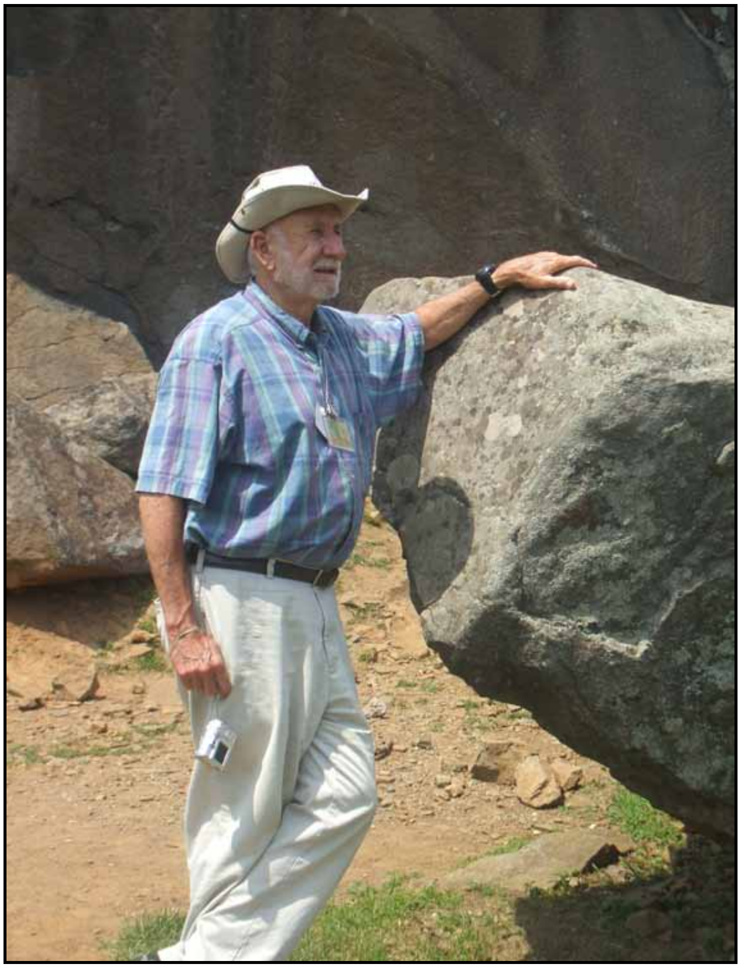
GEOLOGY, NATURAL GAS POTENTIAL, AND MINERAL RESOURCES OF LEE, CHATHAM, AND MOORE COUNTIES, NORTH CAROLINA

Timothy W. Clark, Kenneth B. Taylor, & Philip J. Bradley

Carolina Geological Society
FIELD TRIP GUIDEBOOK
October 22-23, 2011

The 2011 Carolina Geological Society Field Trip and Guidebook is dedicated to the memory of

CHARLES H. GARDNER
1937-2011



North Carolina State Geologist
1990-2002

"He stood in awe of the beauty of nature"

CAROLINA GEOLOGICAL SOCIETY
2011 FIELD TRIP

GEOLOGY, NATURAL GAS POTENTIAL, AND MINERAL RESOURCES OF LEE, CHATHAM, AND MOORE COUNTIES, NORTH CAROLINA

OCTOBER 22-23, 2011
ABERDEEN, NC

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Cabot Oil & Gas

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Cover Figure:
Pekin Formation exposed in the inactive Boren Clay Product pit. Photo by Jeffrey C. Reid

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Saturday October 22:

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DEPOSITIONAL AND STRUCTURAL FRAMEWORK OF THE DEEP RIVER TRIASSIC BASIN, NORTH CAROLINA

Disclaimer: *The following article was originally published as part of a Field Trip Guide for the 50th Annual meeting of the Southeastern Section of the Geological Society of America, April 2001, p. 27-50. It has been included in this guidebook as is, without any editorial changes to the text. However minor reformatting was necessary to accommodate different page sizes. References should be made to Clark and others (2001).*

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INTRODUCTION

The Deep River Triassic basin has one of the longest recorded histories of geologic research in North Carolina, starting with the work of Olmsted in 1820. Since that time, numerous investigations have attempted to unravel the complex nature of the basin's geology and mineral resources. As a result, varying methods of geologic mapping and stratigraphic nomenclature are found throughout the published literature. These differences typically manifest themselves by one particular map area using one particular system of stratigraphic nomenclature, with an adjacent map area using a different and incompatible system of nomenclature. Because of these incompatibilities, no basin-wide compilation of the entire Deep River basin has ever been produced using one standard system of map units and stratigraphic nomenclature.

This article highlights recent work to develop a standardized method of mapping that is flexible enough for the wide variety of lithologies and depositional environments encountered throughout the Deep River basin. Smoot and others (1988) proposed a system of uniform map symbols for all of the Mesozoic rift basins along the Atlantic margin of North America. The North Carolina Geological Survey (NCGS) adopted this system during recent geologic mapping in the Durham basin. This system uses map units called *lithofacies*, which can be composed of one to several different rock types (e.g., sandstone, siltstone, and mudstone). Similar *lithofacies* can be grouped together to form a *lithofacies association,* based on both lithology and interpreted depositional environment.

The lithofacies system of mapping differs slightly in organization and definition from the more traditional North American Stratigraphic Code units of *formation, member,* and *bed*. The Deep River basin lacks an abundance of good maker beds or horizons for assigning strata to a specific formation or member. This is primarily due to the gradational nature of lithologic contacts common in rift basin environments. Facies are laterally gradational and the same lithostratigraphic unit can vary from conglomerate to siltstone across the basin. Since the lithofacies system of stratigraphic nomenclature is unfamiliar to many geologists, this article compares and contrasts the various systems of geologic mapping currently used in the Deep River basin.

GENERAL GEOLOGIC SETTING

The Deep River basin, located in the east central Piedmont of North Carolina, resulted from early Mesozoic rifting of the supercontinent Pangea. This rifting created a series of irregularly-shaped half-graben along the Atlantic margin of North America. The Deep River basin is the southern-most exposed of these basins (Fig. 1). During rifting, the basin filled with a variety of Late Triassic clastic sediments, their depositional environments strongly controlled by local basin tectonics. Alluvial fans prograded into the basin from the topographically-higher, faulted margins. Sediment was transported along the basin axis by meandering river systems and deposited in large alluvial plains. Freshwater lakes formed in basin depocenters, accumulating deltaic (delta), lacustrine (lake), and paludal (swamp) deposits.

The deposits of the Deep River basin were buried and lithified, and are now recognized as the Chatham Group, part of the Newark Supergroup (Fig. 1) as defined by Olsen (1978) and Luttrell (1989). The Chatham Group in the Deep River basin consists of varying amounts of conglomerate, sandstone, siltstone, claystone, shale, coal, and small amounts of limestone and chert (and gypsum in cuttings from several wells).Bedding generally dips east to southeast, but local variations are common, especially near faults and dikes. Thus, the lowermost (oldest) strata typically occur on the western side of the basin and the uppermost (youngest) strata occur on the east.

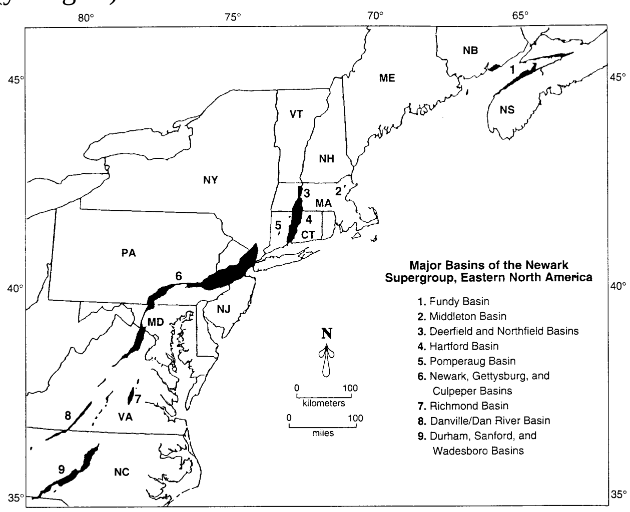


Figure 1. Exposed early Mesozoic basins of the Newark Supergroup. Note the Deep River basin (9) is listed by its three component basins (Durham, Sanford, and Wadesboro). Figure from McDonald (1996), after Unger (1988).

The Deep River basin is a north to northeast trending half graben. It is bordered on the east by the Jonesboro fault, a west-dipping high-angle, normal fault (Campbell and Kimball, 1923) that separates the Triassic sedimentary rocks from the Raleigh metamorphic belt and the Carolina zone metavolcanic and metasedimentary rocks (Fig. 2). The total amount of displacement along the fault is unknown but estimated to be a minimum of 3.0 to 4.5 kilometers of dip-slip displacement, depending on location (Campbell and Kimball, 1923; Reinemund, 1955; Bain and Harvey, 1977; Parker, 1979; Bain and Brown, 1980; Hoffman and Gallagher, 1989). Bain and Brown (1980) suggested that the Jonesboro is actually a fault zone, characterized by step faulting along numerous individual faults, with rider blocks occurring between these faults. Clark (1998) showed that the Jonesboro fault plane itself is extremely sharp, commonly with a 1-3 meter wide gouge zone of clay and foliated breccia in the footwall.

Several intra-basinal faults, both synthetic and antithetic to the Jonesboro, are also recognized throughout the basin (Fig. 2). Along the basin's western margin, sedimentary rocks of the basin unconformably overlie Late Proterozoic and Cambrian metavolcanic and metasedimentary rocks (NCGS, 1985). Minor (post-depositional?) faults also form the basin boundary locally along the western border.

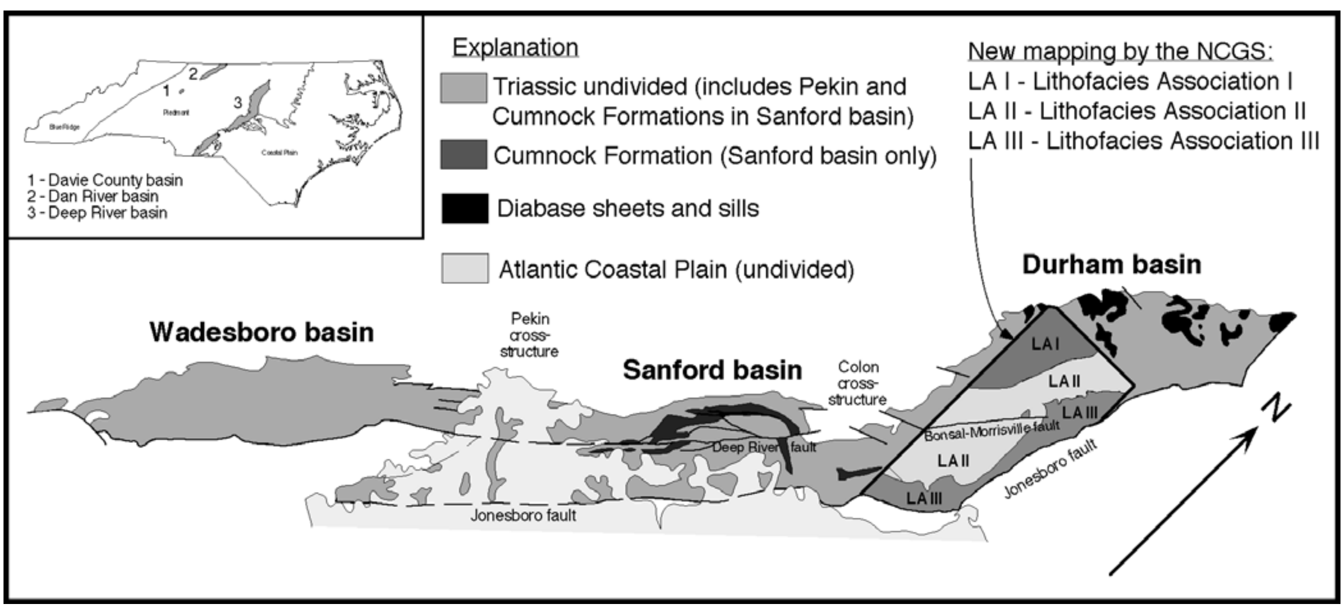


Figure 2. Generalized geologic map of the Deep River basin, NC. Modified from Reinemund (1955), Bain and Harvey (1977), NCGS (1985), Olsen and others (1989, 1991), Hoffman and Gallagher (1989), Clark (1998), and Watson (1998).

The Deep River basin is subdivided into three smaller basins, the Durham, Sanford, and Wadesboro basins, from north to south, respectively (Fig. 2). The boundaries of these smaller, component basins are undefined. The width of the Deep River basin dramatically narrows at the Colon cross-structure (Fig. 2), a basement high that separates the Durham basin from the Sanford basin (Campbell and Kimball, 1923).

The Colon cross-structure is well constrained by field mapping and seismic reflection data. Analyses of these data suggest that it formed by differential subsidence of the Durham and Sanford basins (Reinemund, 1955, Bain and Harvey, 1977, Dittmar, 1979). Slightly different lithologies occur on either side of the Colon cross-structure, suggesting that it may have acted as a barrier to sedimentation. A similar structure, the Pekin cross-structure, has been proposed between the Sanford and Wadesboro basins (Fig. 2). The existence of the Pekin cross-structure is speculative due to a thin veneer of Atlantic Coastal Plain sediments that blankets the area, as well as a lack of good subsurface data.

DEVELOPMENT OF MAP UNITS

A quick perusal of nineteenth and early twentieth century geologic literature in North Carolina reveals that the Deep River basin has received a tremendous amount of attention, second only, perhaps, to the gold deposits of the Carolina slate belt. This interest is attributed to the discovery of coal along the Deep River and the extensive efforts to determine its extent and recoverability. While these early researchers' primary interests were the coal deposits, many other important discoveries, observations, and hypotheses resulted from their investigations. The most noteworthy contributions are by Olmsted (1820, 1824), Emmons (1852,1856), and Wilkes (1858).

Emmons (1852) was the first to recognize and map lithologic units in the Sanford basin. He identified an upper and lower unit of red sandstone and conglomerate separated by a finer-grained unit of gray sandstone, black shale, and coal. Campbell and Kimball (1923) modified Emmons' work and formally named the three units the Pekin, Cumnock, and Sanford Formations, providing type localities for each of the formations (Fig. 3). Although Campbell and Kimball applied these names throughout the Deep River basin, their use today is applied only to the Sanford basin.

Campbell and Kimball (1923) also identified and described type localities of the Jonesboro, Deep River, and Carbonton faults. Although an inadequate understanding of rift basin development flawed many of their conclusions, the work of Campbell and Kimball should be regarded as the first modern foundation in our understanding of the Sanford basin.

Reinemund (1955) built on Campbell and Kimball's stratigraphic framework with the addition of detailed surface mapping and subsurface data from coalmines and exploratory coreholes. The U.S. Bureau of Mines drilled 8 coreholes totaling 11,890 feet into the Cumnock Formation between 1944 and 1948. In addition, Walter Bledsoe and Company drilled 11 coreholes in 1945-1946. This data, combined with observations from the numerous coal mines in the area, greatly increased the understanding of the basin's subsurface.

Reinemund's compilation of this information (1955) includes a thorough mining history of the area as well as technical data on coal quality and mine conditions. In addition to the three-sheet color geologic map of the region, the report presents detailed geologic surface mapping and subsurface mine mapping of the Carolina mine, concentrating on the extent and thickness of coal, faulting, and diabase intrusions. Reinemund also provides detailed discussions of the Pekin, Cumnock, and Sanford Formations and their depositional environments. This all-encompassing compilation still stands today as the most comprehensive report about the Sanford basin. At the time of this writing, copies were still available from both the U.S. Geological Survey and the North Carolina Geological Survey.

