near Hwy. 64. This rock type is a viscous lava and forms volcanic domes (cm scale, Bradley, 2021).



Andesite Hyco volcanic rock sample collected from the Haw River vicinity near Hwy. 64. This rock type is less viscous and tends to flow forming thin sheets of lava. Rapid cooling caused crystallization to occur quickly forming very small grains (Bradley, 2021).

Overland volcanic eruptions deposited tuff and tephra rocks. Pumice is formed from explosive eruptions called pyroclastic flows. These flows are composed of super heated ash, rock fragments and volcanic gas. They are extremely destructive and can flow at speeds 100+ mph destroying everything in thick blankets of super heated ash, gas and rock. When flow movement ends the entire mass squeezes and welds hot rock fragments together into a solid mass.

Surface volcanism welded tuff volcanic rock from Terrells Mountain the Haw River basin. The dark minerals and volcanic ash are flattened from the weight of the extremely hot flows (Bradley, 2021).

Volcanic tuff layers in Robeson Creek a tributary of the Haw River. These layers were deposited by the eruption and later folded and tilted (source Bradley, 2021).

The West and East Farrington Plutons in northeast Chatham County are igneous intrusive granitic rocks formed after the Hyco rock formation at about 579 mybp. The slower granitic crystallization deep underground allowed larger grain sizes to form. This difference in grain size results the rapidly cooling surface extrusive andesite, dacite and welded tuffs. These rocks were metamorphosed as the tectonic movements proceeded.

Farrington meta-granite plutonic rock (Bradley, 2015).

Farrington meta-granite rock boulders outcrop (Bradley, 2015).

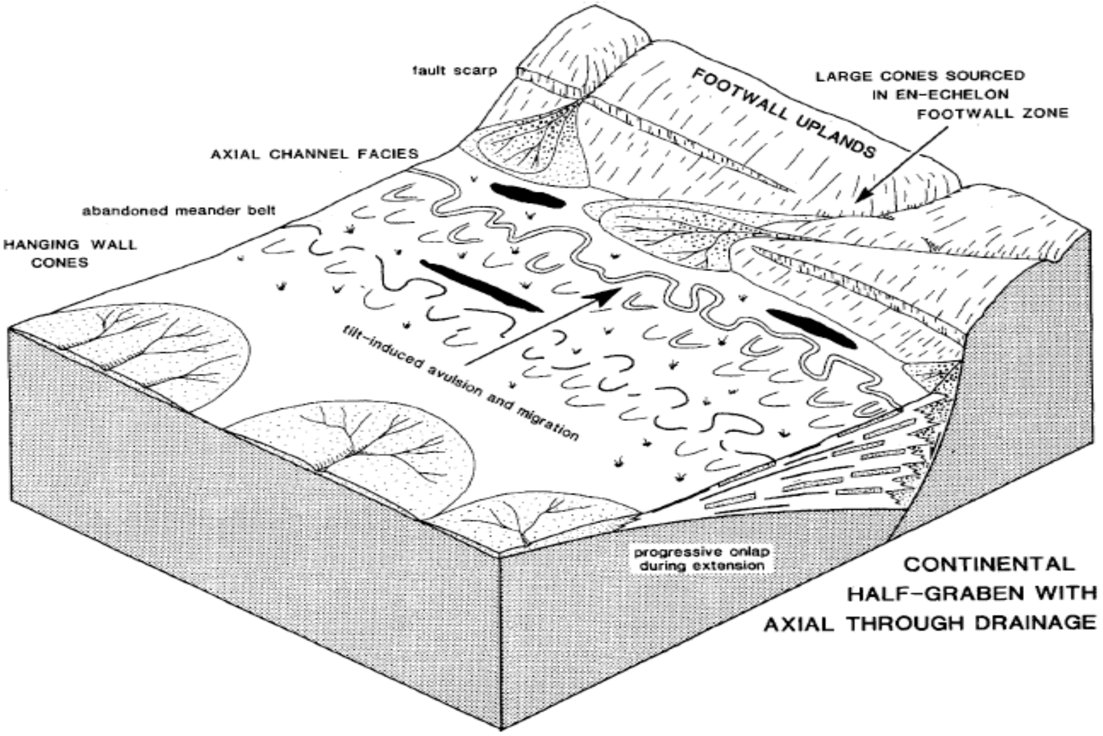
Triassic Basin Rock Example Photographs

The Triassic Deep River Basin opened depressions forming valleys that deepened with time. Erosion and weathering broke up and decomposed rock into sediment that rivers transported into low area deposits. As basins extended laterally and vertically more sediment was deposited filling them. The basin sedimentary rocks roughly 6,000 to 8,000 feet thick were deposited during this time. From oldest to youngest these sediments formed the Pekin Formation, Cumnock Formation and Sanford Formation (Reinemund 1955). These rocks have economic potential and have historically been mined.

Age	Formation Name	Lithology Rock Type	Potential Commodity
Upper Triassic	Stanford Formation	Red Sandstone and Mudstone	Bricks, Building Stone
Upper Triassic	Cumnock Formation	Interbedded Brown Sandstone with Black and Gray Shale; Coal and Black Oil Shale	Coal, Natural Gas; Thin iron beds; Shale-bearing ammonia and phosphate for fertilizer use
Upper Triassic	Pekin Formation	Mudstone, Sandstone and Conglomerate	Clay for Brick Manufacture

Coarse gravel and sand eroded from the mountains deposited alluvial fan gravel and sand conglomerates at the mountains and valley edge. Rivers and streams flowing further onto the lower valleys and plains were deposited sand, silt and clay. The lowest areas crossed by rivers flowed into lakes and swamps (see Sedimentary Environments diagram below).

Triassic conglomerate outcrop at Jordon Lake indicates a “high energy” (steep gradient) alluvial fan and river flow environment moving large rock clasts and sweeping silt and clay further downstream from mountains (source Bradley, 2021).



Examples of Sedimentary Depositional Environments diagram interpreted present in Deep River Basin rocks. Alluvial fans occur at the mountain edges and the graben edge. The normal fault movement creates an asymmetric "graben" valley that deepens resulting in a basin. Sediment is deposited by alluvial fans, rivers, lakes and swamps in the basin (concept diagram from Leeder and Gawthorpe 1987).

Triassic aged sedimentary interbedded sandstone and siltstone near New Hope Audubon Wildlife viewing platform Martha's Chapel Road (source Bradley, 2021).

The sedimentary environments and rocks of the Pekin, Cumnock and Sanford formations are similar to the interpretive diagram in the Basin.

Alluvial fan streams deposit coarse gravel and sand (high flow energy), rivers deposit sand, silt and clay (medium flow energy) and lakes with swampy areas (low flow energy) predominantly silt and clay with thin sand beds. The swampy environments generated abundant plant organic matter to form coal beds and organic shale in the Cumnock Formation.

Rivers meandering flowing through floodplains carry coarser sediment (gravel and sand), and the floodplains receiving clay and silt during high stream flow and periodic floods. At times these sedimentary strata mixed or interbedded with each other. Each stratum represents a time period and surface environment that was later buried by more sediment.

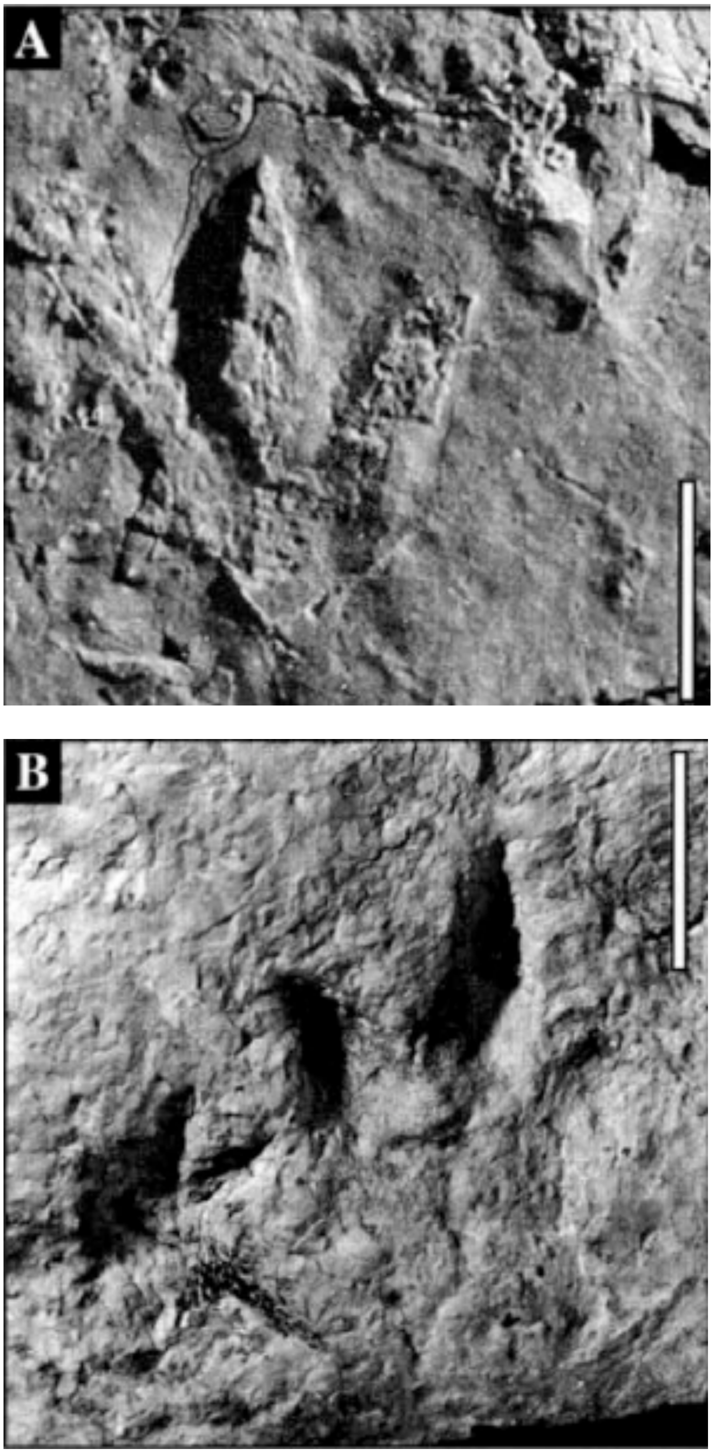
Triassic fossils contained in these sediments or any other basin presents a time history of the depositional environment conditions and paleoecology that are reconstructed using superposition principles. Plant and animal fossils indicate terrestrial life in the Deep River Basin in a warm and humid climate (Reinemund 1955).

Fossils

Fossils are present in the Deep River Pekin Formation. Example fossils below were found at the now closed Boren Clay Pits near the town of Gulf.

Plant fossils (cycadeoids) from the Boren Clay Pits, car keys for scale (Clark et al, 2011).

The association of plants with the animal fossils indicates a subaerial (land) environment and clay and siltstone indicate streams, lakes, and swampy conditions. Other fossils include plants, fish, invertebrates and early dinosaurian tracks.



A and B. Examples of early dinosaurian tracks from the Boren quarry, white bar scale is 5 centimeters long. These are the oldest Triassic footprints found in North America (Olsen and Huber, 1998).

Diabase Dikes

Diabase dikes are tabular volcanic rocks. The diabase dike rocks are dated to early Jurassic and were intruded as molten masses flowing into cracks crosscutting into preexisting rock. They tend to form long, thin outcrops of very hard diabase rock. The dikes are associated with Deep River Basin extension faulting that occurred during Jurassic time and Atlantic Ocean opening.

Numerous diabase dikes have intruded into older Hyco and Triassic rocks. These dikes tend to be oriented to the north-northwest and most are vertical. Dikes can vary from inches to hundreds of feet wide and extend laterally for miles (Reinemund 1955; Bradley 2021).

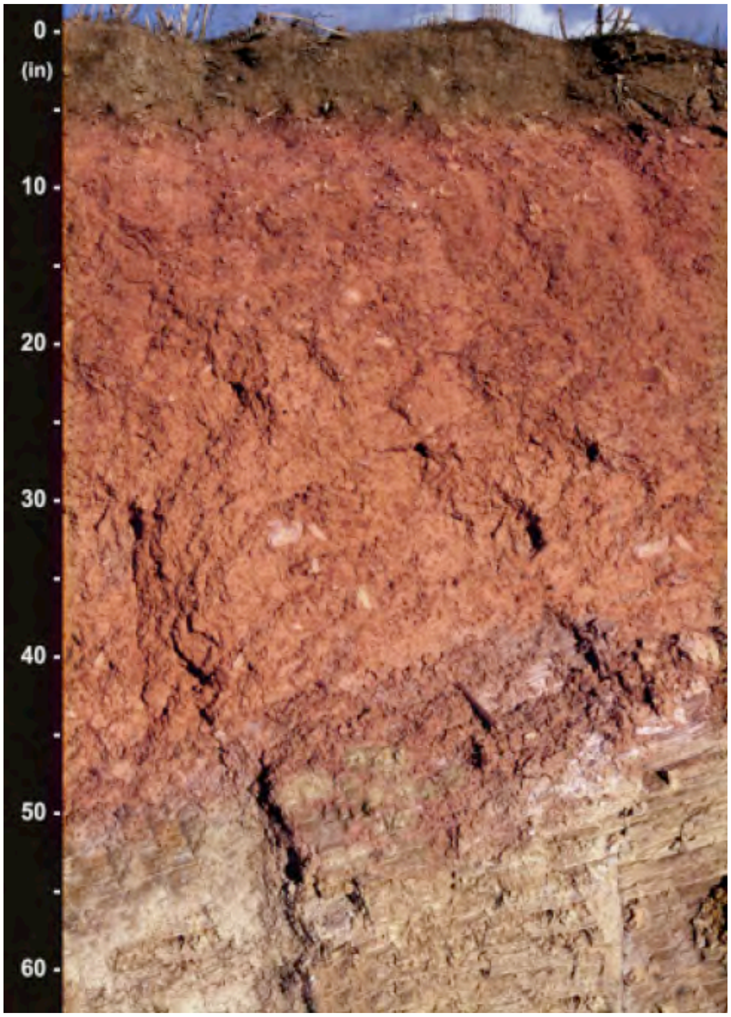
Dark colored Jurassic diabase dike intrusion crosscuts into older Paleozoic granite (men at lower right give scale (source Stoddard, NCGS).

Soil Formation

The Chatham County Soil Survey (USDA 1937; 2005) reports most soils in the County have developed upon the highly weathered rocks described above. Weathering is the process that decomposes existing rock and minerals into gravel, sand, silt and chemical changes that form new clay minerals. This process forms thin soil profiles termed saprolite or regolith. Soil profiles typically transition into less weathered bedrock at depths below about 5 feet. These weathering processes leave a “residual” of oxidized highly weathered rock that grades into less weathered rock at depth.

The 2005 Chatham County Soil Survey notes that various soil types developed over the Hyco Formation metavolcanic and meta-sedimentary rocks and cover about 72% of the County. As these rocks continue to weather and decompose, they oxidize and give a yellow, red-brown and/or “rusty” reddish orange color.

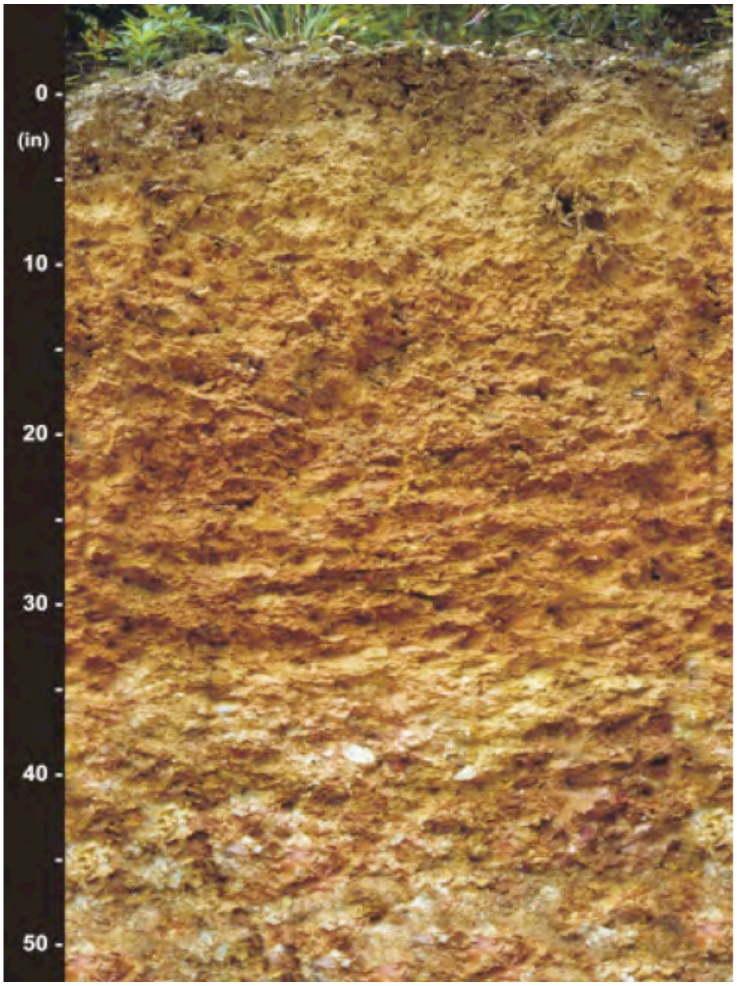
These soils have low to moderate expansiveness (shrink-swell potential). Shrink-Swell potential describes the volume change of a clayey soil caused by water absorption expansion followed then contraction when drying and losing water. A large shrink potential is indicated by large surface cracks in soil on drying.



Example of Tarrus soil series profile formed over fine-grained metavolcanic rock (USDA 2005, pg. 371). Note transition into from soil to light gray weathered metavolcanic rock below about 50 inches.

The Durham Triassic Basin in eastern Chatham County covers about 11% of the County. These soils formed over sandstone, interbedded claystones, siltstones, shale and conglomerates. These varied weathered rocks have a varied mineralogy with clayey subsoil and a high to very high shrink-swell potential.

Soils in the Sanford Triassic Deep River Basin comprise about 5% of the soil cover. These have formed over sandstone and siltstone weathered rock. These soils tend to be clayey and may range from moderate to high shrink and swell potential.



Example of Carbonton soil series profile that may form over Triassic siltstone, mudstone, shale or conglomerate rocks (USDA 2005 pg. 327). Note transition into weathered conglomerate below about 40 inches.

Groundwater Hydrogeology

Groundwater is water that flows below the surface and is a very important resource. Groundwater is recharged by precipitation and this water moves through soil or sediment grains openings called pores, and through lithified and crystalline rock cracks and fractures (both creating porosity). All "solid" rock is fractured to some degree at the surface and deeply into the subsurface. These water bearing and conducting strata and bedrock are called aquifers. Water migrates vertically into rock fractures below the soil profile and ultimately may discharge into springs, streams as well as recharging groundwater aquifers.

While subsurface groundwater flow may mimic the surface topography, groundwater everywhere flows through aquifers (hydraulic conductivity) toward pressure lows. It may discharge into surface springs, streams and lakes. Fracture rock aquifers that underlie a majority of the Chatham County are predominantly composed of metavolcanic and metagranitic and sedimentary rocks. However fracture porosity is somewhat limited depending upon location and rock type due to fracture intersections, density and apertures (openings) to roughly 5-6% of the total rock volume.

These fractures, faults and diabase dikes are called “groundwater features” due to their increased permeability and hydraulic conductivity (Bradley and Bolich 2019). Water wells drilled into fracture rock aquifers to withdraw water for residential, agricultural and industrial use. These wells may depending upon location produce much of the needed water especially in agricultural and rural areas (see Groundwater Features Map below and in Appendices).

Bedrock (“hard rock”) aquifer wells typically have limited groundwater yield quantity over time. Water quantities decline and slow water movement due to fewer fractures with more narrow apertures at depths of 300 feet or deeper. Fractures below about 300 feet may yield water but quantities are typically limited. Large water bearing openings below 300 feet are likely old faults (Heath 1980). Water movement depends upon the density and interconnection and the amount of rainfall and connection to surface water bodies (lakes, rivers streams, etc.).

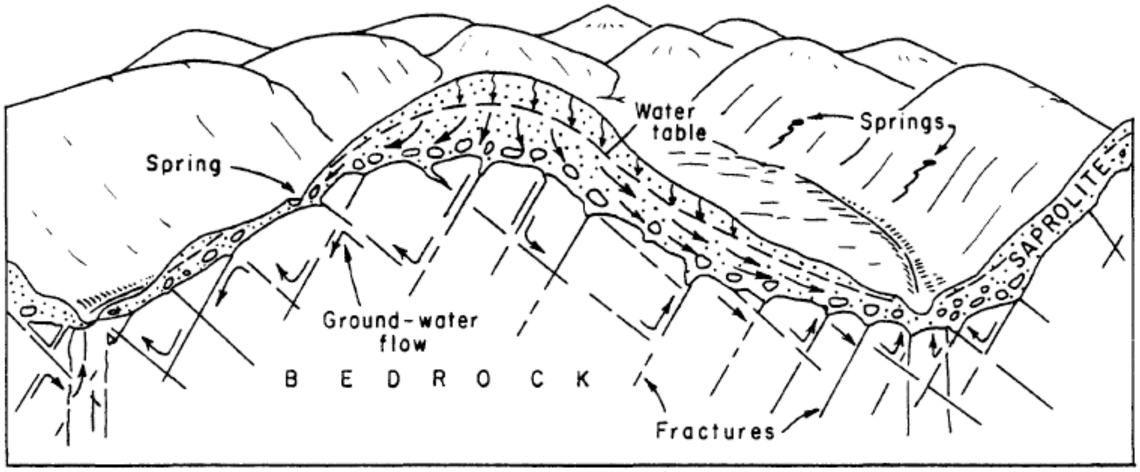


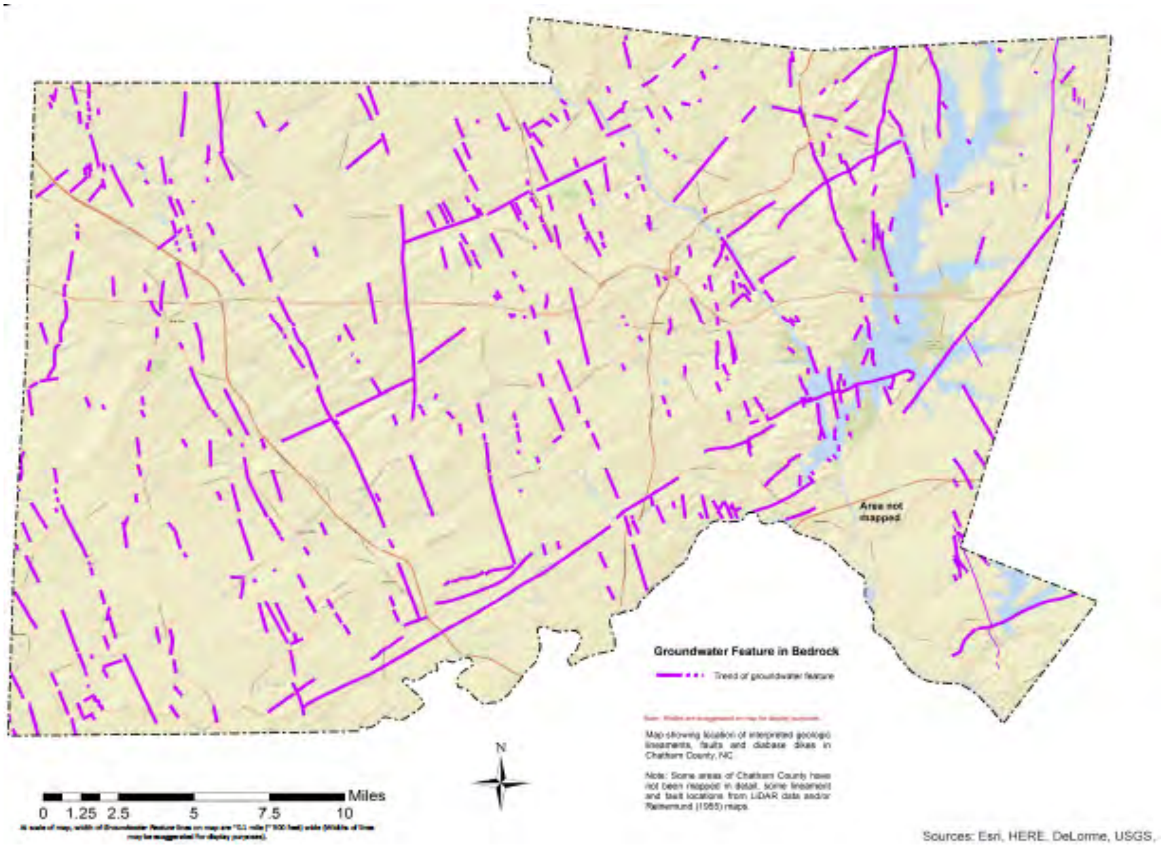
Diagram of Bedrock NC Piedmont Hydrogeology

This diagram shows “typical” ground water occurrence and flow in bedrock underlying the Piedmont. Arrows indicate possible subsurface groundwater flow directions in rock fractures. Precipitation provides ultimate groundwater recharge and water can discharge into springs, or streams rivers in valleys (Heath, 1980).