Later researchers learned that the three-layer system of formations in the Sanford basin was not present in the Durham or Wadesboro basins. Randazzo and others (1970) did recognize a "coarse-fine-coarse" sequence similar to that of the Sanford basin (Fig. 3), but did not produce any detailed geologic maps depicting the extent of the deposits. No other investigations of the Wadesboro basin have occurred since that time.

In the Durham basin, Bain and Harvey (1977) identified seven mappable "facies" (Fig. 3). These facies were later consolidated into four facies during compilation of the 1985 State Geologic Map (NCGS, 1985). These facies were subsequently replaced entirely during NCGS geologic mapping of the southern and central Durham basin using the Smoot and others (1988) lithofacies system of nomenclature.

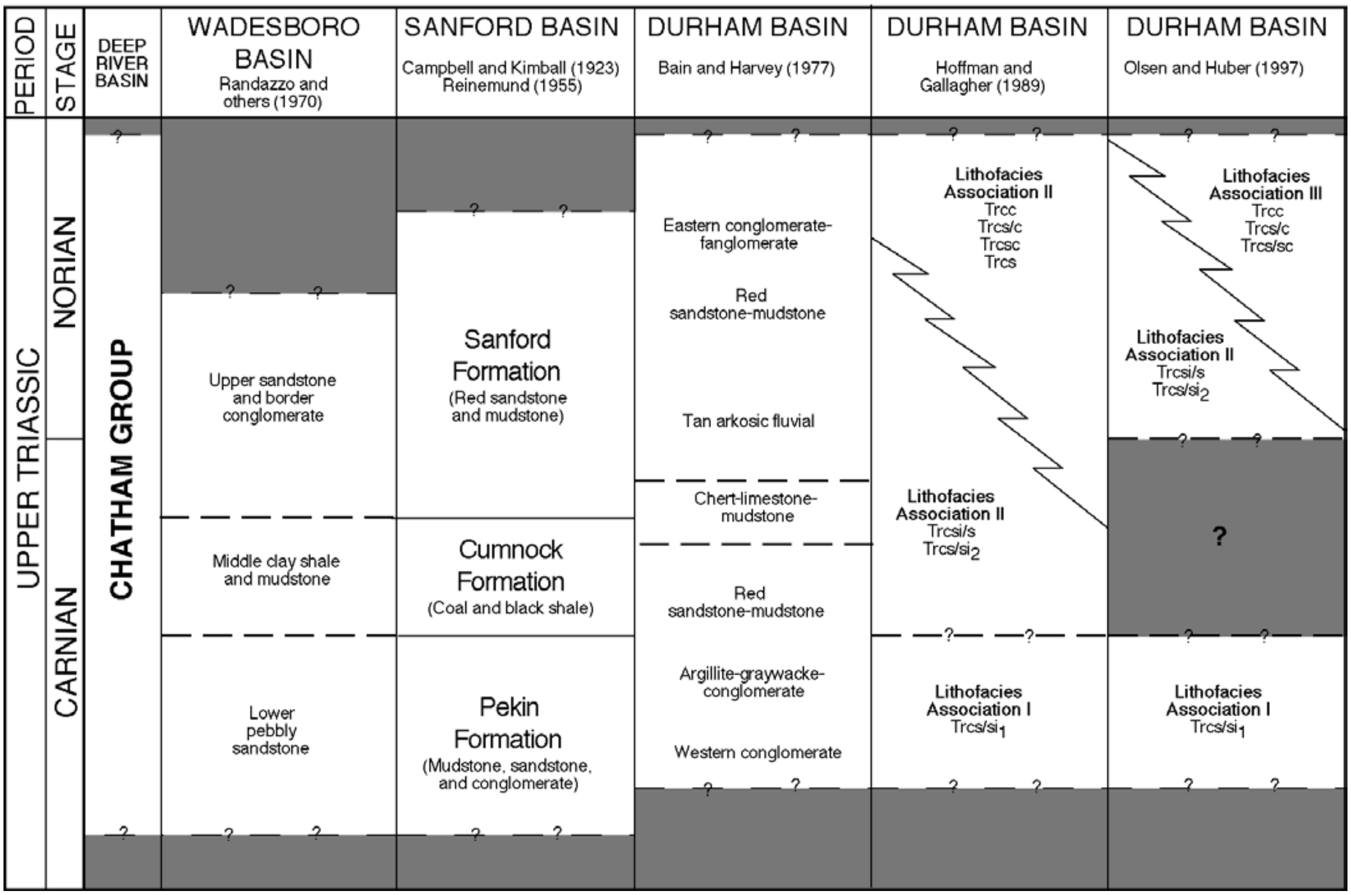


Figure 3. Stratigraphy of the Chatham Group in the Deep River basin of North Carolina and South Carolina. Modified after Olsen and others (1991), Huber and others (1993), Olsen and Huber (1997), and Clark (1998).

In the 1980's, multiple investigators conducted abundant sedimentological and paleontological work in the in the Sanford and Durham basin. Gore (1986) provides a good compilation of these researchers' work along with site-specific details at several locations throughout both basins. Their work refined the depositional framework of the Sanford and Durham basins within the context of the two different systems of stratigraphic nomenclature currently in place. Since none of these investigations included detailed geologic mapping, no new map units were produced.

Hoffman and Gallagher (1989) conducted detailed geologic mapping in the central Durham basin utilizing the lithofacies system of Smoot and others (1988). Further mapping by Clark (1998) and Watson (1998) extended Hoffman and Gallaghers's lithofacies map units from the central Durham basin south to the Colon cross-structure. Here, the lithofacies mapping of Clark (1998) abuts the formation mapping of Reinemund (1955), resulting in an incompatible match of map units. The mapping of Bain and Harvey (1977) is still used in the northern Durham basin since detailed geologic mapping there is not yet underway. Detailed geologic mapping is completely absent from the Wadesboro basin and stratigraphic units are only generally defined (Randazzo and others, 1970).

As a result of these different styles and types of mapping, no basin-wide system of stratigraphic nomenclature exists for the Deep River basin. This work is an attempt to link these systems of stratigraphic nomenclature in the Sanford and Durham basins together through the use of lithologic descriptions, correlation diagrams, and map patterns, all derived from detailed geologic mapping. The stratigraphic units of the Sanford and Durham basin are presented first, followed by a brief summary discussion of the stratigraphic correlation between the two basins.

STRATIGRAPHY OF THE SANFORD BASIN

The three formations currently recognized in the Sanford basin are the Pekin, Cumnock, and Sanford Formations, in ascending stratigraphic order (Fig. 4). The Pekin and Sanford Formations are dominated by fluvial and alluvial fan deposits and the Cumnock Formation is dominated by lacustrine (lake) and paludal (swamp) deposits. These formations grade into one another, and are in part lateral facies equivalents (Gore, 1986). The best descriptions of Pekin, Cumnock, and Sanford Formations are provided by Gore (1986) and are summarized below.

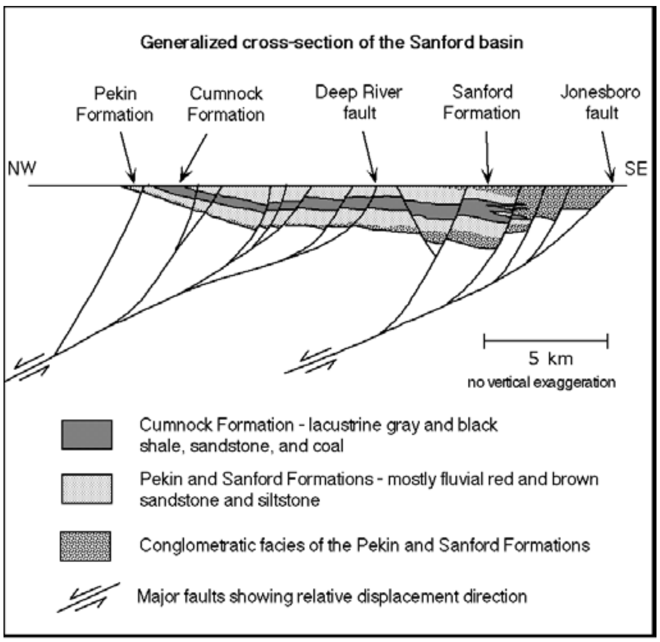


Figure 4. Generalized cross section of the Sanford basin showing the Pekin, Cumnock, and Sanford Formations and the approximate locations of the Jonesboro and Deep River faults. Based largely on seismic profiles and deep drill hole data. Modified from Olsen (1991).

The formations can be traced northeastward towards the Colon cross-structure but the Cumnock grades into coarser-grained sediments very similar to the Pekin and Sanford Formations, and cannot be traced into the Durham basin (Fig. 2). The Cumnock is absent throughout most of the Colon cross-structure, and the contact between the Pekin and Sanford Formations is difficult to position because of their lithologic similarity.

Herein lies one of the failings of the traditional system of formational, stratigraphic nomenclature. The Pekin and Sanford Formations are so lithologically similar, that they cannot be discerned from one another except when the Cumnock Formation is present between them.

Pekin Formation

The Pekin Formation is present along the western border of the Sanford basin and is dominated by red terrigenous clastics. The formation is between 542 to 1240 meters thick, depending on location in the basin. The base of the Pekin contains a distinctive gray, quartz-rich conglomerate, up to 10 m thick, known as the “millstone grit” (Reinemund, 1955). Stagg (1984) determined the “millstone grit” was derived from the Carolina zone to the west. The “millstone grit” is interpreted as an alluvial fan deposit that formed under humid conditions (Textoris and others, 1986). The remainder of the Pekin Formation is dominated by red, brown, and maroon cross-stratified sandstone, siltstone, and mudstone with minor conglomerate and shale, interpreted as fluvial and floodplain deposits (Reinemund, 1955). Wells near the center of the basin (Butler #1 well, V. R. Groce #1 well) show nodular and bedded gypsum associated with light brown to red shales and conglomerates in the lower Pekin Formation, interpreted as playa lake deposits. Near the center of the Pekin Formation in the northern part of the basin near Gulf, gray sandstone, siltstone, and shale are present indicating deposition in a reducing environment, probably in a shallow floodplain lake.

Spectacular plant fossils occur in gray siltstone beds of the Pekin Formation at the Boren Clay Company pit near Gulf (Hope and Patterson, 1969a; Delevoryas, 1970; Hope, 1970; Hope and Patterson, 1970; Delevoryas and Hope, 1971, 1973; Schultz and Hope, 1973; Hope, 1975, 1977; Gensel, 1986). Several vertebrate fauna, footprints, and trackways have also been described in the area (Baird and Patterson, 1967; Patterson, 1969; Olsen and Galton, 1977; Olsen and others, 1989; Olsen and others, 1991). A reconsideration of these flora and fauna assemblages by Olsen and Huber (1997) suggests an early Tuvalian (early Late Carnian) age for the middle Pekin Formation. They also hypothesized that a syn-rift unconformity exists between the middle Pekin and the upper Pekin, largely based on vertebrate biostratigraphy. A similar syn-rift unconformity is recognized in the Newark, Richmond, Taylorsville, and Fundy basins of the Newark Supergroup and the Argana basin of Morocco (Olsen, 1997).

Cumnock Formation

The Cumnock Formation overlies the Pekin Formation in the middle and northeastern portions of the Sanford basin. The Cumnock is a distinctive unit approximately 230 to 250 m thick, dominated by black and dark gray shale, with associated gray sandstone and coal (Reinemund, 1955). The lower part of the Cumnock is dominated by gray siltstone and fine sandstone with minor shale and claystone. These beds are in part laterally equivalent to the upper Pekin Formation and probably represent a deltaic complex (Gore, 1986; Olsen and Huber, 1997).

Approximately 60 to 80 m above the base of the Cumnock, two major coal seams (and several thinner seams) are present. The lower Gulf coal seam consists of one bed ranging from a few centimeters to nearly 1 m thick. The upper Cumnock coal seam consists of three beds ranging from 1 to 3 m thick. The coal beds are thickest in the northwestern part of the Sanford basin, approximately 5 km northeast and southwest of Gulf (Reinemund, 1955). The coal-bearing interval is overlain by 150 to 155 m of locally calcareous and carbonaceous gray and black shale with minor claystone, siltstone, and sandstone (Reinemund, 1955). The middle Cumnock Formation was deposited in a large, hydrologically-open, quiet-water lacustrine environment (Gore, 1986; Gore 1989). The thick sequence of black lacustrine shale overlying the coal appears to represent a profundal (deep-water) lacustrine environment, apparently uninterrupted by major transgressions and regressions, subaerial exposure, paleosol development, or fluvial deposition (Gore, 1989). The open-basin model is also based on the absence of evaporites in the Cumnock, and the presence of siderite concretions, which form in low-sulfate, freshwater lakes (Gore, 1989).

The upper part of the Cumnock is dominated by gray shale, siltstone and fine sandstone, grading upward into red and brown fluvial deposits of the Sanford Formation. This probably represents a delta or shoreline prograding into the lake from the southeast.

Hu and Textoris (1994) found evidence of sedimentary cycles in wells through the Cumnock Formation, using gamma-ray logs. They interpreted these cycles to be related to astronomically-controlled climate change, corresponding to the Van Houten cycles noted in other Newark Supergroup basins (Olsen, 1996). Astronomically-induced climate changes led to changes in precipitation, which caused the expansion and contraction of a hydrologically-open lake. The climate did not become dry enough, however, to produce red evaporitic subaerial cycles that are found in some of the northern Newark Supergroup basins (Hu and Textoris, 1994). Hu and Textoris (1994) also identified five lithofacies within the Cumnock, interpreted as lacustrine deposits, turbidites, deltaic deposits, paludal or swamp deposits, and basin-margin sands.

Abundant non-marine invertebrate and vertebrate fossils are documented in the Cumnock (Emmons, 1852, 1856, 1860; Baird and Patterson, 1967; Patterson, 1969; Swain and Brown, 1972; Olsen and others, 1982; Gore, 1985a, 1985b). The invertebrates include conchostracans or clam shrimp, ostracodes, and insects. Vertebrates include fish, amphibians, reptiles, dinosaurs, and mammal-like reptiles. Vertebrae, ribs, teeth, and portions of a cranium of the phytosaur *Rutiodon* have been collected from coaly shale in the lower Cumnock Formation. Traverse (1986) and Robbins and Textoris (1986) reported a late Julian (middle Carnian) age based on pollen and spores, but Olsen and Huber (1997) reassigned the Cumnock (and uppermost Pekin) as late Tuvalian (middle to late Carnian).

Sanford Formation

The Sanford Formation conformably overlies the Cumnock Formation and is exposed in the central and southeastern part of the Sanford basin. The Sanford Formation is a 930 to 1240 m thick sequence dominated by lenticular beds of red to brown terrigenous clastics, including claystone, mudstone, siltstone, fine-grained sandstone, and conglomerate (Reinemund, 1955). There are few distinctive beds, and no consistently mappable subdivisions within the formation (Reinemund, 1955). Lenticular beds of gray, coarse-grained to conglomeratic, arkosic sandstone are present in the lower 425 to 490 m of the formation, decreasing towards the southwest. Red to brown, coarse-grained, arkosic sandstone and conglomerate, with associated claystone, siltstone, and fine-grained sandstone dominate the upper 300 meters of the Sanford Formation. Grain size coarsens to the southeast, and conglomerate units, interpreted as alluvial fan deposits, are present along the southeastern edge of the basin adjacent to the Jonesboro fault. Fossils are scarce in the Sanford Formation. Gore (1986) documented one the few known fossil localities.

STRATIGRAPHY OF THE DURHAM BASIN

The map units recognized in the Durham basin differ greatly from those of the Sanford basin. Unlike the Sanford basin, no formal formations are identified in the Durham basin, largely due to the absence of good marker beds equivalent to the Cumnock Formation.