Diabase dikes, fractures and faults are important for locating domestic and agricultural groundwater wells. All rocks are fractured and where dikes and/or faults intersect other fractures, it creates more porosity for water recharge and subsurface movement. Wells that intersect more fractures typically produce more water over time.

These dikes tend to be associated with more rock fractures and can produce higher water well yields than the surrounding bedrock (Stoddard et al). Wells placed near dikes may produce more groundwater hence water production wells may be clustered around them. This is important for agriculture and residential developments that require long-term available water reservoir and quantity yield.

These dikes may also form the “diabase glades” with distinctive plants growing on them (Stoddard et al). Wells away from the dikes may produce very little water and dry up from time to time due to drought or overpumping groundwater from nearby wells. Groundwater may supply about 30% of water throughout North Carolina, however surface water bodies are major drinking water sources in our region.



Groundwater Features Map, 2019 NCGS. Map shows linear features that are cracks/fractures in bedrock. These convey precipitation through the rock into fractured rock aquifers that supply water to domestic and agricultural wells. These aid well siting locations to interest fractures for maximum well yield.

Groundwater chemical quality varies due to rock type, location, groundwater depth, aquifer recharge and discharge, proximity to pumping wells and agricultural and urban land use. Natural chemical groundwater quality is highly influenced by dissolved mineral content of various rocks the water flows through.

As a general rule County natural water quality is “good” and classified as calcium bicarbonate. A Statewide project was conducted to assess general groundwater quality in domestic wells in 2009-2010. This compilation above is of preliminary regional groundwater quality sampled from domestic wells in Chatham County. Chemical analyses include dissolved metals and selected organic contaminants are tabulated in the Appendices. These are preliminary data reported as County averages for each parameter.

Surface water drainage and shallow groundwater occurrence are important in Chatham County and have implications to our homes. Surface drainage and limiting shallow groundwater under houses is important to limit formation of mold. All water has to be drained to prevent erosion of soil/saprolite around structures and possible deleterious effects (cracking and uplift from soil shrink-swell potential) to building foundations, walls and pavements. Shrink-swell also indicates soil hydraulic conductivity that is important to location, usefulness and performance for septic on-site wastewater disposal.

Energy, Rock, Mineral Resources

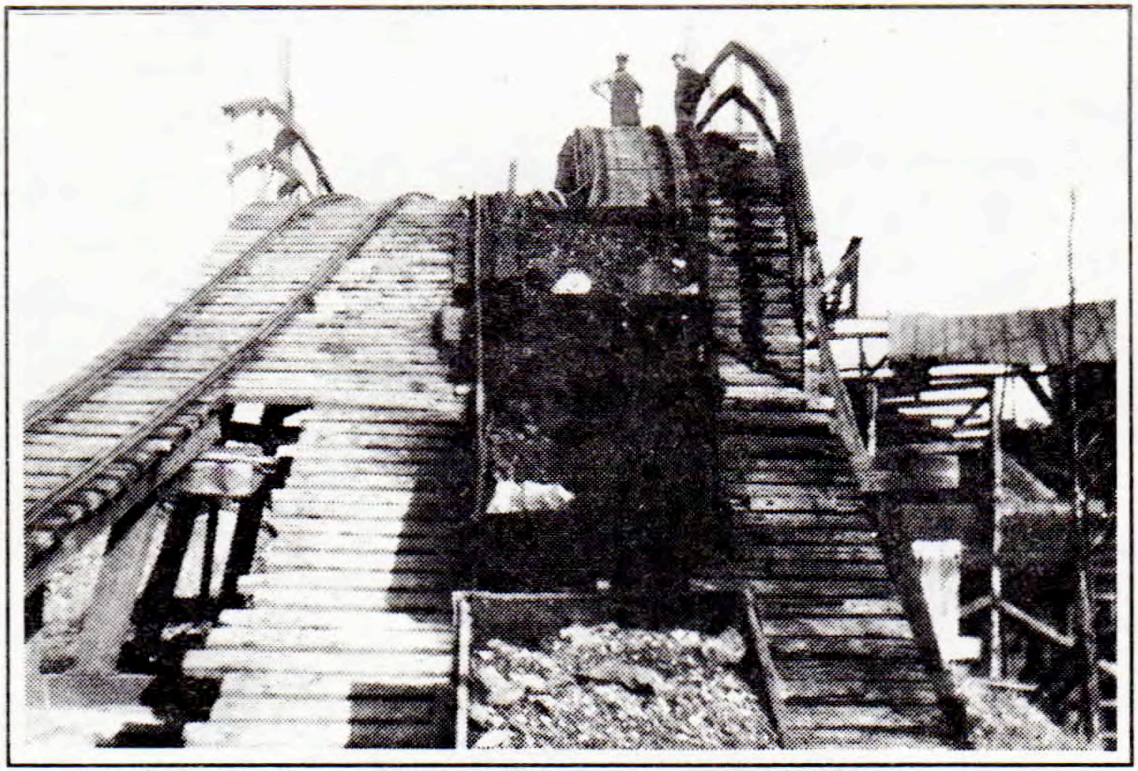
Rocks, minerals stone and energy resources have historically been mined in Chatham County. Coal, Iron (carbonaceous siderite, hematite), Clay, Stone and Pyrophyllite are the most developed. Very minor copper mineralization has been observed in the southeastern County.

Coal and Petroleum

Coal had been known since the 1700s and mining started in the mid-1850s (Nitze, 1893; Hadley et al, 1976; Hadley, 1993). This small-scale mining produced predominantly bituminous coal for ironsmithing, railroad fuel and iron mining use. The Cumnock (formerly Egypt) mine started about 1852 sinking a vertical shaft 460 feet deep. This coal was an important resource during the Civil War and through to mid 1800s. Coal mining continued until 1929 when the mine was permanently closed. The Carolina Coal Company started the Coal Glen Mine sinking a shaft and produced coal by June 1923.

An early map of Chatham County coal fields and nearby counties noted as the "Mineral Region." Coal is located in the southeastern portion of the County along the Deep River (map dated 1874 reproduced by CCHA).

Fatal mine accidents stopped mining until about 1931 following which production started again (Chapman 2017). However the 1930s economic Depression caused the mine to close in 1933. New ownership briefly reopened the mine in the late 1940s but later ceased active mining. The mine was closed in 1952.



Loaded cars from the Carolina Mine at Coal Glen.
(Photo from North Carolina State Archives)

Nitze (1893) reported on content of petroleum shale oil of the Deep River coalfields. This content judged at that time was "modest," but abundant oil was not found. Borehole sample testing for oil revealed its presence however no known producing oil wells are reported in the region.

The U. S. Geological Survey (2011) published a fact sheet assessment for undiscovered oil and gas in U. S. East Coast Mesozoic basins. The assessment revealed that economically recoverable oil was not present. The estimated quantities of economically recoverable natural gas and gas liquids were a low percentage of the total estimated quantity of gas. Currently natural gas development plans do not appear to be viable in the Deep River Basin for the foreseeable future.

Iron

Iron ores occur as minerals siderite and limonite blackband in the Cumnock Formation, and as hematite or red limonite in the Pekin and Sanford Formations (Nitze, 1893). Iron was mined prior to and during the Civil War used in the production or rail car wheels. Some ore may have gone to the Endor Iron Furnace just across the Deep River in Lee County. Additional iron used in the Endor furnace was mined about 22 miles south down stream on the Cape Fear River.

After the war the furnace produced iron for local use. The furnace operated until 1880 when northern mines and furnaces flooded the market with inexpensive iron (Hairr 2001 in Clark 2011).

Iron was historically mined at Ore Hill several miles south of Siler City (Hadley at al, 1976). An iron furnace was constructed in 1776 near Bonlee to produce Revolutionary War arms and munitions.

Endor Iron Furnace ruins near Cumnock (photo source Clark, 2011).

The Sapona Iron Company operated a furnace at Ore Hill for similar work during the Civil War. The company operated intermittently and only produced limited quantities of iron (Weisner 1996). The North Carolina Steel Company performed last mining activity between 1893 and 1903 (Hadley et al 1976).

Clay

Clay for bricks was mined at the Boren Clay Pits (now closed) near Goldston. This clay was used to produce millions of bricks. Pekin Formation sedimentary rocks are known for numerous Triassic plants, invertebrate trace fossils (such as burrows) and, plant, invertebrate and vertebrate track fossils (Olsen and Huber 1998; Clark et al 2011).

Stone

Sandstone was mined from the Sanford Formation (Reinemund 1955). It was used for building facing stone and some other construction uses.

Pyrophillite

Pyrophillite was known in the area since early to mid 1800s. Pyrophillite has been historically mined in the County notably at the Standard Minerals Mine (Glendon Pyrophillite Rock Quarry Inc.) near Goldston. Pyrophillite is used to manufacture products for refractory, ceramics and filler industries (Clark et al 2011).

The Standard Minerals Mine is located near Glendon. Four areas have been mined within the property (Source Bradley in Clark 2011).

Reinemund (1955) described the Pyrophillite deposit as a volcanic tuff of rhyolite or dacite composition that overlies a hematite rick volcanic breccia. Hydrothermal alteration associated with the pyrophyllite formation deposited trace amounts of gold (Clark et al 2011).

Copper

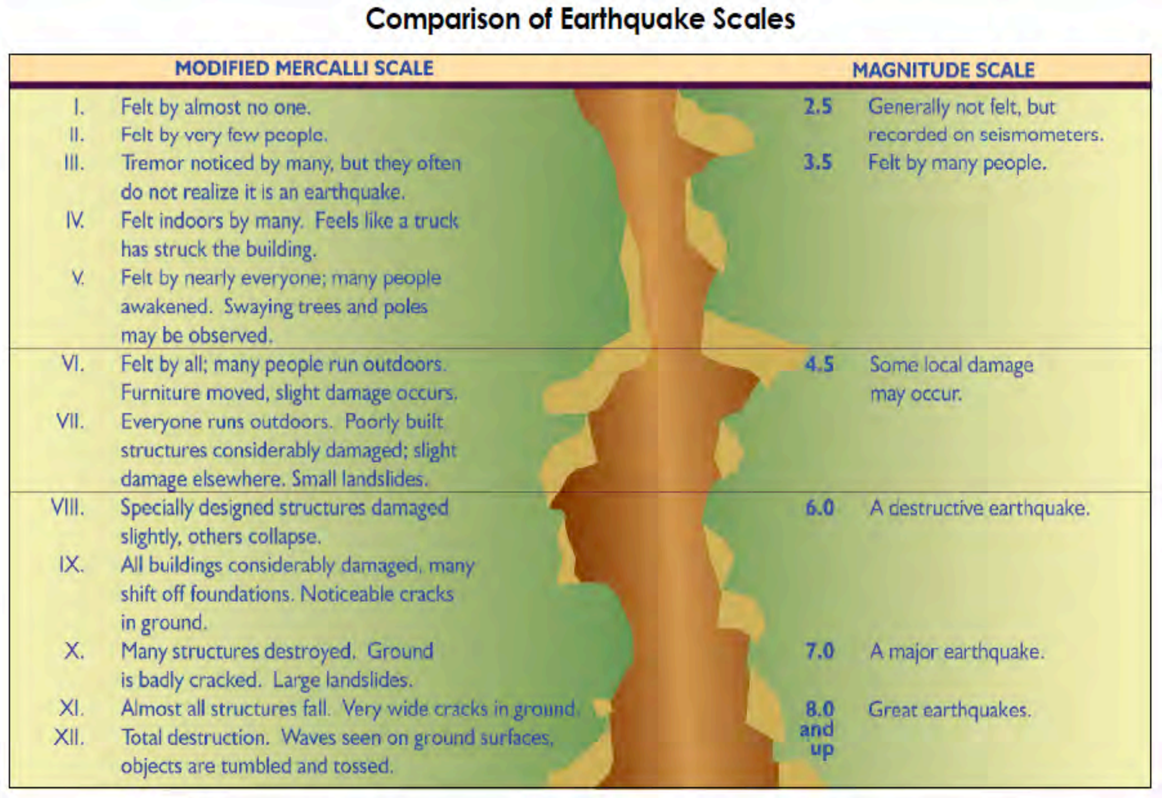
Several copper prospects and mines occur in the central southern County. Local mining has occurred at various times with limited production. No active mining is reported at the time.

Earthquake Activity In Chatham County and Around North Carolina

Earthquakes occur in North Carolina and large earthquakes are rare but can occur. Seismic sources in Tennessee and Virginia can generate earthquakes (NCGS 2017).

Chatham County may experience ground-shaking effects from nearby in or out of State earthquakes as shown below. Earthquake ground shaking can cause severe damage, but the majority of small earthquakes might be barely perceptible.

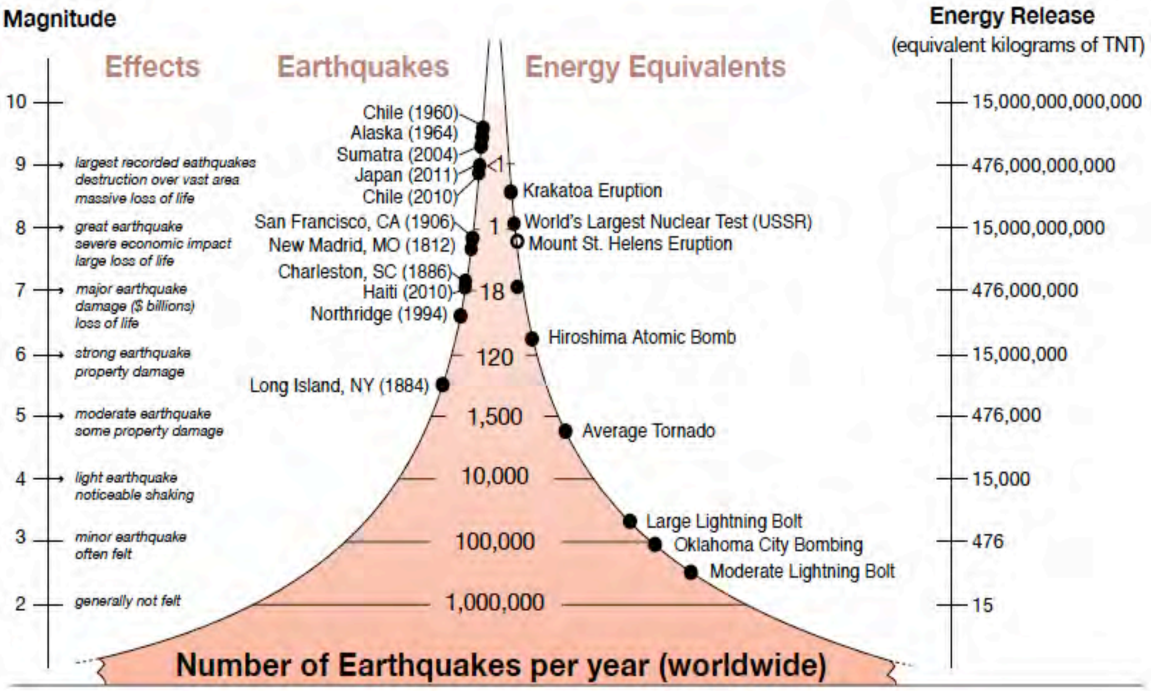
The Modified Mercalli Scale estimates shaking felt at various locations. It can be used to roughly estimate the earthquake magnitude (M) by what is felt and observed during the event. Earthquake magnitude is a logarithmic measure of the rupture length and the energy is related to the ground shaking. Energy rapidly increases in larger earthquakes as shown in the Modified Mercalli Scale and Energy Release diagrams below.



Comparison of Earthquake Scales

MODIFIED MERCALLI SCALE		MAGNITUDE SCALE	
I.	Felt by almost no one.	2.5	Generally not felt, but recorded on seismometers.
II.	Felt by very few people.		
III.	Tremor noticed by many, but they often do not realize it is an earthquake.	3.5	Felt by many people.
IV.	Felt indoors by many. Feels like a truck has struck the building.		
V.	Felt by nearly everyone; many people awakened. Swaying trees and poles may be observed.		
VI.	Felt by all; many people run outdoors. Furniture moved, slight damage occurs.	4.5	Some local damage may occur.
VII.	Everyone runs outdoors. Poorly built structures considerably damaged; slight damage elsewhere. Small landslides.		
VIII.	Specially designed structures damaged slightly, others collapse.	6.0	A destructive earthquake.
IX.	All buildings considerably damaged, many shift off foundations. Noticeable cracks in ground.		
X.	Many structures destroyed. Ground is badly cracked. Large landslides.	7.0	A major earthquake.
XI.	Almost all structures fall. Very wide cracks in ground.	8.0 and up	Great earthquakes.
XII.	Total destruction. Waves seen on ground surfaces, objects are tumbled and tossed.		

(Source Bechtel et al 2006)



Earthquake Magnitude Related to Estimated Energy Release
(Source: IRIS, 2011; Pacific Northwest Seismic Network, 2021)

The Magnitude Related to Energy Release diagram presents the relationship of earthquake magnitude related to estimate of amount of energy released as measured in equivalent pounds of explosives. Magnitude (M) is logarithmic so every increase is 10x the previous M number. Energy release is about 32x more for each increase in magnitude. NOTE: This scale shows magnitude estimates to a M10 event however the largest historically recorded earthquake occurred in Chile in 1960 was about M9.5.

Seismicity and Example Earthquakes

Typically the eastern United States is not seismically active compared to tectonic plate boundaries and the U. S. west coast. Moderately damaging earthquakes may occur every few decades in the Carolinas.

Small (M2-4) earthquakes might be felt every few years and very small earthquakes that occur somewhat regularly may not be felt at all. Most earthquakes are small and random and do not line up with known faults. The crust periodically experiences some stress adjustments that may cause and/or influence earthquake activity. Some very small earthquakes (M1-2) may occur at any time in the region.

The East Tennessee Seismic Zone has numerous small earthquakes some of which may occur in western North Carolina. A M4.5 earthquake occurred near Richmond, VA in December 2003. The most recent out of State earthquake was the August 2011 M5.5 Virginia EQ that occurred in the Central Virginia Seismic Zone (NC DEQ Earthquakes in North Carolina 2017; Bechtel 2006).

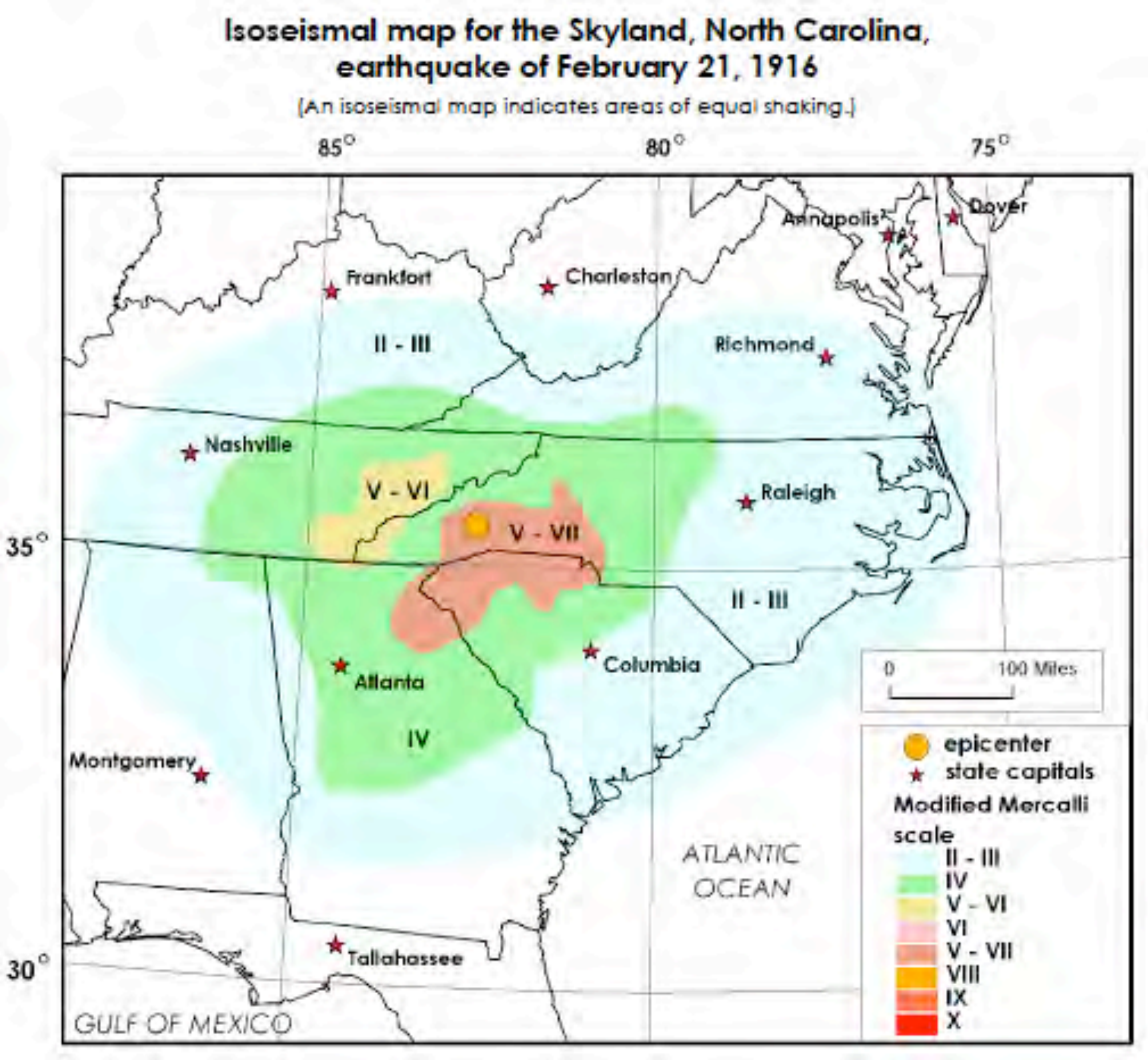
Three historic North Carolina and South Carolina earthquakes are presented below. These are three of the larger historic earthquakes with maps showing areas of perceived shaking.

- The 1916 Skyland M5.5 Earthquake occurred in the southwestern part of the State. The earthquake caused light building damage and general alarm to residents.

- The 1886 Charleston, South Carolina M7.3 Earthquake is included since it is one of the largest in the Southeast in recorded history and the area affected covered much of the eastern United States. There was widespread damage including liquefaction and ground distortion and panic.

- The Sparta M5.1 Earthquake occurred August 9, 2020 in northwestern North Carolina. The USGS earthquake map shows the epicenter and reported shaking from the event.

Aftershocks and numerous small earthquakes may occur after a larger earthquake. These tend to diminish in intensity with time. Small to very small earthquakes occur daily throughout the Nation and residents typically do not perceive any ground motion.



Isoseismal map for the Skyland, North Carolina, earthquake of February 21, 1916

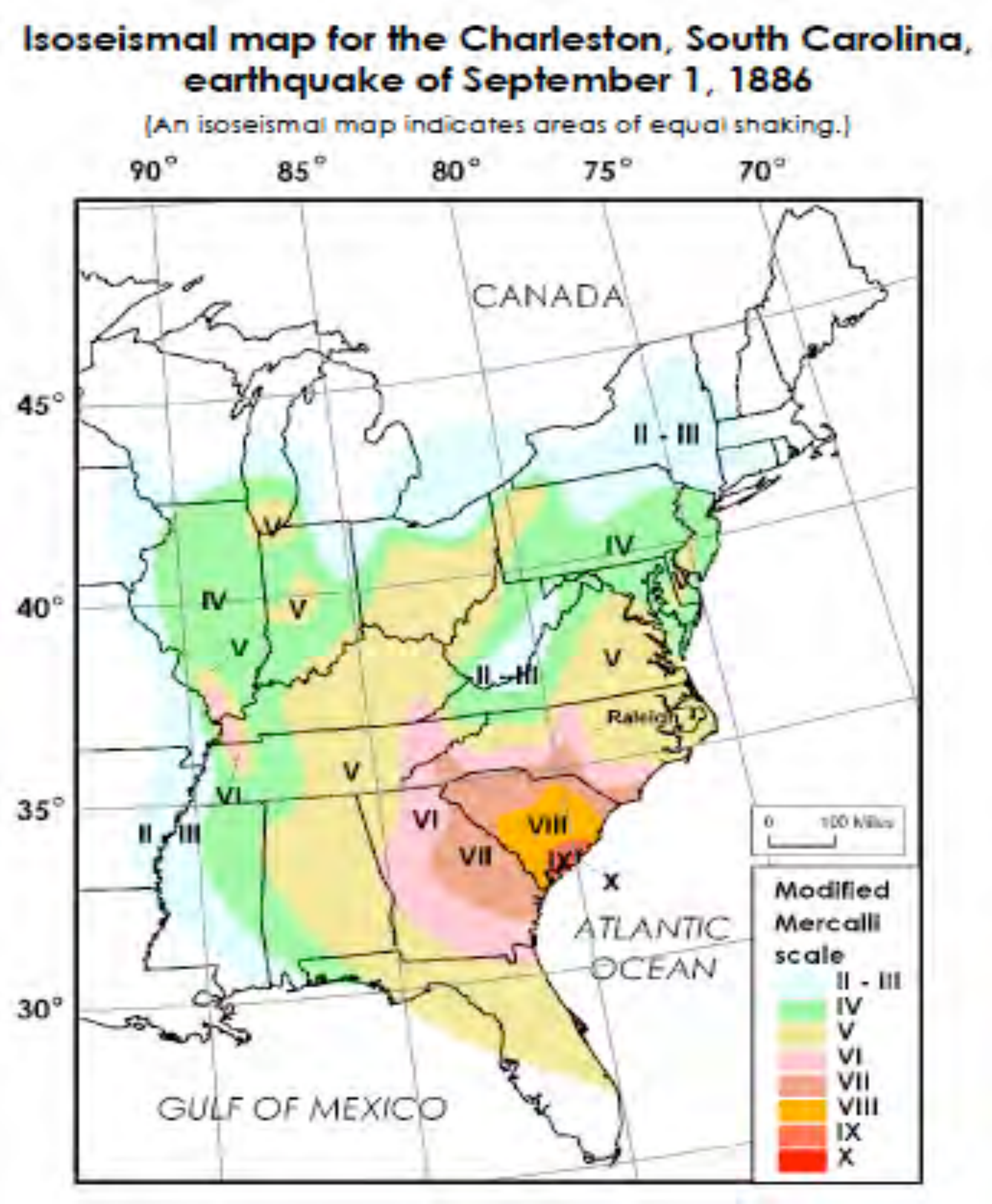
(An isoseismal map indicates areas of equal shaking.)