Bain and Harvey (1977) proposed the first map units internal to the Durham basin, based on reconnaissance-level mapping. The NCGS (1985) later consolidated these into four facies for the State Geologic Map. These four facies are 1) Tan arkosic sandstone facies, 2) Red sandstone-mudstone facies, 3) Chert-limestone-mudstone facies, and 4) Border conglomerate facies. However, during detailed geologic mapping of the central Durham basin (Southeast and Southwest Durham 7.5-minute quadrangles), Hoffman and Gallagher (1989) found these facies, as defined, inadequate for describing the rocks in their map area. They found that several of these facies could be subdivided even further into more specific map units. They subsequently adopted Smoot and others' (1988) lithofacies system of nomenclature for consistency with other geologic mapping throughout the Newark Supergroup.

As a result of their mapping, Hoffman and Gallagher (1989) identified seven distinct lithofacies in the central Durham basin. These lithofacies were grouped in three lithofacies associations, labeled Lithofacies Association I (LA I), Lithofacies Association II (LA II), and Lithofacies Association III (LA III), roughly in ascending stratigraphic order (Fig. 5). Olsen and Huber (1997) proposed an unconformity might exist between LA I and LA II based on vertebrate fossil assemblages (see figure 3). An intertonguing relationship likely exists between LA II and LA III.

In general, LA I contains interbedded sandstone and siltstone and is interpreted as braided stream deposits (Fig. 5). LA II also contains interbedded sandstone and siltstone, but it is interpreted as a meandering fluvial system surrounded by a vegetated floodplain (Fig. 5). LA III contains poorly sorted sandstone, pebbly sandstone, and conglomerate. LA III is interpreted as alluvial fan complexes characterized by broad, shallow channels with high sediment concentrations, and locally, high-energy debris flows (Fig. 5).

The lithofacies terminology of Smoot and others (1988) used by Hoffman and Gallagher (1989) names individual lithofacies by combining the unit's age,

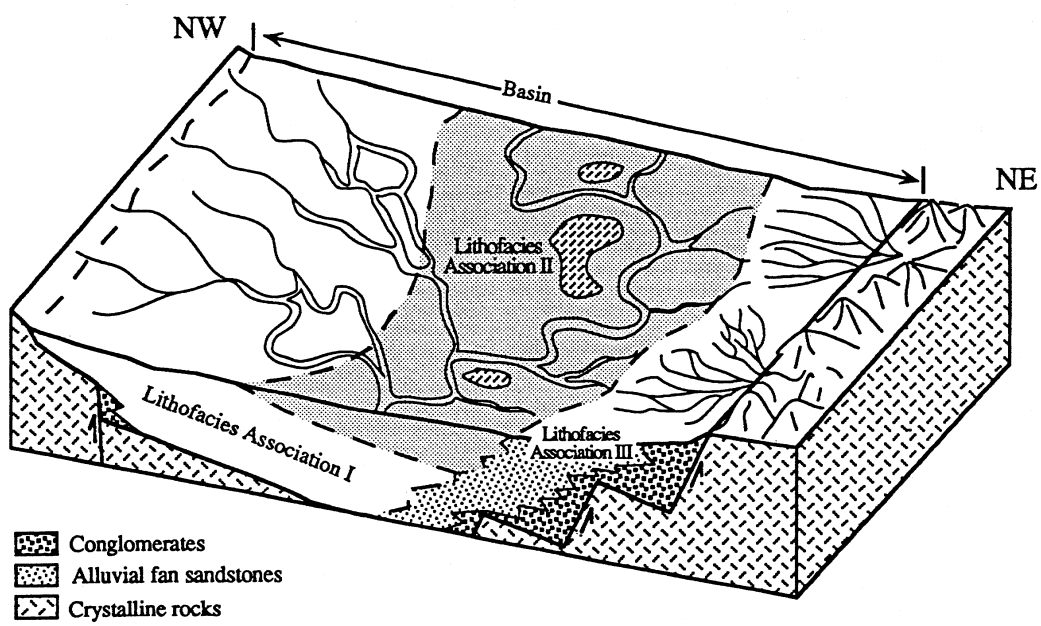


Figure 5. Schematic block diagram illustrating a conceptual model for the distribution of lithofacies associations in the central Durham basin. Lithofacies Association I represents braided stream deposits, Lithofacies Association II represents a meandering river system in a vegetated floodplain, and Lithofacies Association III represents alluvial fan deposits (from Hoffman, 1994).

group, and lithology into one map unit abbreviation. The prefixes for age (Tr = Triassic) and group (c = Chatham Group) are common to all Triassic lithofacies in the Durham basin. The remainder of the unit name is reserved for the dominant lithology (i.e., si = siltstone, s = sandstone, sc = pebbly sandstone, c = conglomerate). Interbedded lithologies are separated by a slash, dominant lithology given first (i.e., s/c = interbedded sandstone and conglomerate). Similar lithofacies of different lithofacies associations are notated by subscript numerals (i.e., $Trcs/si_1$ vs. $Trcs/si_2$).

Mapping by Watson (1998) extended some of Hoffman and Gallagher's lithofacies into the central Durham basin (Green Level 7.5-minute quadrangle). Clark (1998) also utilized the lithofacies system in the southern Durham basin (Cary, New Hill, Cokesbury, Apex, and Fuquay-Varina 7.5-minute quadrangles). Clark (1998) found that two lithofacies of Hoffman and Gallagher (1989), Trcs (sandstone) and Trcsc (pebbly sandstone), were so intermixed in map pattern that he combined them into one mappable unit, Trcs (interbedded sandstone and pebbly sandstone). All other map units are consistent with Hoffman and Gallagher (1989) and Watson (1998).

A discussion of each of the map units in the central and southern Durham basin, along with their interpreted depositional environments, follows.

Lithofacies Association I

Lithofacies Association I is interpreted as sandy, braided channel belts intercalated within thick sequences of heavily bioturbated siltstones, mudstones, and fine-grained sandstone lenses representing vegetated, flood basin facies (Hoffman and Gallagher, 1989; Watson, 1998). They further interpret LA I as representing deposition by anastomosing streams on a muddy floodplain (Fig. 5). LA I consists of a single, mappable lithofacies: sandstone with interbedded siltstone ($Trcs/si_1$).

$Trcs/si_1$ - Sandstone with Interbedded Siltstone

This lithofacies consists of 1) pinkish-gray to light-gray, fine- to medium-grained, micaceous arkoses and lithic arkoses; 2) pale red, muddy, fine-grained sandstones; and 3) reddish-brown, bioturbated siltstones and mudstones. Fine-grained biotite and very fine-grained heavy minerals are distinctive accessories. Fine- to coarse-grained muscovite is also common, though not diagnostic to this facies.

Sequences of sandstone, one- to more than five-meters thick, contain fining-upward cosets of trough crossbeds (Fig. 6). Individual cosets decrease in thickness from the base of a sequence to the upper portions. The base of these sequences is sharp or scoured. Sandstone overlying the erosional base is pebbly, granular, or very coarse-grained, and contains abundant mudstone intraclasts scattered along scour surfaces. Locally, along the shoreline of Jordan Lake, the tough crossbedded sandstone fines upward into ripple-laminated, very fine-grained sandstone and siltstone.

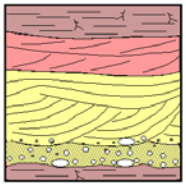
Bioturbation is extensive in the finer-grained siltstones and mudstones and within the thinner, sandy beds of this facies. Light greenish-gray, threadlike bifurcating horizontal mottles and/or vertical to oblique mottles (elliptical in diameter and interpreted as root marks) are common to ubiquitous. Meniscate *Scoyenia* burrows and other sand or mud in-filled burrows are common, extending downward from the upper surfaces of beds. Locally, thin zones of carbonate nodules (interpreted as caliche and indicating an arid to semi-arid climate), ferric concretions, and platy to curved fractures occur within the sequences of finer-grained strata (interpreted as paleosols?).

Lithofacies Association II

Lithofacies Association II is interpreted as deposits of a meandering fluvial system flowing into a deltaic and lacustrine depositional environment (Fig. 5). LA II is dominated by 1 to 4 meter-thick, fining-upward, trough cross-bedded channel sequences scoured into underlying fine-grained siltstone (Fig. 6). Grain size of the deposits gradually increases from west to east in the area west of the town of Apex until the siltstone component can no longer be found. Conglomeratic basal lags in these channel complexes can have clasts in excess of 20 cm in diameter.

Lithofacies Association II consists of two similar lithofacies: 1) sandstone with interbedded siltstone ($Trcs/si_2$) and 2) siltstone with interbedded sandstone (Trcsi/s). The subscript numeral 2 differentiates the $Trcs/si_2$ lithofacies from the similar sandstone and interbedded siltstone ($Trcs/si_1$) of Lithofacies Association I. An arbitrary break of 50% sandstone verses siltstone separates LA II into its two component lithofacies.

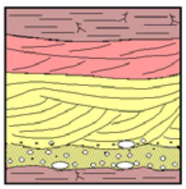
Lithofacies Association I



Trcs/si$_1$:
sandstone w/ interbedded siltstone

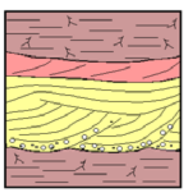
Sandstone sequences represent sandy braided streams, surrounded by thick sequences of heavily bioturbated siltstone, suggesting channel avulsion on a muddy floodplain.

Lithofacies Association II



Trcs/si$_2$:
sandstone w/ interbedded siltstone

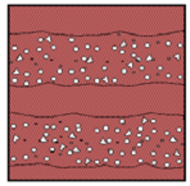
Lateral point bar aggradation within a meandering fluvial system surrounded by a vegetated floodplain. Abundant potassium feldspar and muscovite and coarse- to very coarse-grain size suggests a granitic source area.



Trcsi/s:
siltstone w/ interbedded sandstone

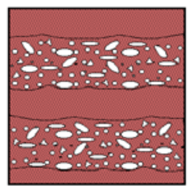
Fluvial overbank deposits with locally developed, areally limited, ephemeral, shallow, freshwater lakes. This facies may represent a local lowland away from the main fluvial belt or a change to muddier conditions in the later stages of LA II deposition.

Lithofacies Association III



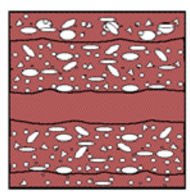
Trcs:
interbedded sandstone & pebbly sandstone

Deposition in broad shallow channels incised into muddy flats. Muddy, matrix-supported sandstones may also represent distal debris flow deposits or hyperconcentrated stream flow deposits. Some deposits may be low-viscosity debris flows.



Trcs/c:
sandstone w/ interbedded conglomerate

Deposition in broad shallow channels by streams with high sediment concentrations or as debris flows or as both. Streams that deposited this facies were apparently larger and deeper than those that deposited the Trcsc facies.



Trcc:
conglomerate

Debris flow deposits and channel deposits associated with alluvial fans developed along the Jonesboro fault scarp.

Figure 6. Lithofacies found in the Durham basin. Lithofacies Association I is interpreted as braided stream deposits. Lithofacies Association II is interpreted as a meandering fluvial system. Lithofacies Association III is interpreted as alluvial fan and related deposits. Based on interpretations of Hoffman and Gallagher (1989).

$Trcs/si_2$ - Sandstone with Interbedded Siltstone

This unit consists of cyclical depositional sequences composed of whitish-yellow to grayish-pink to pale red, coarse- to very coarse-grained, trough cross-bedded lithic arkose that fines upward through yellow to reddish-brown, medium- to fine-grained sandstone, to reddish-brown, burrowed and rooted siltstone (Fig. 6). Bioturbation is usually surrounded by greenish-blue to gray reduction halos. Coarse-grained portions contain abundant muscovite, and basal gravel lags consist of clasts of quartz, bluish-gray quartz crystal tuff, and mudstone rip-ups.

Exposures of the $Trcs/si_2$ lithofacies are deeply weathered owing to the unit's high feldspar and muscovite content. The high feldspar content suggests that the lithofacies was derived from a different source area than LA III. Exposures are usually limited to man-made outcrops, creating large data gaps in areas of little human disturbance. Topography in the $Trcs/si_2$ map unit generally consists of low, rounded ridges with few surface streams. This unit is one of the few in the entire Deep River basin suitable for farming. The boundaries of this map unit can be crudely determined by tracing on a U. S. Geological Survey topographic map the extent of the "white areas", which indicate open areas (usually farms).

Trcsi/s - Siltstone with Interbedded Sandstone

This unit consists of reddish-brown, extensively bioturbated, muscovite-bearing, siltstone interbedded with tan to brown, fine- to medium-grained, muscovite-bearing, arkosic sandstone, usually less than one meter thick (Fig. 6). Siltstones can contain abundant, bedded, calcareous concretions (interpreted as caliche) and iron nodules. Bioturbation is usually surrounded by greenish-blue to gray reduction halos.

The Trcsi/s lithofacies, due to its fine grain size, is not very resistant to erosion. Topography in this map unit usually consists of broad, flat areas, with little to no surface streams. The unit is poorly exposed except for excavations in brick pits.

The Triangle Brick pit in the Trcsi/s lithofacies is a world-class locality for both continental invertebrates and vertebrates, particularly reptiles (Olsen, 1977; Renwick, 1988; Gore and Renwick, 1987; Olsen and others, 1989; Good and Huber, 1995, Olsen and Huber, 1997). Recovered specimens include fragmentary plants, clams, crayfish, fish, reptile (phytosaur) teeth, and abundant coprolites.

Olsen (1977), Olsen and others (1982), and Olsen and others (1989) argued that the presence of the fish *Turseodus* in the Triangle Brick quarry indicated a late Carnian age, similar to that of the Cumnock Formation in the Sanford basin. However, Huber and others (1993) pointed out that *Turseodus* ranges throughout the Carnian and Norian, and therefore was of limited time-stratigraphic value. Huber and others (1993) instead suggested that the presence of *Stegomus* in the Triangle Brick quarry indicated an early to middle (?) Norian age (Olsen and Huber, 1997). If the Triangle Brick quarry deposits are indeed Norian in age, they are significantly younger than Cumnock Formation of late Carnian age.

Lithofacies Association III

Lithofacies Association III, as defined by Hoffman and Gallagher (1989), consists of four lithofacies: 1) sandstone (Trcs); 2) pebbly sandstone (Trcsc); 3) sandstone with interbedded conglomerate (Trcs/c); and 4) conglomerate (Trcc). Clark (1998) found the sandstone and pebbly sandstone lithofacies so intermixed in the southern Durham basin, he combined them into one map unit. This lithofacies is termed Trcs - interbedded sandstone and pebbly sandstone.

LA III is interpreted as an alluvial fan complex (Fig. 5). Outcrops contain good examples of chaotically-bedded, broad, shallow channels, with numerous scour surfaces, characteristic of high-energy fan environments.

Surface widths of LA III map units vary greatly. LA III obtains a maximum surface width of several kilometers around the Harris Reservoir (Cokesbury quadrangle) and near the Raleigh Durham (RDU) airport (Cary quadrangle). Conglomerate clast size increases eastward at these locations as well, with clasts locally in excess of 1 meter in diameter.

LA III is almost non-existent in the southern Durham basin (near the town of Apex), Small "jogs" in the surface trace of the Jonesboro fault suggest this area may contain several non-overlapping faults segments. These "jogs" could be small relay ramps where fault displacement was minimal. This condition would result in a topographic low along the border fault, which would be an ideal location for sediment-carrying rivers and streams to enter the basin. The coarse-grained fluvial nature of LA II rocks in close proximity to the Jonesboro fault at this location supports this hypothesis.

The variability of the surface widths of LA III map units can be explained in several ways. First, variability in shape can occur as a result of the lobe-shaped depositional nature of alluvial fans. Interfingering of multiple fans can produce complicated map patterns. Second, Clark (1998) reported several broad, open anticlines and synclines, which are most likely superimposed on the lobe-shaped alluvial fans. A third factor may lie in the definition of the map units themselves. All the contacts between lithofacies internal to LA III are gradational in nature, and components of one lithofacies can occur within another map unit, only not in great abundance. Owing to the high amount of vegetation and the lack of numerous surface streams, poor data density can strongly influence the location of geologic contacts.