(Source Bechtel, R. et al, 2006)

The Skyland Earthquake M5.5 occurred in 1916 with a high of Modified Mercalli intensity of V-VII. The map shows the regional ground shaking effects by isoseismal lines of Modified Mercalli ground shaking effects.

Chimneys and windows were broken and people rushed into the streets. Some springs increased their water flow. The map shows that the ground shaking was felt in most of the southern States.

“Light to moderate” earthquakes (typically M4 and M5) may be capable of causing damage, especially to old and unreinforced masonry buildings. Chimney cracks and falls are common as are cracks to old or poorly constructed building foundations anywhere in the U. S. As earthquake magnitude rises the energy release can create widespread damage to well-built and reinforced buildings, bridges roads and railways.



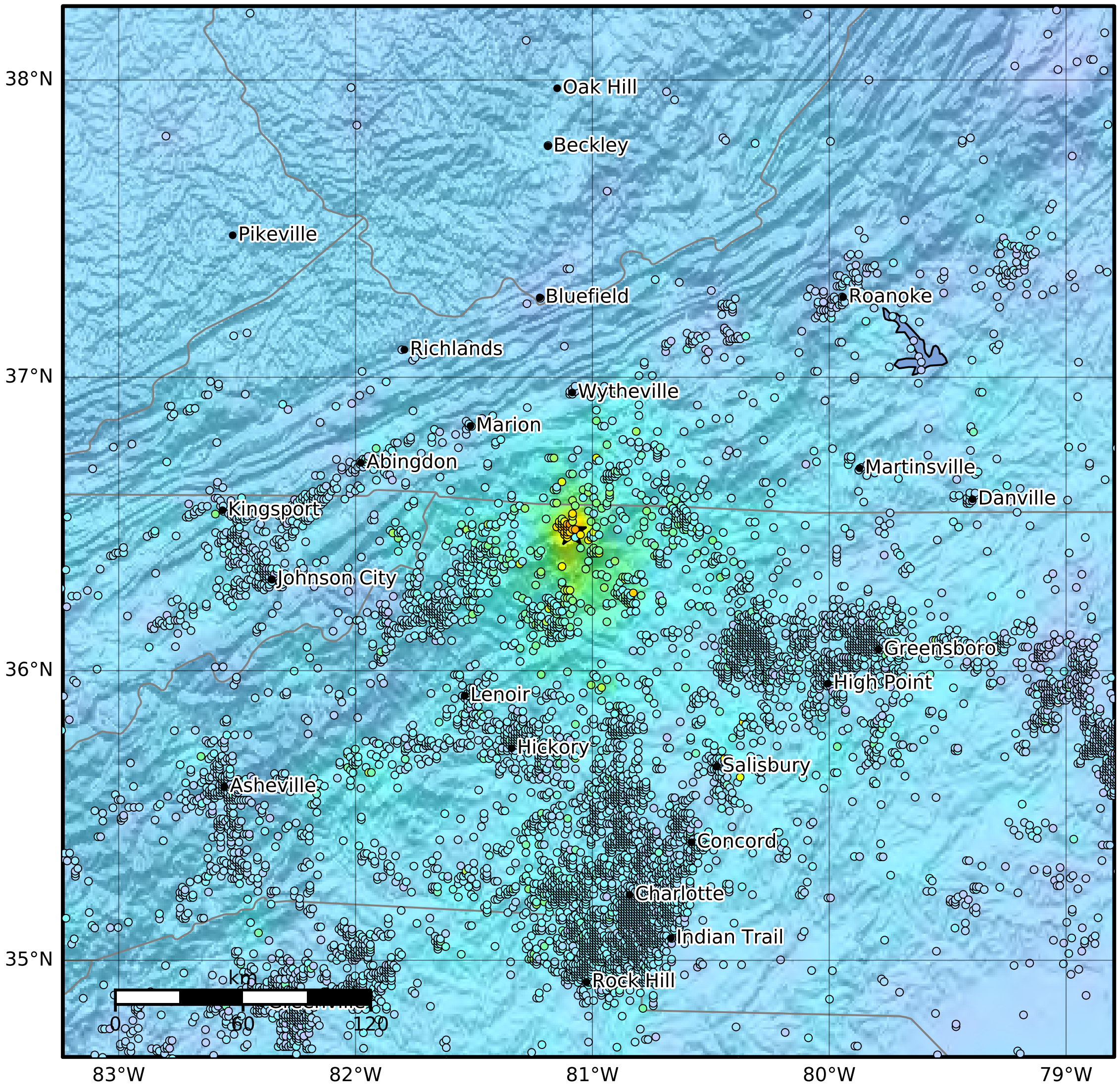
(Source Bechtel, R. et al, 2006)

The 1886 Charleston, South Carolina estimated to have been M7.3 and Modified Mercalli Intensity of X. This earthquake was located about ten miles north of Charleston and aftershocks continued for years (USGS 2021). It is the strongest earthquake to have occurred in recorded history in the southeastern U. S.

It caused widespread damage to the city and ground surface deformation in the surrounding area. Ground shaking from this event was felt in most of the eastern United States.

M 5.1 “Sparta” Earthquake Northwest of Greensboro August 9, 2020
Map downloaded from https://earthquake.usgs.gov

Macroseismic Intensity Map USGS
ShakeMap: 4 km SE of Sparta, North Carolina,
Aug 09, 2020 12:07:37 UTC M5.1 N36.47 W81.09 Depth: 4.1km ID:se60324281



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.00663	0.0795	0.954	4.99	8.76	15.4	27	47.4	>83.2
PGV(cm/s)	<0.0028	0.0383	0.524	3.03	6.48	13.9	29.6	63.4	>136
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Atkinson and Kaka (2007) Version 1: Processed 2020-10-15T15:44:32Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter

USGS reports Modified Mercalli color keys for each earthquake that indicate the severity of ground shaking and potential for damage. The higher the peak ground acceleration (PGA) and peak ground velocity (PGV) the more potential for severe shaking, ground deformation and higher likelihood for general and widespread damage. Some minor damage was reported for this event. The small circles are reports of shaking intensity in the nearby region.

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"Map of the Coal fields of Chatham and a portion of the Mineral Region of N.C.", 1874: map reproduced by Chatham County Historic Association (CCHA).

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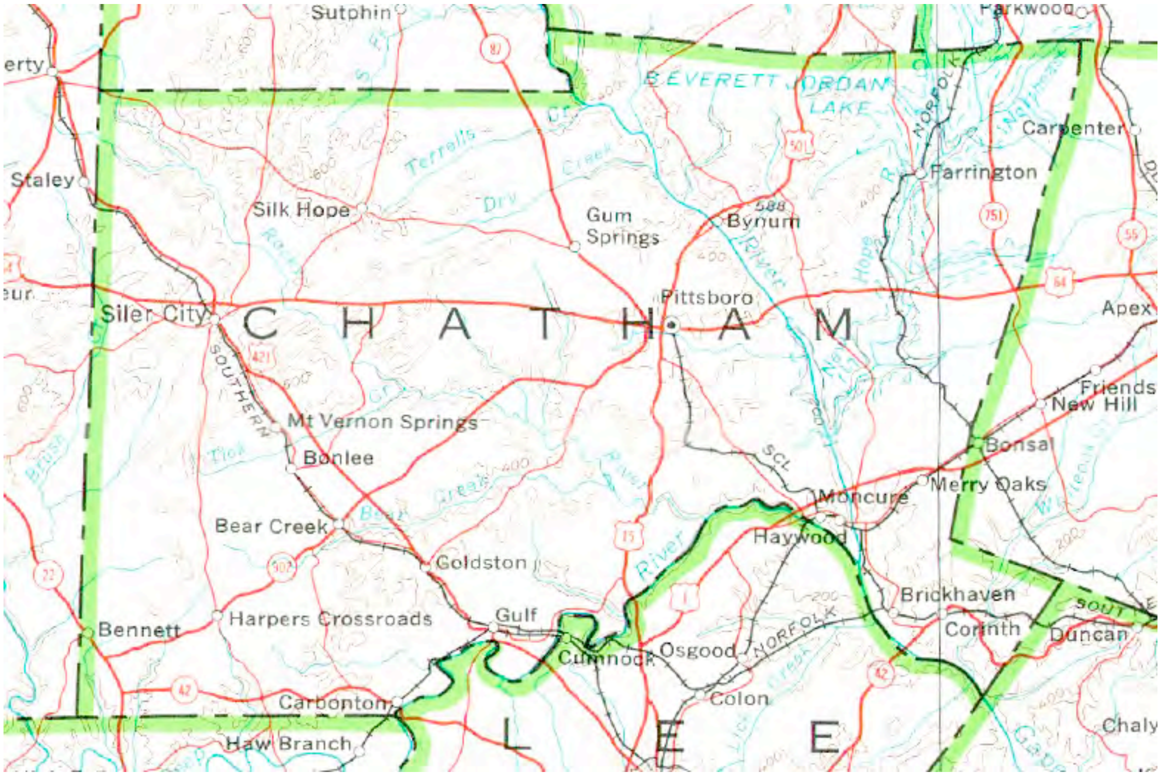
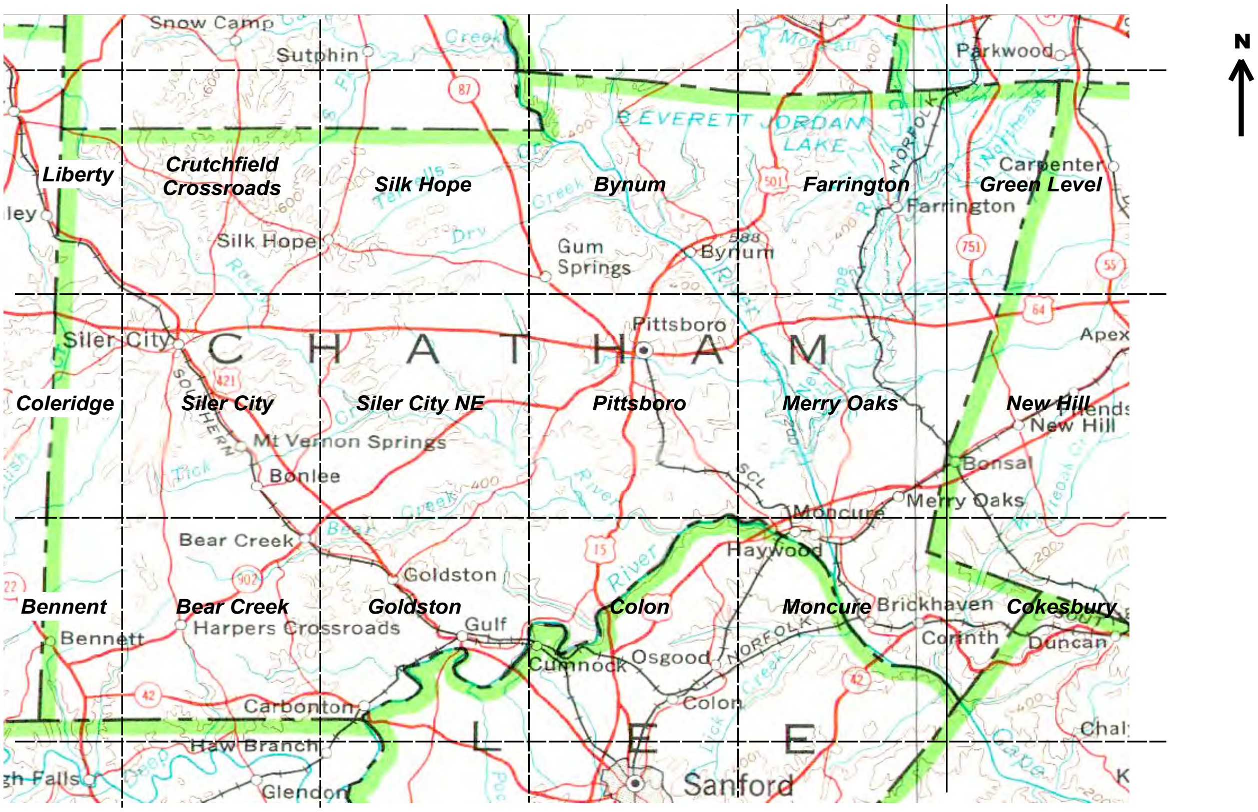
APPENDICIES