Topography in LA III is generally steep and rugged in the Trcs/c and Trcc lithofacies. Erosion-resistant bedding holds up both ridges and waterfalls. In some cases, strikes of parallel ridges and first-order drainages can be used to predict bedding strike in areas of sparse outcrop data. Topography usually decreases in elevation and gradient as one moves away from the Jonesboro fault. The rocky nature of the deposits and the steep terrain limit the agricultural potential, and as such, the area is sparsely populated and few roads exist in this isolated region of the basin.

Trcs - Interbedded Sandstone/Pebbly Sandstone

This unit consists of reddish-brown to dark brown, irregularly bedded to massive, poorly to moderately sorted, medium- to coarse-grained, muddy lithic arkoses, with occasional, matrix-supported granules and pebbles or as 1-5 cm thick basal layers (Fig. 6). Muscovite is common to absent. Occasional bioturbation is usually surrounded by greenish-blue to gray reduction halos. Beds are tabular, 1-3 meters thick, with good lateral continuity. This unit grades eastward into Trcs/c.

Trcs/c - Sandstone w/ Interbedded Conglomerate

This unit consists of reddish-brown to dark brown, irregularly bedded, poorly sorted, coarse-grained to pebbly, muddy lithic sandstones with interbedded pebble to cobble conglomerate (Fig. 6). Muscovite is rare to absent in the matrix. Well-defined conglomerate beds distinguish this unit from conglomerate basal lags of Trcs. An arbitrary cut-off of less than 50 percent conglomerate distinguishes this unit from the Trcc conglomerate facies. Clasts are chiefly miscellaneous felsic and intermediate metavolcanic rocks, quartz, epidote, bluish-gray quartz crystal tuff, muscovite schist, and meta-granitic material, with rare banded gneiss (Raleigh gneiss?) near the town of Apex. Conglomerate beds are channel-shaped and scour into the underlying sandstone beds. This unit grades eastward into Trcc.

Trcc – Conglomerate

This unit consists of reddish-brown to dark brown, irregularly bedded, poorly sorted, cobble to boulder conglomerate (Fig. 6). Muscovite is rare to absent in the very coarse-grained to gravelly matrix. An arbitrary cut-off of greater than 50 percent conglomerate distinguishes this unit from the Trcs/c facies.

Clasts are chiefly miscellaneous felsic and intermediate metavolcanic rocks, quartz, epidote, bluish-gray quartz crystal tuff, muscovite schist, and rare meta-granitic material. Maximum clast diameters are in excess of 1 meter along the shore of Harris Reservoir and in excess of 2 m along Haleys Branch east of the RDU airport. These large clast sizes suggest paleo-relief along the Jonesboro fault scarp was great enough to produce high stream gradients capable of transporting boulders-sized clasts.

CORRELATION OF MAP UNITS

A thorough attempt to correlate between the Sanford and Durham basins cannot be performed until additional geologic mapping is conducted. This article merely attempts to document the current state of mapping and interpretations in the Deep River basin. However, several general observations can be made at this time regarding correlation between the Sanford and Durham basins.

There is not a one-to-one match between the three formations in the Sanford basin and the three lithofacies associations in the Durham basin. For example, the top and bottom of the Cumnock Formation is defined by the first occurrence of gray shale. This definition excludes any of the reddish-brown siltstone or purple mudstone above or below the first gray shale, but all of these units have a similar depositional environment. In the lithofacies mapping system, the gray shale would be combined with the reddish-brown siltstone and purple mudstone as part of one map unit, namely the Trcsi/s lithofacies.

Another example of this incompatibility exists in the coarser-grained sections. By definition, the Sanford Formation includes everything stratigraphically higher than the last gray shale of the Cumnock, including both fluvial sediments and alluvial fan conglomerates. In the lithofacies system of mapping, fluvial and alluvial fan sediments are separated into two completely different lithofacies associations, namely LA II and LA III.

This incompatibility between map units is further complicated by the apparent temporal differences between the basins. As stated previously, Olsen (1977), Olsen and others (1982), and Olsen and others (1989) argued that the Trcsi/s sediments at Triangle Brick (central Durham basin) indicated a late Carnian age, similar to that of the Cumnock Formation in the Sanford basin. However, Huber and others (1993) suggested an early to middle (?) Norian age (Olsen and Huber, 1997). If the Triangle Brick quarry deposits are indeed Norian in age, they are significantly younger than Cumnock Formation of late Carnian age. In contrast, Clark (1998) mapped Trcsi/s sediments nearly identical to the Triangle sediments in the extreme southern Durham basin that preliminarily appear to be Cumnock equivalents (P.E. Olsen, personal commun.). Therefore, lithology certainly cannot be used alone in assigning stratigraphic order, let alone age.

If indeed there is missing section between LA I and LA II in the Durham basin, and between the middle and uppermost Pekin in the Sanford basin, as Olsen suggests, then where is the unconformity? Does it manifest itself as a period of non-deposition between conformably map units? Is it an angular unconformably not yet recognized? Has basin-longitudinal faulting played a role? These are questions without easy answers. Unfortunately, the LA I/LA II contact is either concealed by Jordan Lake or occurs in an area of poor exposure. Additional mapping is needed along the basin's western border to clarify the nature of the contact. Even then, the issue probably won't be resolved without subsurface data or new fossil finds.

The opportunities are limited for new fossil finds in the Durham basin for comparison with the Sanford basin. The Durham basin sediments are coarser-grained than the Sanford basin and there is no evidence for a large paleolake like the one responsible for the fossil-rich Cumnock Formation.

The next step in correlating between the two basins is to revisit many of the outcrops along the "mismatch" between Reinemund (1955) and Clark (1998). Special care should be given to the Cumnock Formation and its fine-grained equivalents in the northern Colon cross-structure.

In conclusion, it is premature to attempt any stratigraphic correlation between the Sanford and Durham basin at this time. Additional geological mapping is needed, coupled with any supporting data that might present itself in areas of poor exposure. A thorough link between the formation mapping of the Sanford basin and the lithofacies mapping in the Durham basin will require a multidisciplinary approach of field mapping and supporting data such as fossils, pollen, subsurface coring, and geophysics.

ACKNOWLEDGMENTS

We would like to dedicate this fieldtrip and guidebook to John A. Reinemund on the 50th anniversary of his mapping of the Sanford basin for USGS Professional paper 246: Geology of the Deep River Coal Field, North Carolina. This all-encompassing compilation still stands today as the most comprehensive report about the Sanford basin.

We wish to acknowledge the U.S. Geological Survey's STATEMAP and EDMAP programs that provided the resources to conduct parts of this study. We are indebted to many individuals for their earlier work in the Triassic rocks of North Carolina, their inspiration, or their advice and assistance, including Paul Olsen, George Bain, Dan Textoris, Walt Wheeler, Skip Stoddard, Rick Wooten, Kathleen Farrell, Bill Hoffman, Jeff Karson, Peter Malin, Mike Medina, Rich Hayes, Steve Driese, Joe Smoot. TWC especially would like to thank his wife Karen and family for the sacrifices made during field mapping.

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A HISTORY OF EARLY GEOLOGIC RESEARCH IN THE DEEP RIVER TRIASSIC BASIN, NORTH CAROLINA

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ABSTRACT

The Deep River Triassic basin has one of the longest recorded histories of geologic research in North Carolina. A quick perusal of nineteenth century geologic literature in North Carolina reveals the Deep River basin has received a tremendous amount of attention, second only, perhaps, to the gold deposits of the Carolina slate belt. While these early researchers' primary interests were coal deposits, many other important discoveries, observations, and hypotheses resulted from their investigations. This article highlights many of the important advances made by these early geo-explorers by trying to include information from every major geologic investigation made in the Deep River basin from 1820 to 1955. This article also provides as thorough a consolidated history as is possible to preserve the exploration history of the Deep River basin for future investigators.

INTRODUCTION

The Deep River Triassic basin (figure 1) has one of the longest recorded histories of geologic research in North Carolina. From the first published report in 1820 by Denison Olmsted, geologists have continuously been curious about the origin and timing of the basin's development. A quick perusal of nineteenth century geologic literature in North Carolina reveals the Deep River basin has received a tremendous amount of attention, second only, perhaps, to the gold deposits of the Carolina slate belt. This interest is attributed to the discovery of coal along the Deep River and the extensive efforts to determine its extent and recoverability, The majority of these investigations were performed by the North Carolina Geological Survey, and later, the U. S. Geological Survey and the U. S. Bureau of Mines. Research interest waxed and waned through the decades, prompted by periods of great economic development, destroyed by calamities such as the Civil War and the Great Depression.

While these early researchers' primary interests were the coal deposits, many other important discoveries, observations, and hypotheses resulted from their investigations. Most noteworthy is the paleontological work in the 1850's by Ebenezer Emmons, a major con-

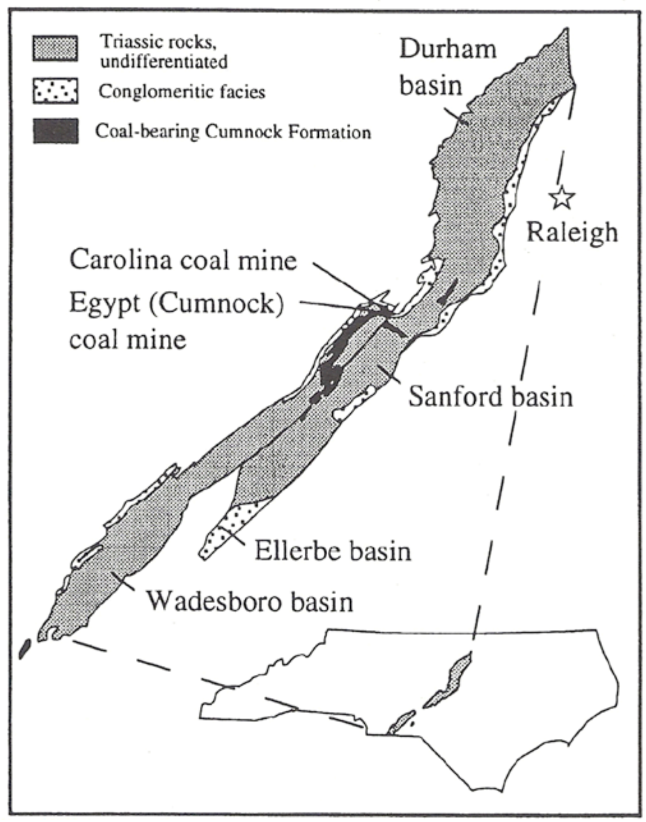

Figure 1. Simplified geologic map of the Deep River Triassic basin showing its component basins and other relevant geographic locations referred to in the text. Map modified from Bain and Harvey (1977), North Carolina Geological Survey (1985), and Olsen and others (1991).

tributor to a geologic sub-discipline still in its infancy, These and many other "ahead of their time" observations will be mentioned below. The work of these early researchers gives fascinating insight into the state of the geological sciences in our country at a time when many of the geologic fundamentals we take for granted today, were considered wild speculation back then. While many of the hypotheses really were wild speculation, their basic field observations were well founded. We must keep in mind that, unlike today, these early geologists had little to no geologic foundations to rest their hypotheses on, let alone such essential equipment as topographic maps, Brunton compasses, or aerial photographs. In light of all the technological advances of our time, it is most humbling to reoccupy an outcrop visited 150 years earlier and find its position plotted correctly, and its strike and dip and lithologic description still accurate by today's standards, The level of quality and attention to detail in these early reports cannot be found in many of today's geologic journals and many an author would be well served to follow their predecessors' examples.

THE OLMSTED AND MITCHELL YEARS (1820-1842)

The Deep River Triassic basin was one of the earliest recognized geologic terranes in North Carolina. The first geological observation of these rocks was made over 175 years ago by Professor Denison Olmsted of the University of North Carolina at Chapel Hill (figure 2). A Yale graduate of 1813, Denison was a student of Benjamin Silliman, founder of the American Journal of Science, and Denison published several papers on the rocks, minerals, and geology of North Carolina in that journal. The first of these, published in 1820, is the first known article describing the geology of the Deep River basin. The article, entitled "Red Sandstone Formation of North Carolina" (Olmsted, 1820), is in the form of a letter (presumably to Silliman) dated February 26, 1820, and states:

"An extensive secondary formation has lately been discovered near us, On the road between this place and Raleigh, traveling eastward, we come to it four miles from the College; but at another point it has been discovered within two miles of us. It is a sand stone formation, The varieties are the red and grey, I have traced it through the counties of Orange and Chatham,

Figure 2. Denison Olmsted (1791-1869), Professor of Chemistry and Mineralogy, University of North Carolina at Chapel Hill, creator of first geological survey in United States, first to recognize Deep River basin sediments.

and have ascertained its breadth, between this and Raleigh, to be about seven miles. Its direction is a little west of south. If a line be drawn through the Richmond bason [sic] parallel to the great mountains west of us, it will pass through this formation. Hence, must we not regard this as a continuation of the great sand stone formation, which W. McClure has traced to the Rappahannock? Must we not consider the Richmond bason [sic] and this as forming parts of the same formation? The variety found nearest to this place is not unlike the old red sand stone found in your vicinity."

Even at this early date, geologists recognized similar rocks up and down the Atlantic seaboard and were attempting to assign them to the same formation. This large-scale correlation would be the foundation of the yet to be named Newark Group. It is unclear when exactly Olmsted recognized these sediments, but not before 1817, when he was appointed to the university. The sandstone had, however, been known locally for some time, since it had been used extensively as decorative building stone in 1793 for Old East, the first campus building at the University of North Carolina.

Olmsted's letter continues: "It was natural to look for coal here and I have for some time directed the attention of my pupils, and of stone- cutters to this object. Two or three days since one of the latter brought me a handful of coal, found in this range, on Deep River in Chatham County about twenty miles south of this place. The coal is highly bituminous, and burns with a very clear and bright flame. It is reported that a sufficient quantity has already been found to afford an ample supply for the blacksmiths in the neighborhood. It is my intention to employ the first leisure I can command in collecting more precise and extended information on this formation." Olmsted was apparently unaware that the coal had been known by locals for almost 50 years, but later acknowledges the fact in a report made in 1824.

The "true" discovery of coal and iron along the Deep River had apparently been made by George Wilcox, who opened a forge and bloomery in 1775 and proposed to make cannon and munitions for the Revolutionary War. "According to North Carolina Colonial Records 1775-1776, Vol. 10, pages 647-650, James Milles on July 3, 1776 wrote the Council of Safety that on the north side of the Deep River there was 'Pit coal' that appeared to be very good and in great quantities" (Stuckey, 1965, p. 512). Chance (1885) states that the discovery occurred at the site of the Horton mine where the "coal was dug from open pits for blacksmithing ... but no systematic attempt was made to open the field until the slackwater improvement of the Deep River." The intended transportation route for the coal was by water to the port at Wilmington, but rapids along both the Deep and Cape Fear Rivers made boating inefficient and dangerous. Primitive locks and dams quickly failed due to limited construction technology and frequent floods, and as a result, the coal was used only for local purposes until the 1850's.

Because of Olmsted's interest in the geology and mineral resources of North Carolina, he proposed the idea of a State Geological and Mineralogical Survey to the Board of Internal Improvements in 1821. Olmsted's original request was denied by both the Board and State Legislature in that year, but on December 31, 1823, the State legislature passed an act "...to employ some person of competent skill and science to commence and carryon a geological and mineralogical survey of the various regions of this State;..." (Stuckey, 1965). Due to his interest and experience, Olmsted was chosen as this person.

Receiving a yearly salary of $250.00, Olmsted traversed the state on horseback, collecting and describing fossils and minerals from Cape Lookout to as far west as the Great Smoky Mountains. In his first report ("Report on the Geology of North-Carolina, Part I", dated November 10,1824), Olmsted describes the lateral extent of the basin from Oxford, NC into South Carolina with a varying width of 8 to 18 miles. Olmsted also discusses the use of sandstone for building material and the agricultural importance of the "Mill-stone grit" of Moore County. He describes the rock as "...a hard, greyish red Sand-stone, in which are thickly imbedded water-worn pebbles of white flint or quartz. These Millstones are very much valued for grinding, and are sought for from distant parts of the State, and bring from thirty to one hundred dollars per pair" (Olmsted, 1824, p, 15).

Olmsted also discusses coal in the area of the Deep River, and how important it would be to the public in the future, if and when timber fuel might become scarce. "Every State in a stage of progressive improvement, although at present supplied with abundant resources for fuel in her native forests, must look forward to a period when those resources will be either partially or wholly exhausted" (Olmsted, 1824, p. 17). "Although, therefore, we may now look around us and see apparently an exhaustless supply of fuel and in our forests, yet the time may not be distant when some large manufacturing establishment shall call loudly for Coal; and perchance in no very distant age, the domestic wants of some portion of our citizens may make them look for this article with very different feelings from that influence the present generation" (Olmsted, 1824, p. 18). Such insight on the future availability of natural resources qualifies Olmsted as one of the state's first conservationists.

Olmsted visited the original coal mine started by George Wilcox, but found it to be abandoned and filled with water and rubbish. He did, however, note the presence of "a finely divided Black Slate," dipping "southeast at an angle of about twenty degrees," as well as the surrounding red sandstones (Olmsted, 1824, p.19). Citing the work of William McClure, who traced the unconnected red sandstones from New England to Virginia, Olmsted stated, "... I have little doubt that both the Richmond and the North Carolina Sandstone belong to the same formation with that north of the Rappahannock" (Olmsted, 1824, p, 18). Thus, Olmsted expanded the known boundaries of the "New Red

Sandstone" hundreds of miles further to the south.

Olmsted produced a second report the following year ("Report on the Geology of North- Carolina, Part II", dated November 1825). This report concentrated on the Coastal Plain and rocks west of the Carolina Slate Belt, and did not include a discussion on the Triassic rocks. Importantly, though, as a result of his travels he produced the first geologic map of North Carolina, dated November 1825. Although in poor condition, the map still survives at the North Carolina State Archives in Raleigh. Hand drafted with color inks, the map displays eight geologic divisions, including the Deep River and Dan River Triassic areas. This map is considered to be one of the oldest, if not the oldest, geologic map of an individual state in the United States (Cliff Nelson, U.S.G.S., oral com- mun.,1998).

Olmsted resigned in 1825 to take a teaching position at Yale and Elisha Mitchell, also of the University of North Carolina, assumed responsibility for the survey. Mitchell had been a classmate of Olmsted's at Yale, and the two were good friends as well as colleagues (Schoepflin, 1977). Mitchell made two additional re- ports to the Board of Agriculture, neither one specific to the Deep River basin. According to Stuckey (1965), "Mitchell made a determined but unsuccessful attempt to continue the work started by Olmsted as indicated by the following entry found in his diary under the date of December 28, 1827, 'The Geological Survey dies a natural death at the end of this year. There is no one who takes any interest in the business, nor, in the present state of the treasury did I find there was the least prospect in succeeding in my applications to the legislature, and therefore gave it up at once.'" While never mentioned officially as the "North Carolina Geological Survey", Olmsted's "Geological Survey" was the first geologic work performed at the public's expense in the United States, and therefore qualifies as our Nation's first geological survey.

Mitchell continued as Professor of Chemistry, Mineralogy, and Geology at the University of North Carolina and produced a general geology textbook in 1842 for use by his students. While the first 122 pages are of a generic nature, the last 18 pages are devoted to the geology of North Carolina. In the four pages concerning the Deep River basin, Mitchell reports observations on such things as the extent and topography of the basin, "small nodules of compact limestone", and the reopening of the coal beds in the late 1830's. In a discussion of the extent of the sandstones, a footnote remarks, "There is in Richmond County, between Catleges' and Mountain creeks, a body of the same kind of rocks, but whether connected with the other, or a separate and independent mass has not been ascertained" (Mitchell, 1842, p. 130). This is the first recognition of the Ellerbe basin, and its connection with the Deep River basin is still a subject of debate between geoscientists. Mitchell also discusses the controversy between William McClure, Edward Hitchcock, and Henry Rogers over the name and age of these soon-to-be-Newark sandstones of the Atlantic Coast, but avoids becoming involved with the conflict. "... I have no theory to offer in regard to the mode of formation, or opinion to ex-press respecting its age, other than it is very old" (Mitchell, 1842, p. l33). A safe statement that no one could argue with. The textbook includes a colored state geologic map, showing more refined contacts of the Deep River basin as compared to Olmsted's 1825 map.

THE EMMONS YEARS (1851-1865)

In 1851 the State legislature reauthorized the Geological Survey with a budget of $5,000 per year. Ebenezer Emmons (figure 3), previously of the New York Geological Survey, became the first official State Geologist of North Carolina and ushered in a renewed period of research in the Deep River basin (Stuckey, 1965). Coal mining had been occurring since 1830 on the Egypt plantation (figure 1) of Peter Evans, located in the great northward bend of the Deep River. Evans sold the Egypt plantation to L. J. Houghton and Brooks Harris in 1851, with Houghton taking full ownership shortly thereafter. Houghton, in an attempt to find higher quality, unweathered coal, sank the "Egypt" shaft in 1852 to a total depth of 460 feet, encountering the main coal beds at 430 feet (Campbell and Kimball, 1923). Systematic mining began and coal was transported via rail and water to Fayetteville and Wilmington, NC. The economic importance of expanding the coal operations soon became a high priority for the Geological Survey.

Emmons spent much time trying to identify the extent of the coal, and as a result collected valuable information on the basin. In his first report to the State legislature, entitled "Report of Professor Emmons on his Geological Survey of North Carolina" (Emmons, 1852), Emmons included a 30-page section describing the basin sediments and subdivided the rocks into three divisions. This was the first recognition in the Deep River basin of an apparent tripartite stratigraphy believed common to many basins throughout the Newark Supergroup. Other important observations of Emmons' 1852 report include:

• The first discussion of the basin geometry: "The Deep River coal field is in the shape of a trough!" (Emmons, 1852, p. 119). Apparently, Emmons believed the basin to be a northeast- southwest trending syncline, with the southeastern limb "concealed beneath a thick mass of soil", presumably upper Coastal Plain sediments. Emmons hypothesized the coal should also occur in the southeastern limb of this syncline and spent much time looking (unsuccessfully) for these coal outcrops.

• The first estimates of the thickness of the sediments: "... the whole thickness of the formation cannot be less than five thousand feet" (Emmons, 1852, p. 137) and "The thickness which the series attain is variable; -in some it exceeds 14,000 feet" (Emmons, 1852, p. 114). Emmons' estimates were based on several measured sections; however, his estimates were most likely too high due to inadvertently measuring repeated sections caused by faulting .

• The first identification of plant and animal fossils from the basin: "...one species of molusca: a small posidonia or cypris; which is regarded as a crustacean, and which is only the size of a grass seed; the teeth of two or three saurians, and the scales of one or two fish" (Emmons, 1852, p. 140). "The presence of the cypris indicates that the slates are fresh water formation" (Emmons, 1852, p. 141). This observation apparently troubled Emmons, since he believed the upper and lower sandstones to be deposited by the ocean: "...what had been a sea became a fresh water lake (Emmons, 1852, p. 141).

• The first mention of a source area for the basin sediments: The quartz pebbles in the lower conglomerate were "derived from the neighboring rock, the gold slates" to the west (Emmons, 1852, p. 120). "The origin of these pebbles is evidently in the slates, and from the quartz seams in the slates. This rock being schistose, and largely intermixed with talc and mica, and frequently thoroughly impregnated with pyrites, is subject both to disintegration and decomposition. The quartz by these processes is then set free, or disengaged from its matrix - When exposed to the action of waves upon a beach, it is rounded and while still in the beds are subjected to pressure which results in the formation of this interesting and curious rock" (Emmons, 1852, p. 121). Again we see that Emmons hypothesized incorrectly that the upper and lower sandstones where marine in origin.

Figure 3. Ebenezer Emmons (1799-1863), North Carolina Geological Survey, paleontologist, first State Geologist of North Carolina.

While Emmons was thoroughly familiar with the Paleozoic fossils of New England from his work at the New York Geological Survey, most of the Mesozoic fossils he collected from the coal seams were species he had not seen before, and was therefore cautious about assigning an age to the basin sediments. Citing the work of numerous authors in America and Europe (including Sir Charles Lyell), he suggested the deposits might be Permian or Triassic and related to the New Red Sandstone of Connecticut and New Jersey.

In 1856, Emmons published his "Geological Report of the Midland Counties of North Carolina". The work was a comprehensive report of the North Carolina Piedmont consisting of 351 pages, 9 plates, and 7 maps. Chapters 32 through 42 (p. 227-342) contain an expanded and revised discussion of his observations from the 1852 report. Also included are a hand-colored geologic map of the Deep River coal field, four hand-colored cross sections of the basin, and numerous, detailed engravings of plant and animal fossils collected from the coal beds and surrounding shales (figure 4). As in 1852, Emmons divided the rocks into three subdivisions, this time suggesting ages based on fossil assemblages:

- lower red sandstone and its conglomerate (Permian);

- the coal measures, including slates, shales, and drab sandstones (Permian);

- and the upper red sandstones, conglomerates, and marls (Triassic).

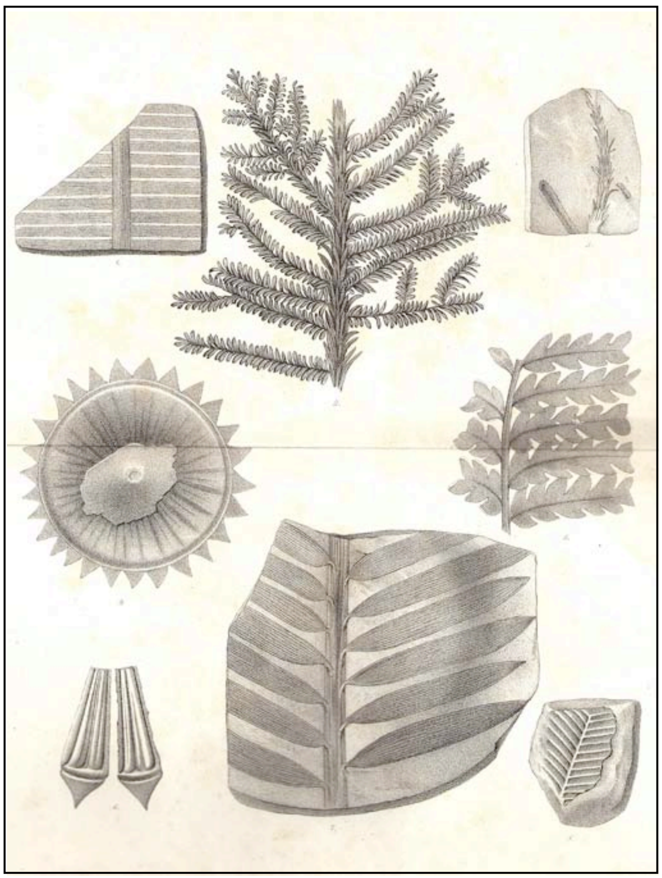

Figure 4. Illustrations of several plant fossils described by Emmons. Plate III from "Geologic Report of the Midland Counties of North Carolina (Emmons, 1856).

The greatest contribution of Emmons, perhaps, was the description of numerous plant and animal fossils, which Emmons considered crucial in assigning an age to the basin sediments. Some of Emmons' beautifully detailed illustrations of fossil plants are shown in figure 4. Emmons documented the first fossils from the Deep River basin, which he found in the coal seams on his very first visit to the area in 1852. In all, Emmons identified about forty new species, including reptiles, fish, batrachians, and mollusks. Most noteworthy are the descriptions of the Parasuchian reptile Rutiodon and the mammal-like reptiles Dromatherium and Microconodon (Olsen, 1991). The latter two, found in the Cumnock coal mine as two, one- inch long jawbones, were considered by Emmons to be true mammals until Simpson (1926) correctly identified them as reptiles. In the same year of Emmons' second report, W. C. Redfield (1856) proposed the term Newark Group for Upper Triassic rocks in New England and included the Deep River basin into the Newark Group after a comparison of fossil samples from Emmons' collection.

In late December of 1857, North Carolina Governor Thomas Bragg requested from Emmons a special report "concerning the advantages of the valley of the Deep River as a site for the establishment of a National Foundry" with the intention of presenting the report to the United States Congress. The 14-page special report was completed in only three days. Emmons concluded the Deep River "is the most ideal spot in the county for a national foundry" based on the abundance of 1) natural resources, including coal, iron ore, timber, and building stone; 2) navigable rivers for transportation and water power; and 3) a hospitable climate, where heat and cold would not close navigation routes or interfere with the movement of machinery (Emmons, 1857). The report was apparently well received, as the following year the U.S. Senate authorized the Secretary of the Navy "to cause a thorough examination of the iron, coal, and timber of the Deep River country.,," for establishment of a National Foundry (Stuckey, 1965). The purpose of this foundry would be to build engines and boilers for naval vessels. The Secretary of the Navy sent Captain Charles Wilkes and several naval engineers, who conducted their investigation in August and September of 1858. Their favorable report (Wilkes, 1858) includes: 1) a simple geologic map of the Deep River basin (from Oxford, NC to South Carolina); 2) a detailed geologic map of the coal field showing seven rock types (similar to Emmons' descriptions); and, 3) a detailed color section of the

Egypt shaft to a depth of 460 feet (figure 5). It is truly fortunate that Wilkes included the color section of the Egypt shaft in his report as Campbell and Kimball remark, "The geologic world is greatly indebted to Captain Wilkes for preserving a record of the rocks penetrated by the shaft, for, so far as the writers are aware, his is the only report in which the original section was published"." (Campbell and Kimball, 1923, p. 26). Wilkes' report also cast a very favorable light on the Deep River area as a site for the foundry.

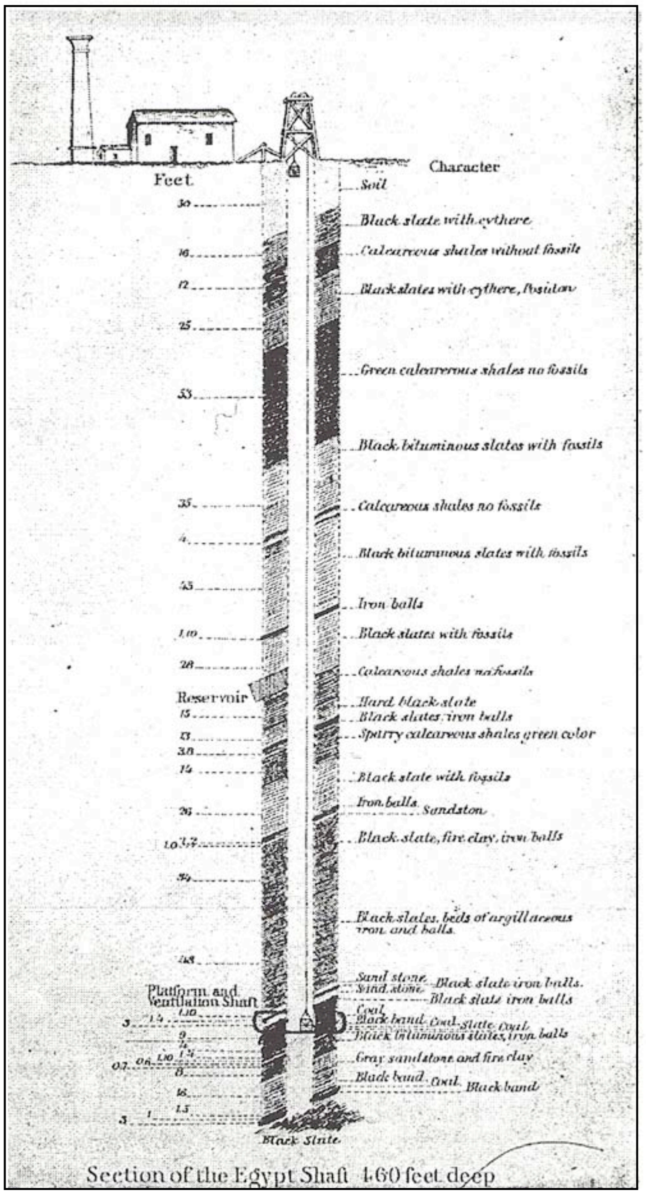

Figure 5. Geologic section of the Egypt shaft, originally opened in 1852 to a depth of 460 feet. Illustration from "Report on the examination of the Deep River district" (Wilkes, 1858).