Chatham County, NC Generalized Topographic Map

(USGS, State of North Carolina Map, 1:500,000, 1972)

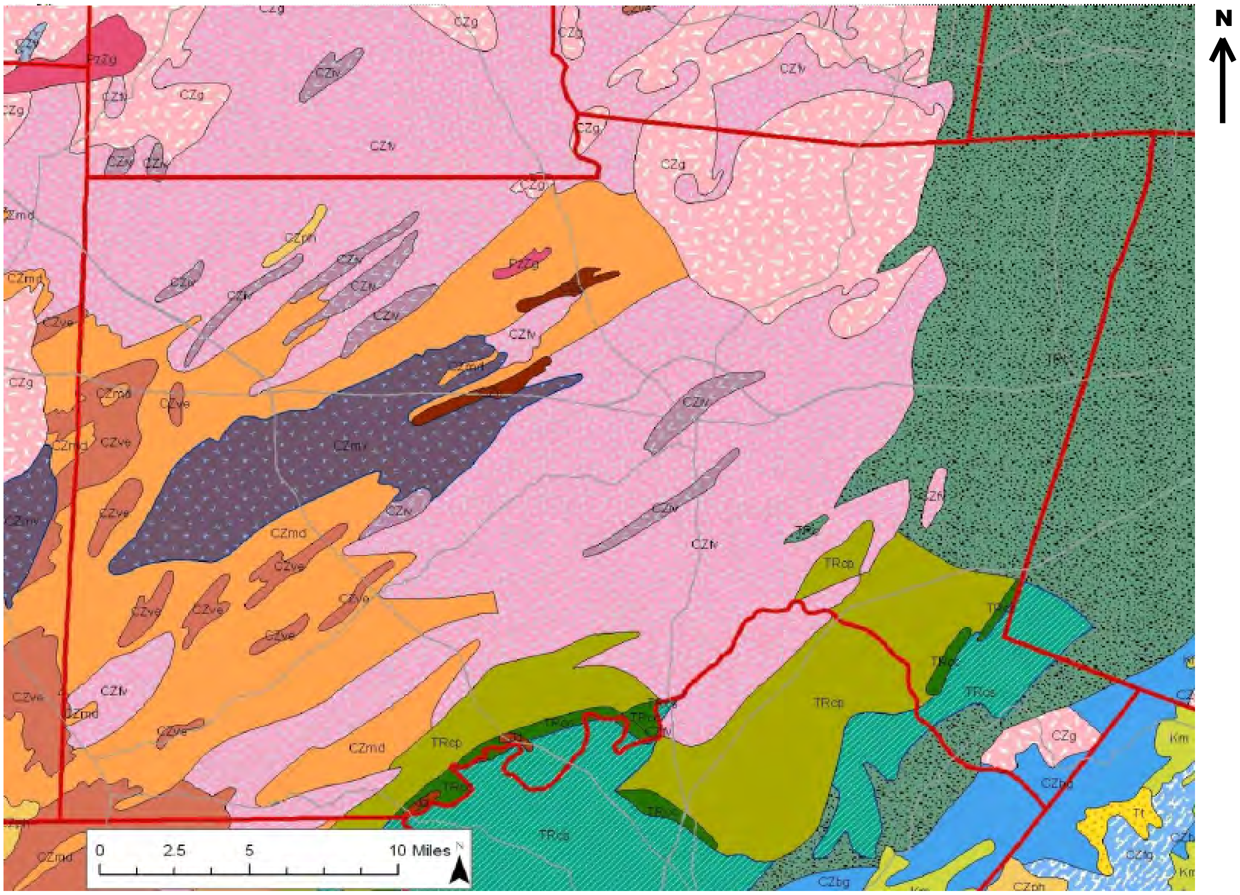


Chatham County, North Carolina
United States Geological Survey
Topographic Map Name Index

0 Scale in Miles 10

Base: US Geological Survey State of North Carolina
Topographic Map scale 1:500,000., rev. 1972.

Simplified Geologic Map of Chatham County, NC
(modified from Bradley, 2006)



Triassic

- 🟩 TRc-Chatham Group Rocks Undivided
- ▨ TRcs-Sanford Formation-Conglomerate, fanglomerate, sandstone and mudstone
- 🟩 TRcc-Cumnock Formation-Sandstone and mudstone, coal beds grades into Pekin and Sanforn Formations
- 🟨 TRcp-Pekin Formation-Conglomerate, sandstone and mudstone

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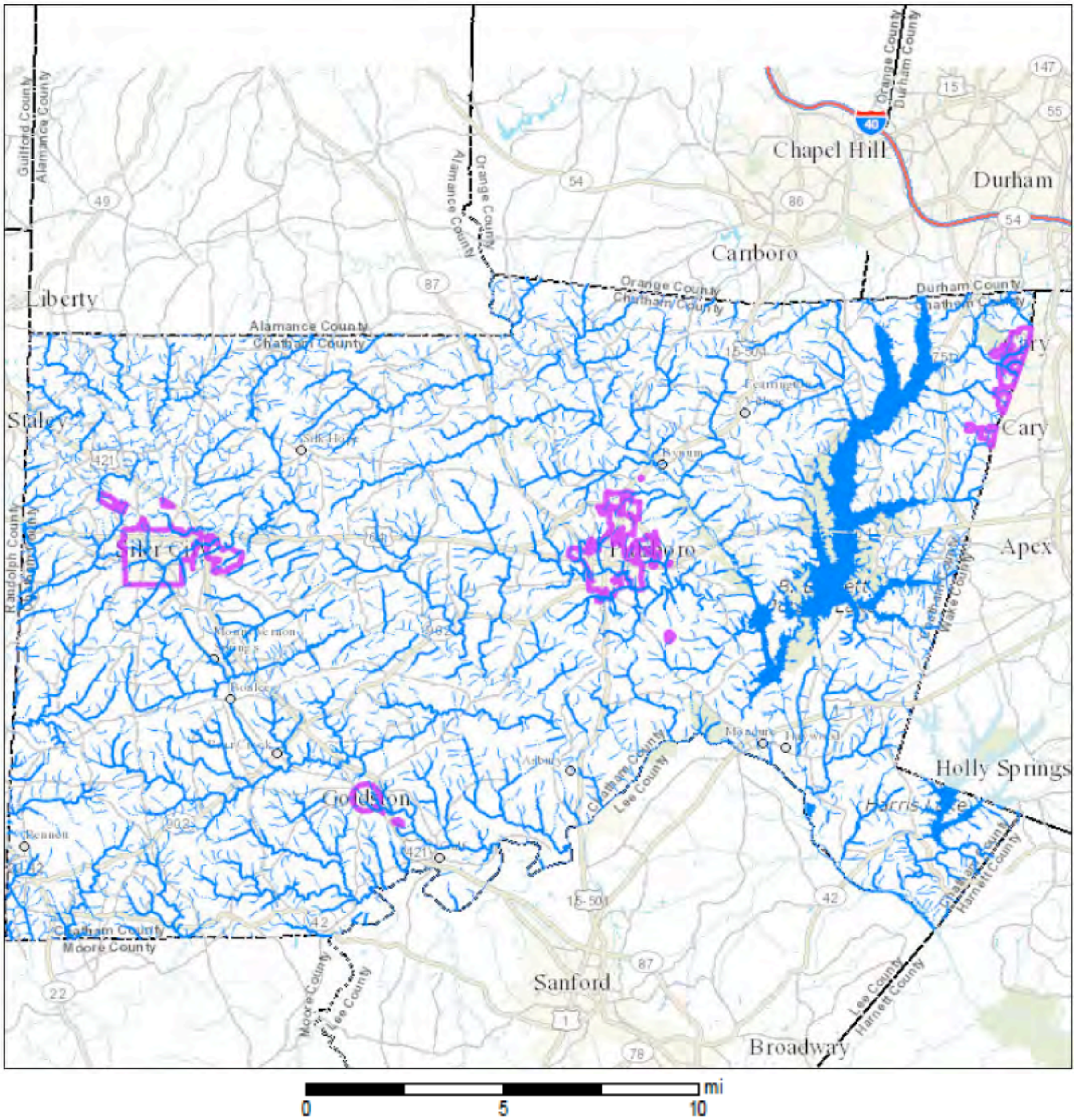
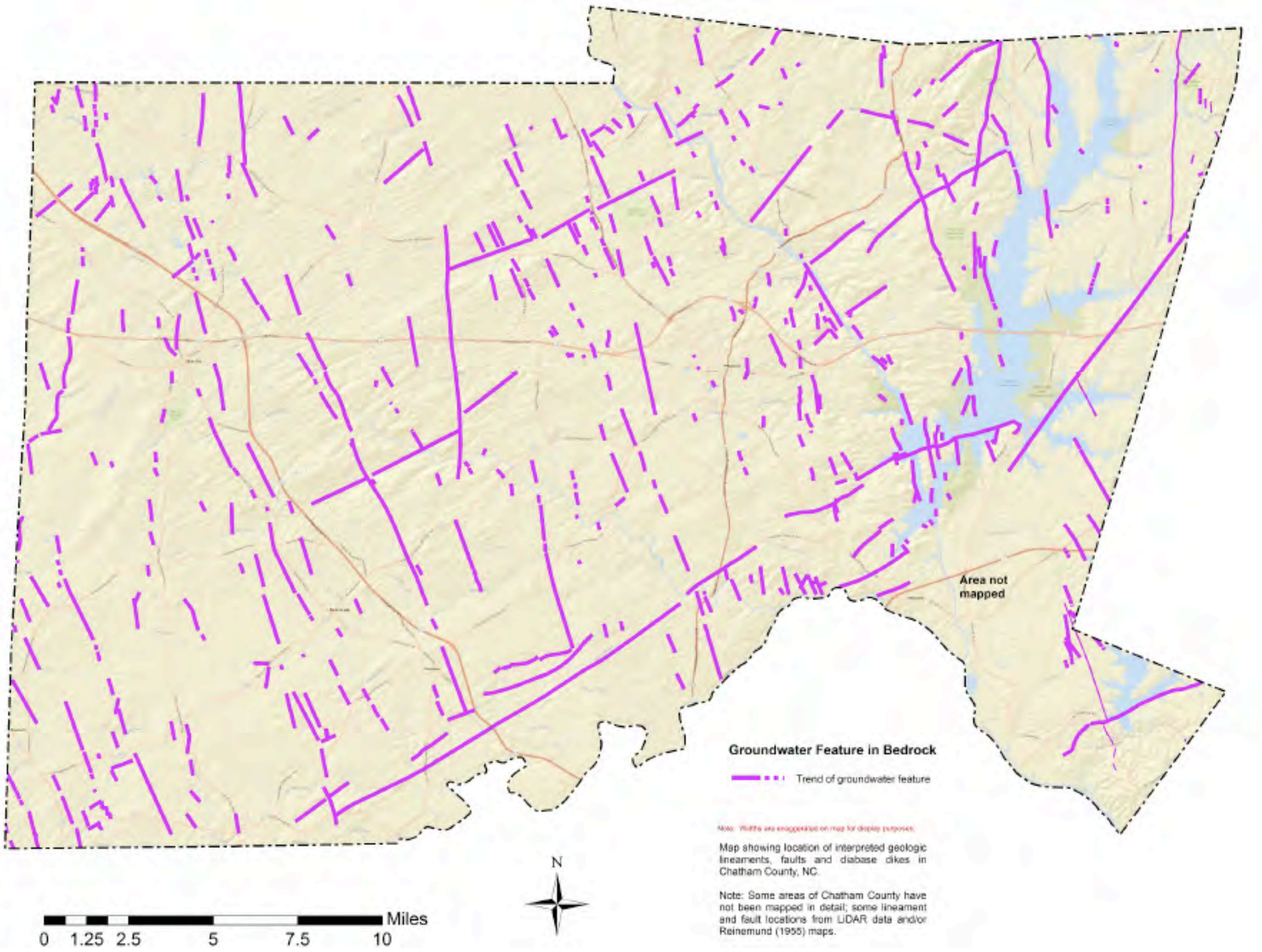
Neoproterozoic to Cambrian

- 🟧 CZmd-Metamudstone and Meta-Argillite
- ▨ CZfv-Felsic Metavolcanic Rock
- ▨ CZiv-Intermediate Metavolcanic Rock
- 🟪 CZmv-Mafic Metavolcanic Rock
- 🟧 CZve-Metavolcanic-epiclastic Rock
- 🟫 CZc-Volcanic Metacomglomerate
- 🟨 CZph-Phyllite and Schist
- 🟥 PzZg-Metamorphosed Gabbro and Diorite
- ▨ CZg-Metamorphosed Granitic Rock



Surface Hydrology Map, Chatham County Planning Department, 2021



Note: Widths are exaggerated on map for display purposes.