Unfortunately, the foundry was never built due to the outbreak of the Civil War. However, considerable coal was mined during the war and transported either by railroad to the arsenal at Fayetteville or by barge to Wilmington. The coal was used primarily by the blockade runners transporting Confederate supplies through the Union blockade at Fort Fisher, at the mouth of the Cape Fear River.

During the war, the North Carolina Geological Survey was forced to change its role to strategic mineral development (i.e., coal and iron) for the Confederacy's wartime needs. As a result, no Survey reports were produced during the war, most probably due to lack of funding. Ebenezer Emmons died on October 1, 1863, before the war's end and was buried in the City Cemetery in Raleigh, North Carolina. His body was later removed to Albany, New York. In 1864, W. C. Kerr was appointed Emmons replacement, who worked without pay to near the war's end in April 1865.

Most of the work by Emmons and his assistants was lost during the war (including mineral and fossil collections, and manuscript geologic maps of the Deep River and Dan River coal fields), presumably at the hands of troops, who occupied the Survey's offices in the State Capitol after the surrender of Raleigh in 1865. Many of Emmons' cataloged fossils have been found in private collections and university holdings up and down the Atlantic Seaboard. In April of 1865, the Geological Survey closed for a second time in its history. Although the Survey was restarted shortly thereafter, no detailed geologic research was published on the Deep River basin for the next 50 years.

THE POST-CIVIL WAR YEARS (1865-1920)

Geologic interest in the Deep River basin for the 50 years following the Civil War can be characterized as minimal at best. After the Civil War, work at the Egypt mine continued, but locks and dams, vital for transportation of coal to market, soon fell into disrepair. As a result, the mine closed in 1870 and was allowed to fill with water.

As part of the post-war reconstruction, the North Carolina Geological Survey was reauthorized and Professor Washington C. Kerr reappointed State Geologist. Kerr and his assistants conducted a renewed survey of the state's geographic and geologic features. Their results were published in "Report of the Geological Survey of North Carolina, Volume 1" (Kerr, 1875). Kerr and his assistants apparently did not conduct any specific investigations in the Deep River basin but Kerr does speculate on the pre-erosional extent of the Triassic rocks of North Carolina. He suggested that the Deep River and Dan River Triassic basins were part of a large, continuous formation that covered almost the entire state of North Carolina (Kerr, 1875, p.145). This sheet was then folded into a broad anticline, which was subjected to a tremendous amount of erosion, leaving the two basins today as erosional remnants over 100 miles apart. Kerr admits that based on average dips of 20-30 degrees for the basin sediments, this would require removal of over 20,000 feet of Triassic and underlying basement material in the core of the anticline, a value much higher than accepted by his contemporaries. Kerr provided no explanation for the origin of the expansive Triassic layer or the cause of the anticlinal folding. Although a large amount of erosion did take place during the Jurassic Period in North Carolina (Stuckey, 1965), there is no evidence to suggest the basins were once connected.

In 1885, Dr. H. M. Chance prepared a report for the North Carolina Department of Agriculture based on extensive prospecting and field tracing of the coal outcrops (Chance, 1885). This was the first true attempt to delineate the lateral extent and thickness of the coal through extensive field traverses and shallow auguring. Although Chance's methods of investigation were detailed and needed, his findings were not quite so favorable on the future prospects of coal mining. According to Campbell and Kimball (1923, p, 8), "Dr. Chance's conclusions were not particularly favorable." Stuckey (1965, p. 509) notes the report was "so discouraging that after publication it was withdrawn and largely destroyed."

Even in light of such negative findings, the Egypt mine was opened again in 1888 and operated minimally under the same poor mining and market conditions as in the past. After a series of gas explosions around 1902, the mine closed in 1905 for financial reasons. In 1915, the Egypt mine was purchased by the Norfolk Southern Railroad Company and reopened as the Cumnock Coal Company, the name Egypt being unacceptable due to its association with financial failure and disastrous explosions, Coal production, however, was small and used only by the railroad.

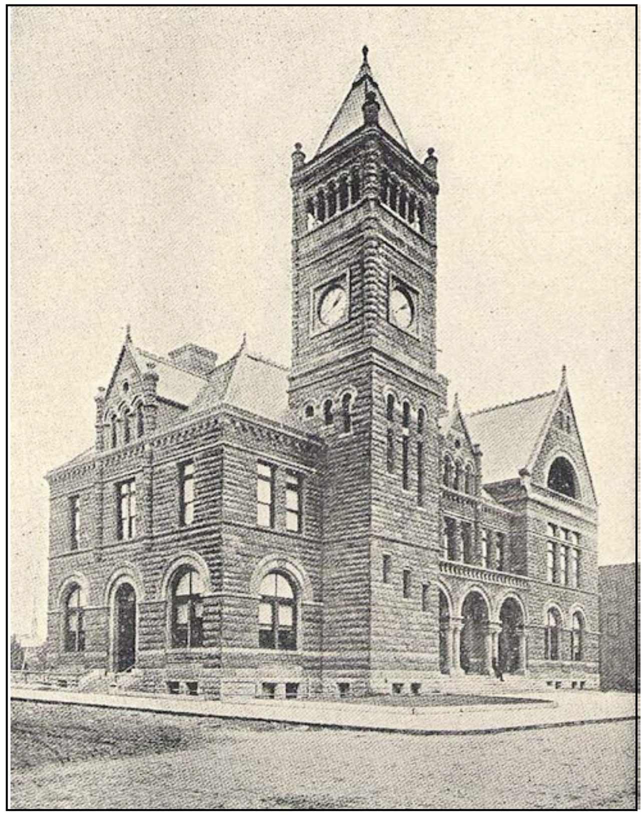

Figure 6. Old post office building in Wilmington, NC built from sandstone quarried near Wadesboro, Anson County, NC. Photo from "The Building and Ornamental Stones of North Carolina' (Watson and Laney, 1906).

The 1880's to 1920's heralded a new use for the natural resources of the basin other than coal. As architectural tastes changed, so did the need for unique building stone. It was found that certain parts of the basin contained a chocolate brown sandstone, hard and massive, and ideal for building. Although quarried locally as early as the 1790's, commercial brownstone quarrying did not occur in the Deep River basin until the mid-1880's. Small quarries operated in the Durham basin, but the more important operations were in the Sanford and Wadesboro basins, specifically in Anson, Moore, Chatham, and Lee Counties (Watson and Laney, 1906). Brownstone was used extensively in public buildings in Asheville, Charlotte, Raleigh, Statesville, and Wilmington, as well as Atlanta and Baltimore (figure 6), The last recorded production of brownstone in North Carolina was in 1927 for remodeling of Holladay Hall, the original campus building at North Carolina State University in Raleigh (Stuckey, 1965).

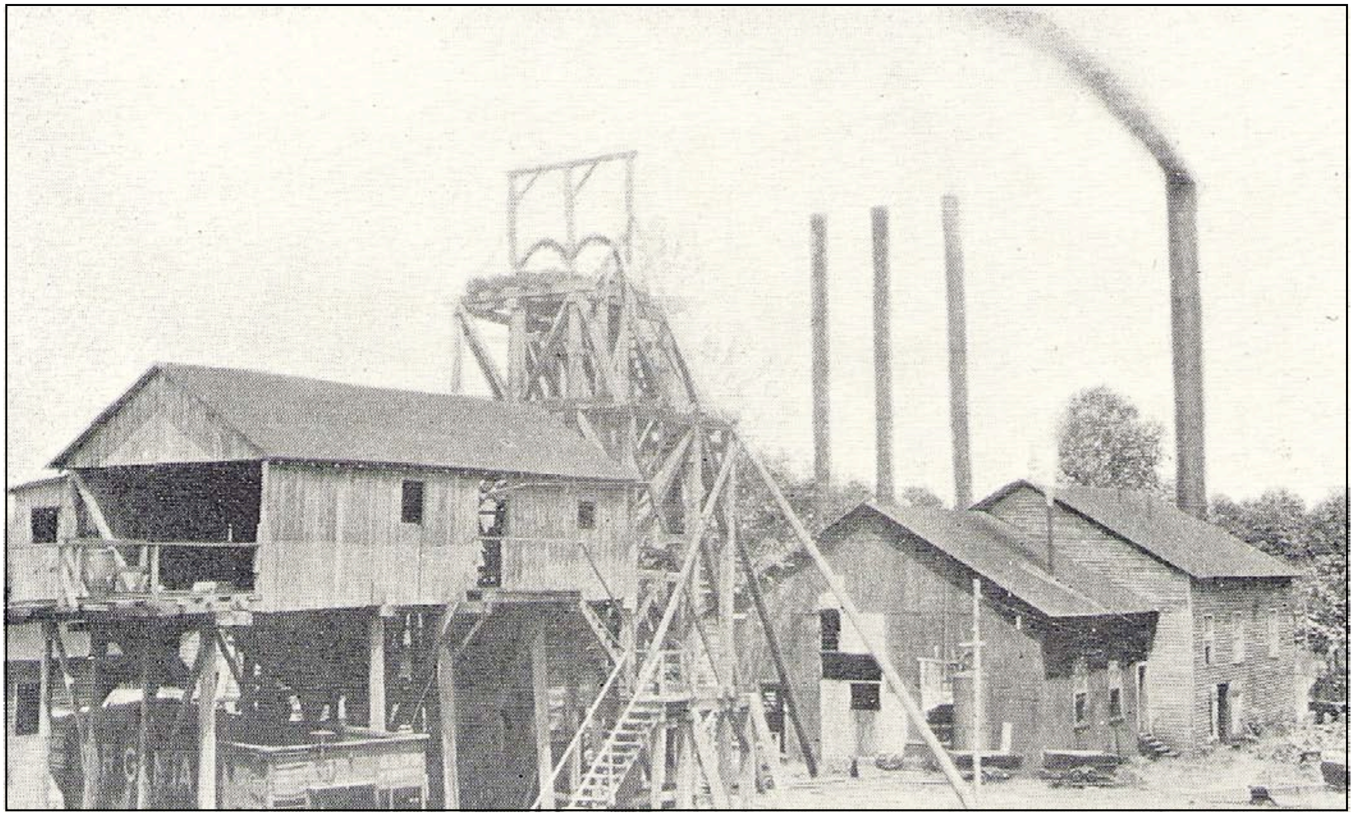

Figure 7. The Cumnock coal mine, around 1923. Photo from "The Deep River Coal Field of North Carolina" (Campbell and Kimball, 1923).

THE ROARING '20'S (1921-1930)

The Egypt mine (now renamed the Cumnock mine) received its first major competition with the formation of the Carolina Coal Company in 1921. The Carolina mine was opened in Farmville, immediately across the river from the Cumnock mine (figures 1 and 7). To evaluate the true amount of recoverable coal reserves, the U. S. Geological Survey sent Marius Campbell and Kent Kimball to the region in the early 1920's. They published their results in North Carolina Geological Survey Bulletin 33: "The Deep River Coal Field of North Carolina" (Campbell and Kimball, 1923). Their report was prepared "with the idea that the coal is much more valuable than believed" (p. 16) and that the coal could be used for both industrial and domestic use in eastern North Carolina. In fact, the later half of their report is devoted to the promotion of the coal as being of much better quality than reported by previous geologists. The authors also believed that a comprehensive geologic investigation would assist in planning mine operations, where the lack of this data in the past had led to failure.

Campbell and Kimball made many advances in the understanding of the stratigraphy and structure of the basin, although many of their conclusions were flawed by an inadequate understanding of rift basin development, a fact that should be overlooked in light of the level of knowledge in the 1920's. Some important contributions include:

• The first real attempt to explain and predict coal outcrops through the use of structural geology: The authors explained the discontinuous map patterns of the coal beds by numerous basin-longitudinal faults (i.e., Deep River, Carbonton faults), but they still held to the idea the basin was a synclinal structure, the southeastern limb cut off by the Jonesboro fault. Based on reconnaissance visit to the Wadesboro basin, they reported a true syncline was observed there with the Sanford Formation in the core and Cumnock and Pekin Formations on the flanking limbs (Campbell and Kimball, 1923, p. 49). This observation has never been verified.

• The identification and description of formal formations; the Pekin, Cumnock, and Sanford Formations: These divisions were nearly the same as those proposed by Emmons (1856), with Emmons' Coal-bearing shales and Salines being combined into the Cumnock Formation. Type localities were given for each of the formations. Although Campbell and Kimball applied these terms throughout the Deep River basin, their use today is applied only to the Sanford basin.

• The identification and description of type localities of the Jonesboro, Deep River, and Carbonton faults: Although the authors correctly identified these as basin-longitudinal normal faults (the Jonesboro with between 7,000 and 8,000 feet of estimated normal displacement), they incorrectly assumed the formation of these faults post-dated the basin infilling. This conclusion was based on the observation that the faults cross-cut all other known geologic features. While they acknowledged the concept of deposition on a subsiding surface due to faulting, the cross-cutting fault relationship led them to conclude "".that faulting did not play an important part in the original deepening of the troughs." (Campbell and Kimball, 1923, p. 61). Geologists now recognize, of course, that faulting plays a dominant role in basin sedimentation .

• Acknowledgment of the magnetism of diabase dikes: When preparing the base map for the report, using a plane-table and alidade, the authors discovered that the dikes in the area were magnetic, and had "a decided influence on the magnetic needle of the plane-table" (Campbell and Kimball, 1923, p. 12). This account is the first published acknowledgment of the magnetic anomalies of diabase dikes in the Deep River basin. The authors also point out that some dikes have an opposite sense of magnetism, thus "neutralizing the effect" of nearby normally magnetic dikes.

• Acknowledgment of the diabase dikes impact on groundwater availability: "It is interesting to note that the dikes have a very decided effect on the circulation of underground water and that this fact is utilized in the field. Thus the inhabitants have learned, through long experience, that water can be secured more readily by sinking wells near a dike than it can in the country rock where there is no dike" (Campbell and Kimball, 1923).

• Acknowledgment of diabase dikes impact on coal quality: "...the coal has been converted into anthracite wherever it has been cut by a dike" (Campbell and Kimball, 1923, p. 48). Campbell and Kimball interpreted the conversion to have taken place hundreds to thousands of feet below ground at the time of dike emplacement with great amounts of erosion now exposing the coal. "The intrusion [of dikes] must have taken place millions of years ago and probably soon after the rock-making materials were deposited." (Campbell and Kimball, 1923, p. 48). The authors, without any type of age dating, probably didn't realize how correct they were. The authors go to great lengths warning future mining operators to be wary of dikes, because of both thermal alteration and fault offsets of the coal beds.

Campbell and Kimball also briefly discuss the possibility of oil in the area. They conclude (based on faulting and dike emplacement), "that from a geological point of view all the evidence collected in the field bearing on this question is of negative character" (Campbell and Kimball, 1923, p. 9). Although mostly confined to the Sanford basin, the work of Campbell and Kimball should be regarded as the first modern foundation of our understanding of the Deep River basin, Campbell and Kimball's report has recently been reprinted (including the geologic map) by the North Carolina Geological Survey.

Unfortunately, the spirit of renewed interest in the Deep River basin started by Campbell and Kimball was quickly extinguished in the years following their report. In 1925 a devastating gas explosion at Carolina Mine killed 53 miners, closing the mine temporarily. Finally, the Cumnock and the Carolina mines both closed in 1929 and 1930 respectively due to the Great Depression. The economic feasibility of coal mining was not regained until an event even more devastating than the Great Depression: the bombing of Pearl Harbor and the beginning of World War II.

THE WORLD WAR II YEARS (1942-1955)

The onset of World War II had a tremendous impact on the identification and development of he nation's natural resources for wartime needs. As the need for strategic minerals rose, so did the need for more basic resources such as coal for fuel. As a result, the Carolina Mine reopened in 1942. Substantial technological improvements were made to avoid the cave-ins and gas explosions that had plagued previous mine operations. It soon became apparent that a modern investigation was needed to determine the coal's extent and recoverable volume. Between 1944 and 1948, the U.S. Bureau of Mines drilled 8 coreholes totaling 11,890 feet into the Cumnock Formation. In addition, Walter Bledsoe and Company who now owned both the Carolina and Cumnock mines, drilled 11 holes in 1945-1946.

By 1949, the Carolina mine was at peak output, producing over 100 tons of coal per day. Most of this coal was purchased by Carolina Power Company who trucked the coal to its nearby steam power plant near Moncure, NC (Reinemund, 1955). As quickly as mining had resumed, however, it suddenly came to an end once more. Poorly understood faulting of coal seams and poor market conditions closed the Carolina mine in 1953. This was the last systematic coal mining in North Carolina.

Fortunately for today's researchers, most of the information gained from the coal investigations has been preserved and can be found in USGS Professional Paper 246 "Geology of the Deep River Coal Field, North Carolina", by J. A, Reinemund (1955). The 160-page report contains a thorough mining history of the area as well as technical data on the coal quality and mine conditions. In addition to the three-sheet color geologic map of the region, the report presents detailed geologic surface mapping and subsurface mine mapping of the Carolina mine, concentrating on the extent and thickness of coal, faulting, and diabase intrusions. This all-encompassing compilation still stands today as the most comprehensive report about the Deep River Triassic basin. At the time of this writing, copies were still available from both the U.S. Geological Survey and the North Carolina Geological Survey.

CONCLUSION

The Deep River Triassic basin has one of the longest recorded histories of geologic research in North Carolina. Readers of this report should have a new respect for the efforts of previous researchers to understand the complex origin of one of North Carolina's more difficult geologic terranes. Advances in geologic understanding have obviously been "spin-offs" of the geologic investigations into mineable coal reserves. As a result, these advances have been sporadic and determined by the upswings and down swings of the economy.

Most of the hypotheses of early researchers have been discarded while a few "ahead of their time" observations have survived to today, The advent of plate tectonics in the late 1960's revolutionized geologist's view of how the Deep River basin developed, and much new work has been done since then to apply these concepts to field observations. This most recent round of research is well summarized in Olsen (1991).

This article highlights many of the important advances made by early geo-explorers by including information from every major geologic investigation made in the Deep River basin from 1820 to 1955. This article provides as through a consolidated history as is possible to preserve the history of the Deep River basin for future investigators.

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FIELD STOPS

INTRODUCTION

This two-day field trip consists of seven stops. The Saturday trip will visit six stops in the Triassic sediments of the Sanford basin. The Sunday trip will visit just one stop in the Carolina terrane just west of the Sanford basin. The objectives of this field trip are to show a variety of rock sequences throughout the Sanford basin and adjacent areas and to discuss the past, present, and future geologic resources these rocks provide. Stops 1-6 locations are shown on the regional index map below. Individual stop locations are shown on reproductions of 7.5-minute quadrangle maps. North is toward the top in all figures. The field trip leaders appreciate the cooperation of representatives of Boren Clay Products, Standard Minerals, and all of the private landowners who graciously permitted us on their property.

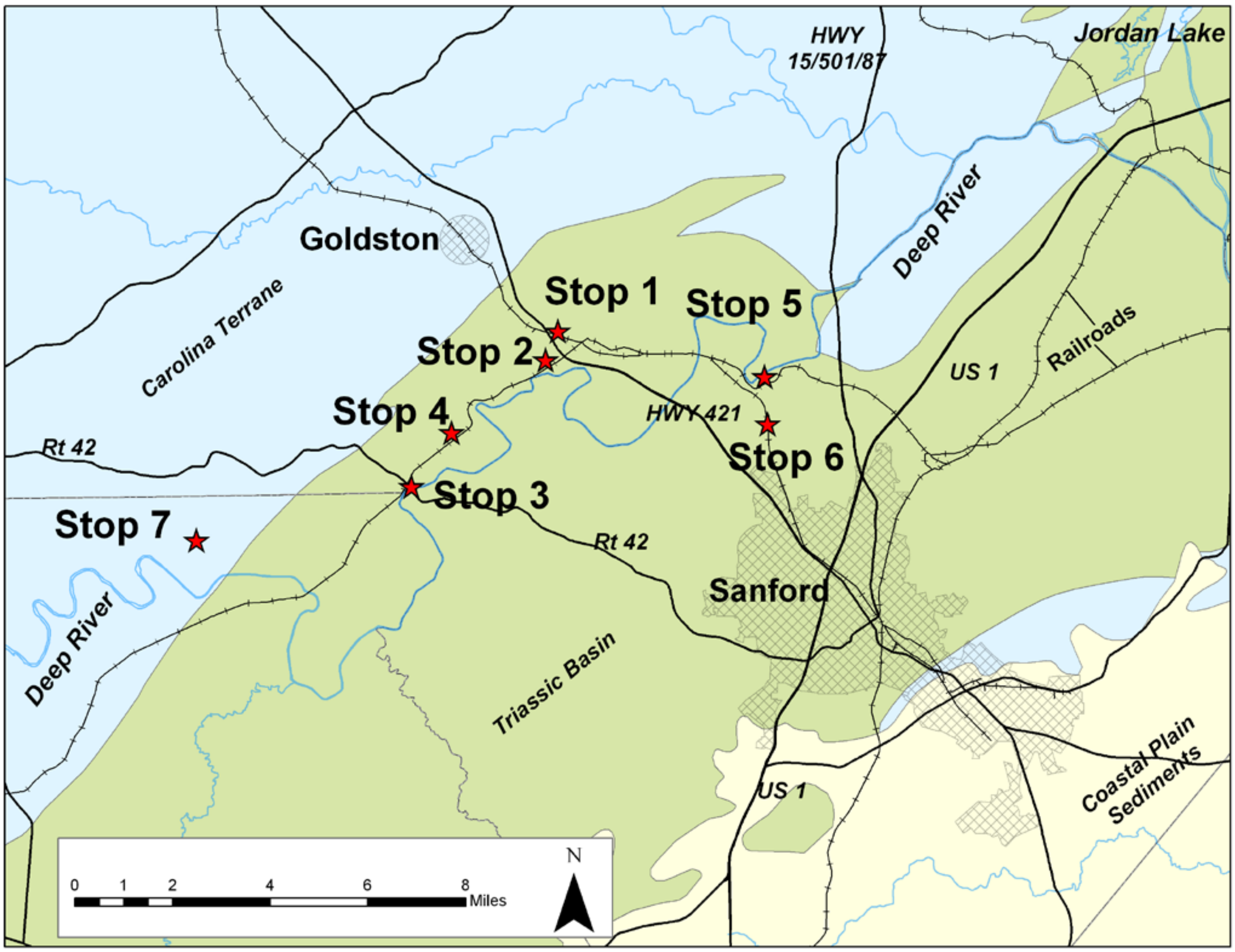

Figure 1a. Locations of Field Trip Stops 1 through 7. Crystalline basement rocks of the Carolina terrane shown in blue, Late Triassic sedimentary rocks of the Deep River basin shown in green, and Cretaceous and Cenozoic Coastal Plain deposits shown in light yellow.

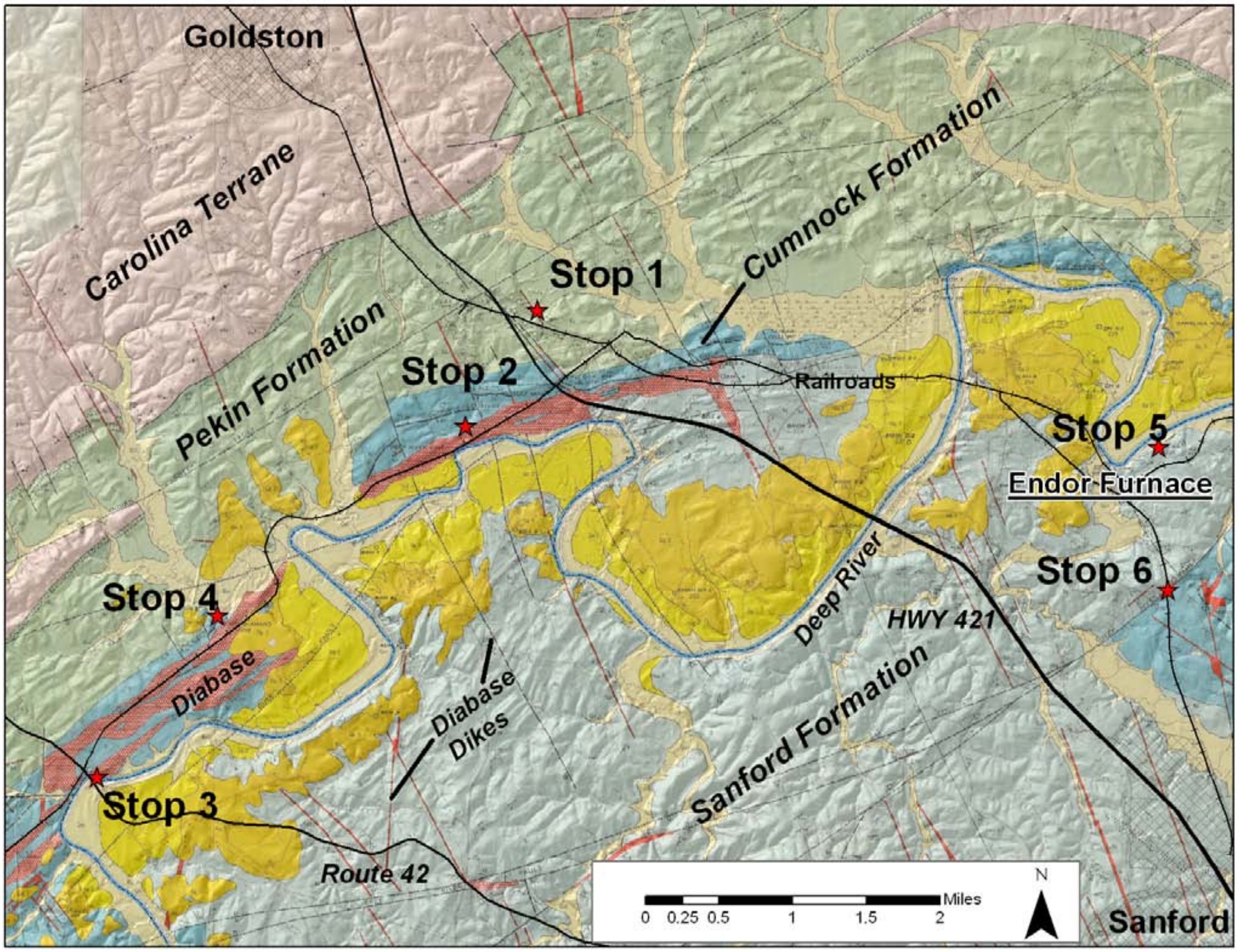

Figure 1b. Locations of Field Trip Stops 1 through 6. Crystalline basement rocks of the Carolina terrane shown in pink, Late Triassic Pekin Formation in green, Late Triassic Cumnock Formation in dark blue, Late Triassic Sanford Formation in light blue, Jurassic diabase (dikes and sills) in red, and Cenozoic surficial deposits in yellow. Base map is from Reinemund (1955) with LiDAR shaded relief overlay.

Field Trip Stops

Saturday October 22:

Sunday October 23:

STOP 1:
Boren Clay Products
Pekin Formation near Gulf, NC

Stop Leaders - Tyler Clark and Kenneth Taylor

Location: 35.566005° N, -79.294256° W

Features of Interest: Pekin Formation, Late Triassic plant fossils, diabase dikes.

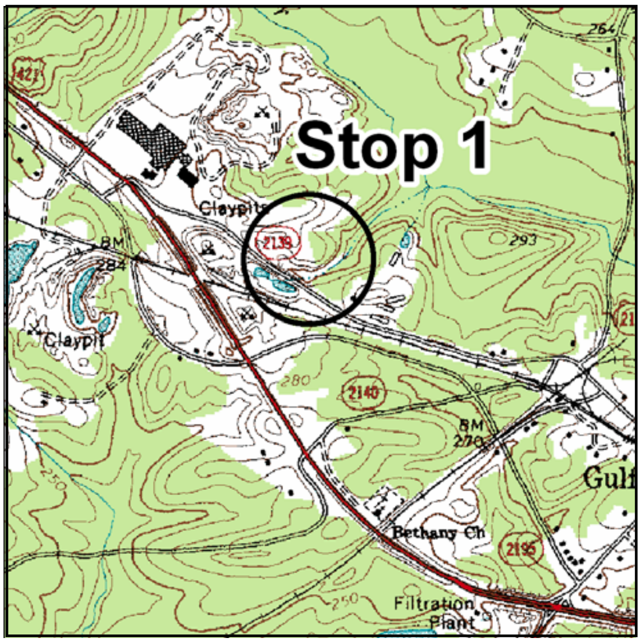

Figure 2. Boren Clay Products brick pits. Goldston 7.5- minute topographic map.

Disclaimer: *The following field stop was originally published as part of a Field Trip Guide for the 50th Annual meeting of the Southeastern Section of the Geological Society of America, April 2001, p. 27-50. It has been included in this guidebook with minor editorial changes to the text. In addition, some figures were replaced. Please reference Clark and others (2001).*

The Boren Clay Products pits are located about 1.5 miles east of the western border of the Sanford basin on both sides of US 421 (Fig. 2). Written permission must be gained from Boren Clay Products before entering the property. The pits expose strata of the middle Pekin Formation (Fig. 3) that are being mined to produce bricks and drainpipes (Gore, 1986). The Boren operations consist of several old pits northeast of US 421, as well as the old Pomona Pipe Works on the southwestern side of US 421. At present, quarrying is concentrated on the southwestern side of US 421.

The rocks in the Boren pits are dominantly reddish-brown siltstone and sandstone. Tan to white, arkosic channel sands and purple mudstones are also present in lesser amounts. Plant fragments are present in some of the finer-grained units. Most units are overprinted by *Scoyenia* bioturbation, including large backfilled burrows, probably attributable to a decapod such as a crayfish (Gore, 1986). Vertebrate tracks are also present. Invertebrate fossils are scarce, but present locally, including conchostracans or clam shrimp and small freshwater bivalves.

Thin diabase dikes are present in the pits on both sides of US 421. These dikes have thermally metamorphosed the sediments, accentuating the bioturbation. Near the surface, the diabase weathers to a yellowish-orange color, contrasting with the surrounding grayish red and reddish-brown strata. Drag folding, faulting, and intense fracturing are common near the dike.