Map showing location of interpreted geologic lineaments, faults and diabase dikes in Chatham County, NC.

Note: Some areas of Chatham County have not been mapped in detail; some lineament and fault locations from LiDAR data and/or Reinemund (1955) maps.

Groundwater Features in Bedrock, Preliminary Map (NCGS 2019)

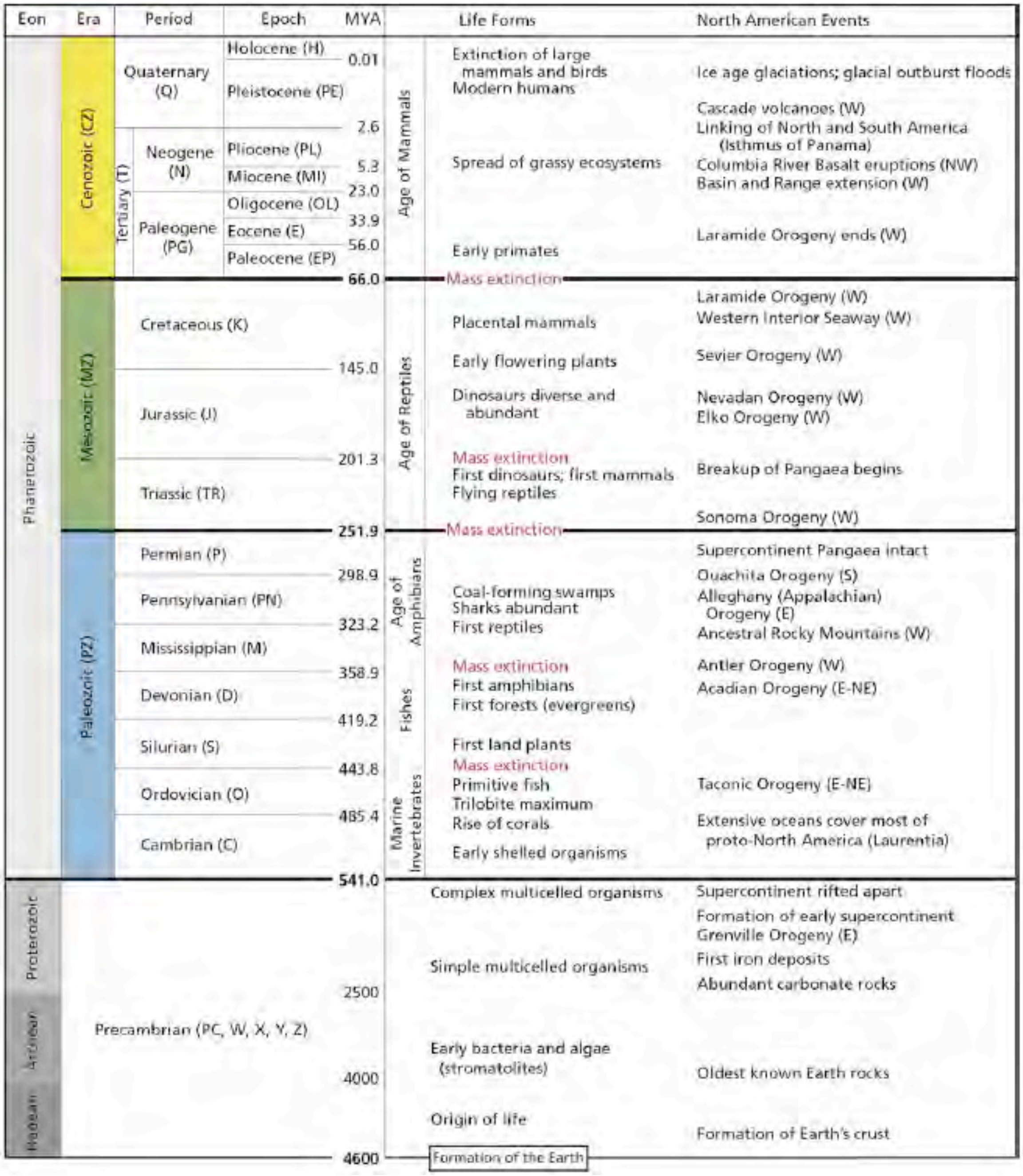
Much of Chatham County is underlain by crystalline bedrock that is locally highly fractured (purple lines). All bedrock is fractured to some degree by faults, dikes and joints. Groundwater features are marked by the purple lines are usually preferred places to locate groundwater wells for “optimal” well yield. The more numerous fractures and intersecting fractures allow rainfall to enter and penetrate deeply into the rock. These mapped fractures are pathways that allow subsurface rock aquifers to recharge with and allow subsurface flow of groundwater. Note the two predominant fractures directions of fractures as well as fractures crossing rivers and underlying Jordon Lake that act as aquifer recharge sources in the County.

Preliminary Groundwater Quality Data from Domestic Wells in Chatham County Sample Data of 2010*

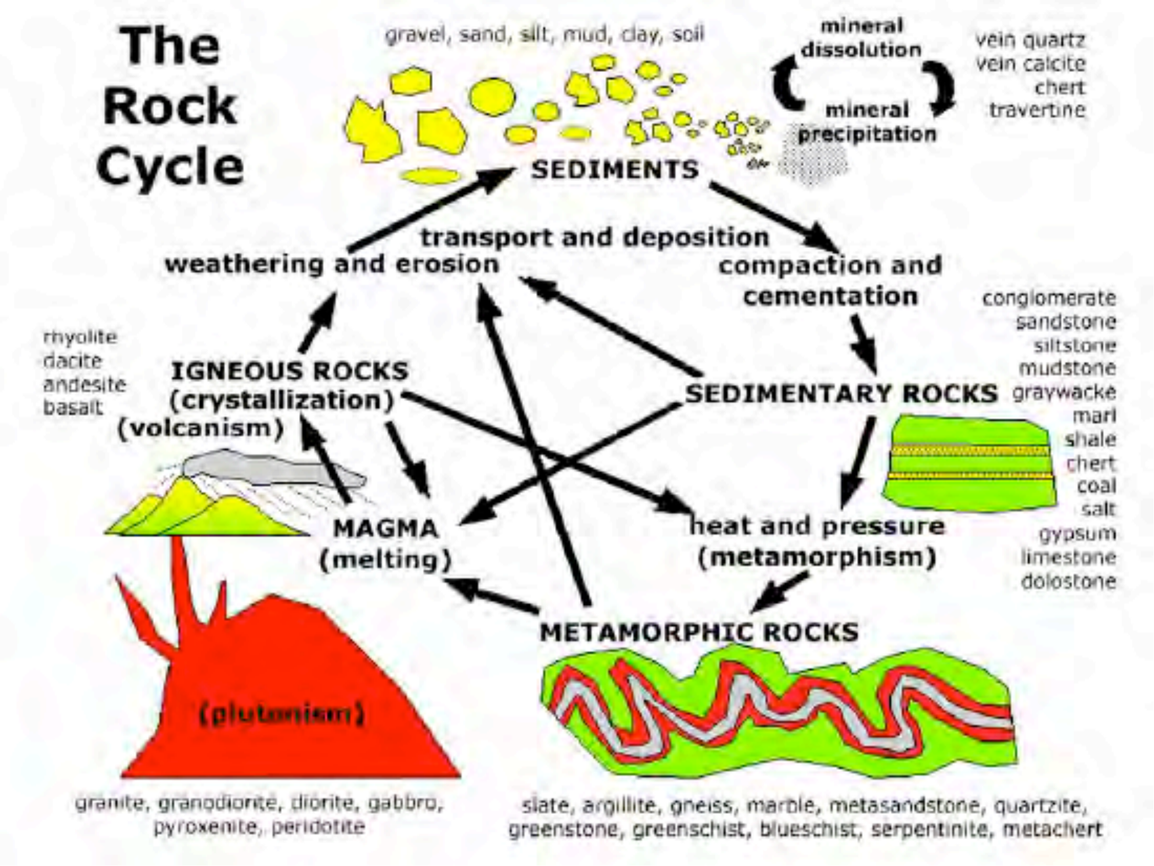
Parameter	Average Concentration ug/l	NC MCL ug/l 2021#	USEPA MCL ug/l 2018
Arsenic (As)	2.44	10	6
Barium (Ba)	50-100	700	2,000
Benzene	0.01-0.25	1	1
Cadmium (Cd)	0.49-0.5	2	5
Cis-1,2-Dichloroethene (c-DCE)	0.01-0.25	70	6
Chromium (Cr)	0.49-1.0	10	100 (Total)
Copper (Cu)	25-50	1,000	1,300
1,2-Dibromoethane	0.01-0.25	None Listed	None Listed
1,2-Dichloropropane	0.01-0.25	0.6	5
Ethylbenzene	0.41-0.75	600	700
Fluoride	100	2,000	4,000
Iron (Fe)	50-300	300	*SMCL*- 300
Isopropyl Ether	0.01-0.25	70	None Listed
Lead (Pb)	4.01-6.00	15	15
Magnesium (Mg)	50.00-2,500.00	None Listed	None Listed
Manganese (Mn)	100.01-281.71	50	*SMCL* - 50
Mercury (Hg)	0.26-0.35	1	2
Methyl-tert-butyl-ether (MTBE)	0.01-0.27	20	13 *SMCL - 5*
Nitrate (as N)	0.01-500	10,000	10,000
Nitrite (as N)	0.01-50.00	1,000	1,000
Tetrachloroethylene (PCE)	0.01-0.28	0.7	5
pH Acidity/Alkalinity	6.85-7.33	6.5-8.5	6.5-8.5
Selenium (Se)	4.01-8.00	20	50
Silver (Ag)	25.00	20	*SMCL*-100
Sodium (Na)	7,501-9,000	None Listed	None Listed
Trichloroethylene (TCE)	0.01-0.25	3	5
Trans-1,2-Dichloroethane (t-DCE)	0.01-0.2555	100	10
Toluene	0.01-0.50	600	1,000
Vinyl Chloride	0.01-0.25	0.03	2
Xylenes (Total)	1.01-5.00	500	10,000
Zinc (ZN)	100.00-250.00	1,000	None Listed

Ug/l – Micrograms per liter (equivalent to parts per billion)
MCL – Maximum Contaminant Limit NC 2013; USEPA 2018**.** *SMCL* **–** Suggested MCL.
***** UNC Superfund Research Program-Research Translation Core Maps 2009-2010; UNC Gillings School of Global Public Health. Averages are interpreted as Countywide.
# 15A NCAC 02L.0202 Groundwater Standards; Eff. April 1, 2013; rev 2021.
See USEPA and NC Groundwater Standards web sites for updates/revisions.

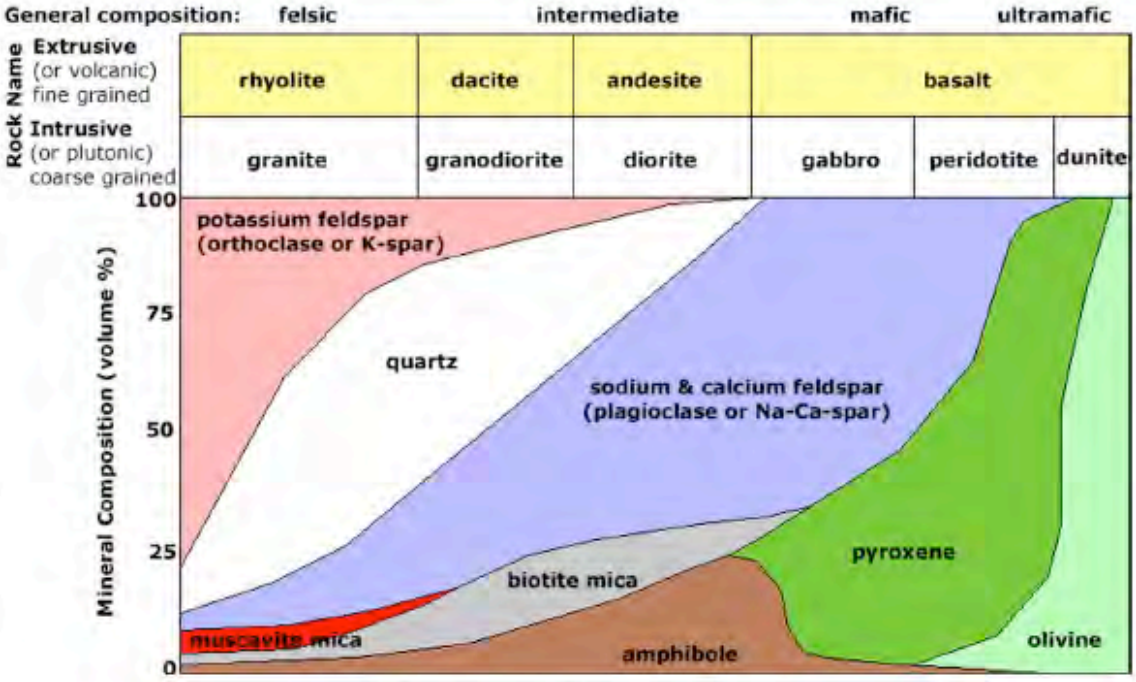
Geologic Time Scale Listing Significant Events
(National Park Service, 2018)



Eon	Era	Period	Epoch	MYA		Life Forms	North American Events
Phanerozoic	Cenozoic (CZ)	Quaternary (Q)	Holocene (H)	0.01	Age of Mammals	Extinction of large mammals and birds Modern humans	Ice age glaciations; glacial outburst floods
			Pleistocene (PE)	2.6			Cascade volcanoes (W) Linking of North and South America (Isthmus of Panama)
		Tertiary (T): Neogene (N)	Pliocene (PL)	5.3		Spread of grassy ecosystems	Columbia River Basalt eruptions (NW) Basin and Range extension (W)
			Miocene (MI)	23.0			
		Tertiary (T): Paleogene (PG)	Oligocene (OL)	33.9			
			Eocene (E)	56.0			Laramide Orogeny ends (W)
			Paleocene (EP)	66.0		Early primates Mass extinction	
	Mesozoic (MZ)	Cretaceous (K)		145.0	Age of Reptiles	Placental mammals Early flowering plants	Laramide Orogeny (W) Western Interior Seaway (W) Sevier Orogeny (W)
		Jurassic (J)		201.3		Dinosaurs diverse and abundant	Nevadan Orogeny (W) Elko Orogeny (W)
		Triassic (TR)		251.9		Mass extinction First dinosaurs; first mammals Flying reptiles Mass extinction	Breakup of Pangaea begins Sonoma Orogeny (W)
	Paleozoic (PZ)	Permian (P)		298.9	Age of Amphibians		Supercontinent Pangaea intact Ouachita Orogeny (S)
		Pennsylvanian (PN)		323.2		Coal-forming swamps Sharks abundant First reptiles	Alleghany (Appalachian) Orogeny (E) Ancestral Rocky Mountains (W)
		Mississippian (M)		358.9		Mass extinction	Antler Orogeny (W)
		Devonian (D)		419.2	Fishes	First amphibians First forests (evergreens)	Acadian Orogeny (E-NE)
		Silurian (S)		443.8		First land plants Mass extinction	
		Ordovician (O)		485.4	Marine Invertebrates	Primitive fish Trilobite maximum	Taconic Orogeny (E-NE)
		Cambrian (C)		541.0		Rise of corals Early shelled organisms	Extensive oceans cover most of proto-North America (Laurentia)
Proterozoic		Precambrian (PC, W, X, Y, Z)		2500		Complex multicelled organisms Simple multicelled organisms	Supercontinent rifted apart Formation of early supercontinent Grenville Orogeny (E) First iron deposits Abundant carbonate rocks
Archean				4000		Early bacteria and algae (stromatolites)	Oldest known Earth rocks
Hadean				4600		Origin of life Formation of the Earth	Formation of Earth's crust

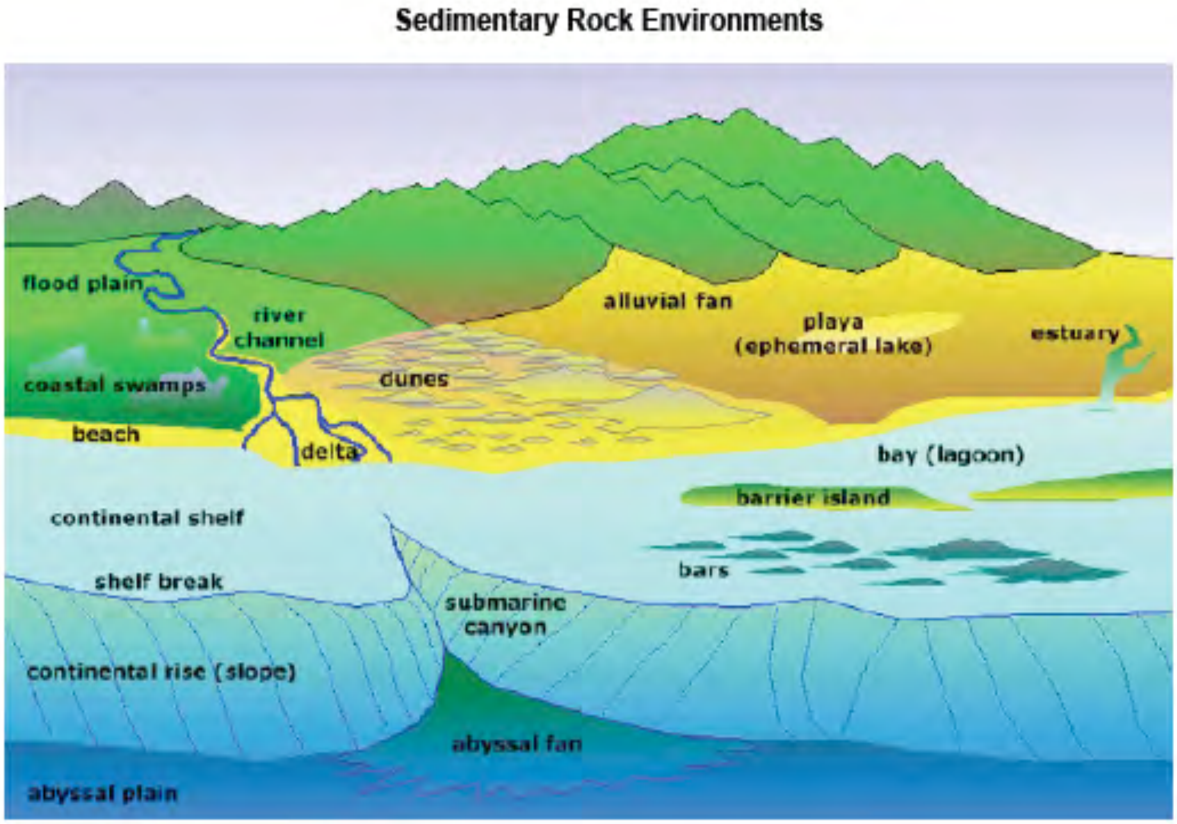


General Igneous Rock Classification



A general classification of igneous rocks.

(Both Diagrams USGS, 2002)

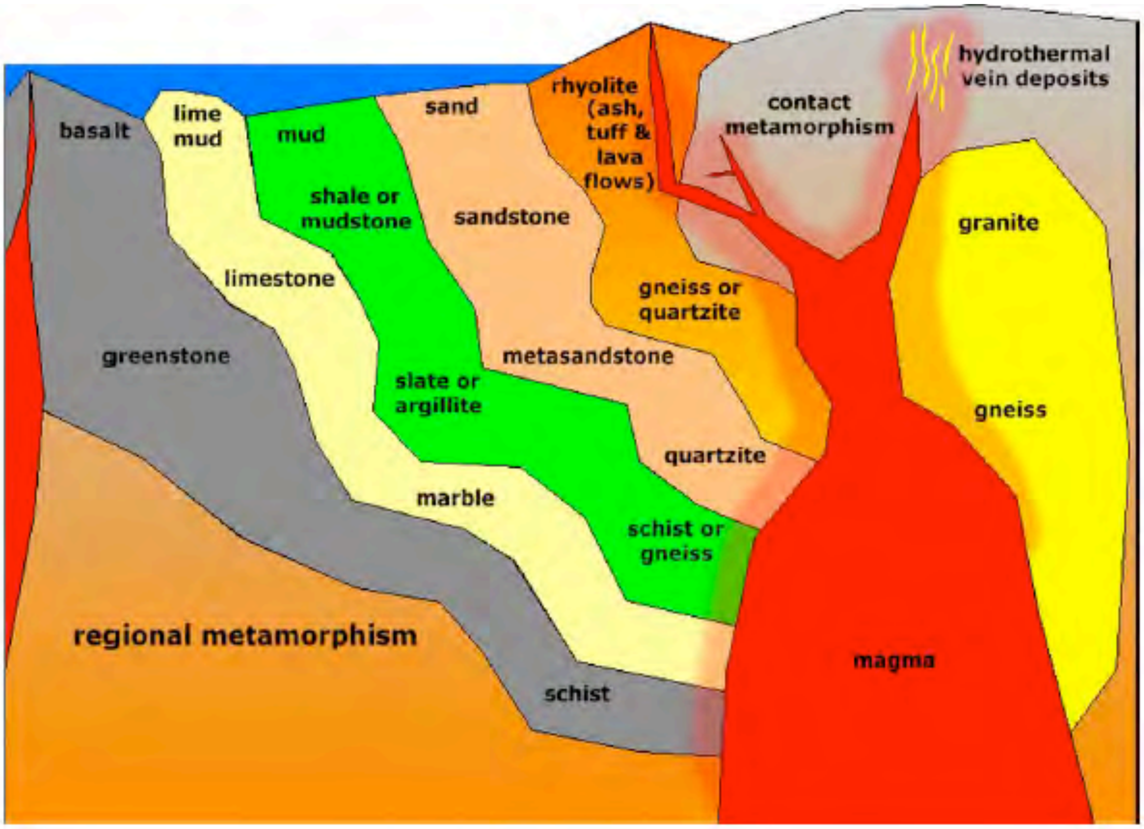


General Summary of Sedimentary Environments and Rock Types

(USGS, 2002)

Terrestrial Environments	**Sediments**	**Rock Types**
Alluvial Fan	Gravel, Sand, Silt, Clay	Conglomerate, Sandstone
River Channel	Gravel, Sand	Conglomerate, Sandstone
Deltas, Swamps	Sand, Silt, Clay	Sandstone, Siltstone, Claystone
Beach, Tidal, Barrier Bar	Sand, Clay	Sandstone, Claystone
Desert, Dunes, Playas	Gravel, Sand, Silt, Evaporites	Conglomerates, Sandstones, Siltstones, Gypsum and Salt Beds
Marine Environments		
Estuary	Sand, Silt, Clay	Sandstone, Siltstone, Claystone
Continental Shelf	Sand, Silt, Clay	Sandstone, Siltstone, Claystone
Continental Shelf	Carbonate Reefs	Limestone
Abyssal Plain	Fine Sand, Clay Carbonates	Deep Sea Muds, Chert, Carbonate Ooze

Metamorphic Rock Formation, Depth Near Surface to roughly 20 miles
(USGS, 2002)



Existing rocks are altered by heat and pressure near continental edges and in subduction zones. As more heat and pressure are applied rocks undergo chemical changes and may become recrystallized. The original rock may lose its original appearance and could be completely melted. As a general rule the more deeply buried, heated and deformed the rocks are more highly metamorphosed as the diagram shows.

Local or contact metamorphism also occurs at margins of volcanoes when magma intrudes rock. The heat in the near proximity of the intruding rock alters both rocks at the contact zone. This metamorphism zone may extend from inches to hundreds of feet thick and can deposit ore veins and bodies with hydrothermal fluids. Contact metamorphism can deposit valuable ore minerals depending upon rock type with favorable lithology and chemistry.