Field trips led by Gore (1986) and Olsen and others (1989) visited the quarry on the northeastern side of US 421, which was active at the time, but which is now abandoned. This pit is one of the premier sites for Triassic plant fossils in the eastern US. The plant fossils are found in gray siltstone and shale units and yellow-tan siltstones, which are not exposed in the new pits on the southwestern side of US 421. The old pits contain abundant stems, roots, cones, and leaves of a variety of seed and non-seed plants (Fig. 4).

Gensel (1986) provided a thorough description of these fossil plants, which include ferns, horsetail rushes, cycads, cycadeoids, and conifers. One of the most unusual plant fossil finds is the only known intact specimen of *Leptocycas gracilis*, one of the oldest known cycads, a gymnosperm sometimes called the sago palm (News release, NC State University, 2000). The plant fossils suggest a tropical to subtropical climate (Gensel, 1986). Fern spores and conifer pollen are present in the gray shales and siltstones. These palynomorphs were interpreted by Traverse (1986) as Julian (middle Carnian) in age.

The Pomona Pipe quarry on the southwestern side, of US 421 (now filled with water) has yielded vertebrate fossils from reddish-brown clayshales. The most abundant vertebrate is a crocodile-like phytosaur, *Rutiodon*, known from teeth and bones. Also present are: *Typothorax*, a 2.5 meter-long armored pseudosuchian; teeth of a large carnivorous theropod dinosaur; and several specimens of *Placerias*, a herbivorous, dicynodont, mammal-like reptile (Baird and Patterson, 1967; Patterson, 1969). Fish scales and bones also occur (Olsen and others, 1989).

Figure 3. Reddish-brown siltstone and sandstone of the Pekin Formation exposed in the inactive Boren Clay Products pit. Photograph by Jeffrey C. Reid

Figure 4. Examples of plant fossils from the Boren Clay pits. Car key for scale.

The Pomona Pipe quarry has also yielded the oldest vertebrate track assemblage in the Late Triassic of eastern North America (Olsen and Huber, 1997. Tracks include both three- and five- toed forms, ranging in size from 10 to 30 cm (Olsen and Huber, 1997). The tracks are apparently dinosaurian, making them among the oldest known dinosaurian tracks in the world (Olsen and Huber, 1997). The vertebrate assemblage indicates an early Tuvalian (early Late Carnian) age. (Huber and others, 1993).

STOP 2:
Alton Creek
Cumnock Formation near Gulf, NC
Stop Leader - Kenneth Taylor

Location: 35.557465° N, -79.298638 ° W

Features of Interest: High angle fracture orientations in the Cumnock Formation.

Figure 5. Alton. Goldston 7.5- minute topographic map.

Figure 6. Black shale of the Cumnock Formation along Alton Creek. Car keys for scale.

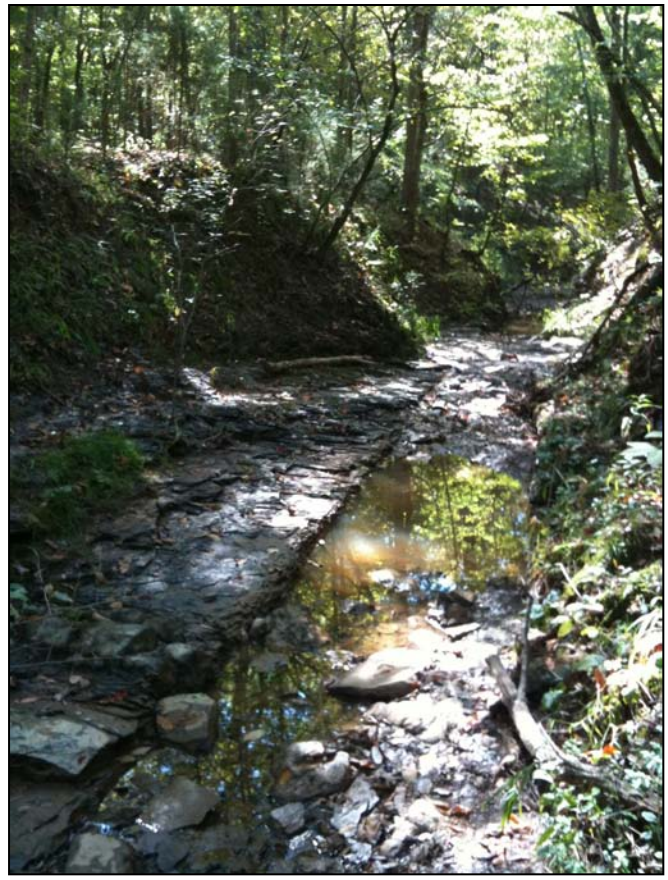

Figure 7. Pavement outcrops of Cumnock Formation.

Figure 8. (next page). Alton Creek, Chatham County, North Carolina. Orthogonal fractures observed at the sub-basin scale in LiDAR occur at the outcrop scale. Fractures are steeply dipping and have smooth sharp edges (inset top center). At this locality the fractures trend easterly (orange flagging and left rose diagram), and northerly (blue flagging and right rose diagram). Slight variations of fracture orientations coincident with LiDAR trends have been observed at different locations in the Sanford sub-basin. Knowledge of fracture orientation and spacing may prove helpful to directional- and horizontal petroleum exploration drill holes.

Two samples from this outcrop were analyzed for TOC (1.58% and 1.30%); the corresponding %Ro values are 1.86% and 3.34% -- apparently from vitrinite. The high maturity is because of heating from nearby intrusive dikes and a diabase sill that precludes identification precisely of the organic matter (OM) type. However, the finely disseminated grains that grade to amorphous size particles suggest that most OM was humic and primarily gas prone at a lower maturity. Plant spores, which are good indicators throughout the oil window are absent. The visual kerogen analysis indicates 90% gas prone, 5% oil prone, and a TAI ranging from 3.5-4.0 consistent with %Ro.

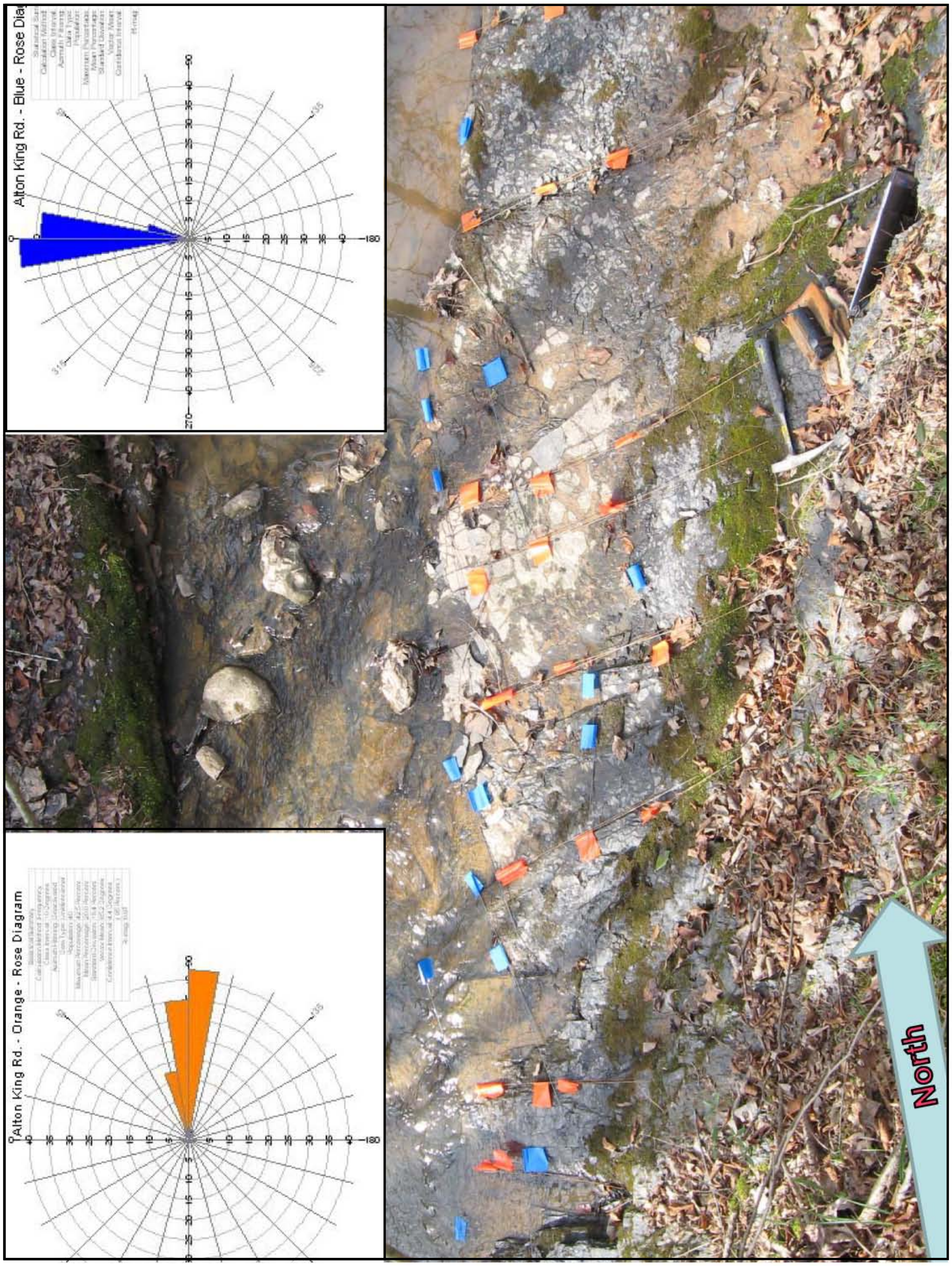

Figure 8. See caption on previous page.

STOP 3:
Carbonton Dam Site
Cumnock Formation along Deep River, near Carbonton, NC

Stop Leaders - Tyler Clark and Kenneth Taylor

Location: 35.519722° N, -79.347317° W

Features of Interest: Cumnock Formation in contact with diabase intrusion, remains of hydroelectric dam.

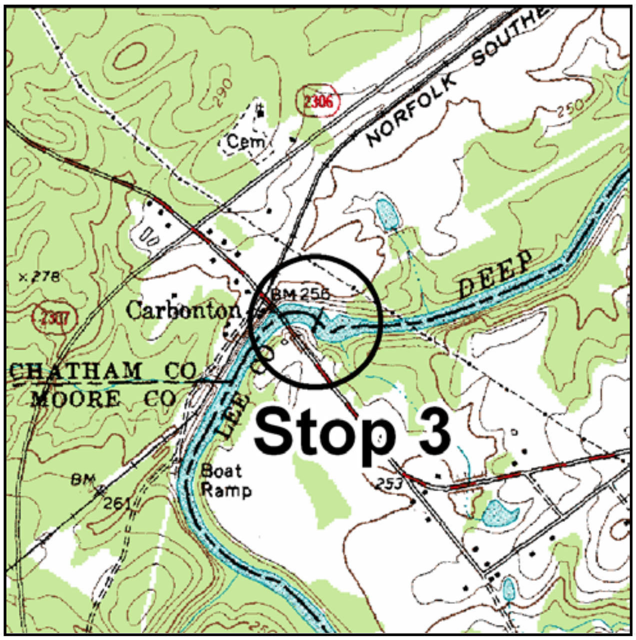

Figure 9. Carbonton Dam site from the Goldston 7.5-minute topographic map.

The Carbonton Dam once stood at this site on the Deep River (Fig. 9). It was built in 1921 and was the first hydroelectric plant in the region. The location of the Carbonton Dam, as well as earlier structures here, was chosen due to the suitable foundation provided by the highly resistant diabase and contact metamorphosed Cumnock Formation. In 2005, the dam was removed by Restorations Systems, Inc. as part of an environmental restoration project on the Deep River.

Geology of the Carbonton Dam Site

The best description of the geology of the Carbonton Dam site comes from Gore (1986), who visited the site as part of a field trip for the Third Annual Midyear Meeting of the Society of Economic Paleontologists and Mineralogists. Gore's description, written before the dam's removal, is included here in its entirety:

"Two types of rock are exposed at the north side of the Carbonton Dam: (1) a diabase (or dolerite) of Jurassic age, and (2) hornfels (contact metamorphosed argillaceous rock of the Cumnock Formation) adjacent to the dike. The diabase is relatively coarse-grained, and weathers to a light brown, granular saprolite, forming the cliff long the north bank of the river. Diabase forms rounded cobbles, which are abundant downstream of the dam, due in part to spheroidal weathering. The hornfels weathers black to dark greenish-gray, and resembles chert. Near the intrusion, unweathered hornfels is bluish-gray, becoming olive-gray farther from the intrusion. In weathered outcrop, it is nearly impossible to discern sedimentary structures, but laminations are distinct in fresh samples. Bedding is nearly horizontal, and dips gently downstream (southeast). About 4.5 m of section are exposed.

The contact between diabase and hornfels is visible below several large boulders of hornfels at the north end of the dam. The contact dips south, cutting across bedding. At the foot of the dam, hornfels overlies the diabase. The hardness of the contact-metamorphosed strata made an ideal spot in which to build the dam.

Some bedding planes in the hornfels are crowded with impressions of conchostracans. An 8 cm long bone fragment is present in a bed near the dam, and coprolites are present locally. In places, the hornfels has white spots several millimeters in diameter. Some of the more rhombohedral white spots are fish scales which have been altered by contact metamorphism (Paul E. Olsen, Lamont-Doherty Geological Observatory, Columbia University, personal communication). Green epidote-rich concretions up to 20 cm in diameter are present in hornfels below the dam. These concretions are probably calcite concretions which have been altered to epidote by contact metamorphism. Similar but smaller (approximately 1 cm in diameter) epidote nodules are present in contact metamorphic aureoles in the Culpeper basin, Virginia (Froelich et al., 1982, p. 64-65).

Diabase dikes are present throughout the Deep River basin, and in other Newark Supergroup basins, as well as the surrounding Piedmont. Metamorphic effects within the basins include changes in mineral assemblages (Froelich et al.; Lee 1982), and color change in which red beds are altered to gray. In the Deep River basin, coal beds in the Cumnock Formation are altered from bituminous coal to anthracite or semianthracite by contact metamorphism, and may be associated with natural coke (Reinemund, 1955, p.

101-104). Anthracite and coke are most extensive near Carbonton, where the intrusions are largest, and nearest the coal (Reinemund, 1955, p. 104). Because of the contact metamorphism, the coal was marketed under the name "Carbone anthracite" by Deep River Coal, Inc. The contact metamorphism also raised the thermal maturity of the organic-rich Cumnock shale. When sampling the shale to determine thermal maturity for analysis of hydrocarbon potential, it is important to collect well away from diabase intrusions so that the samples can be considered representative of the formation as a whole." *End of text from Gore (1986).*

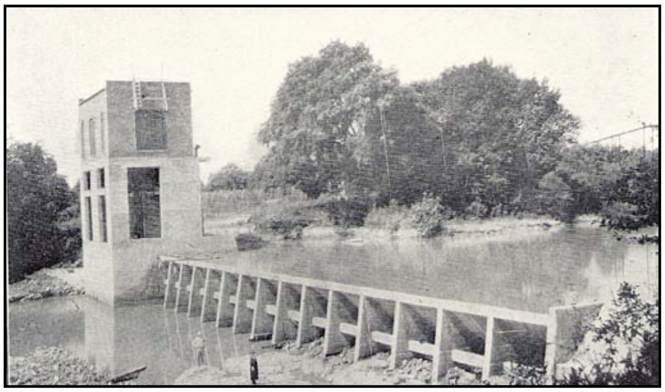

Figure 10. Carbonton Dam as viewed from the north bank of the Deep River. Note the people at the base of the dam standing on flat pavements of contact-metamorphosed Cumnock Formation. Photo from Campbell and Kimball (1923).

Figure 11. Carbonton Dam hydroelectric plant as viewed from the south bank in 2011. Note remnants of the dam on the far riverbank, just above the same pavements in Fig. 6.

Carbonton Dam Removal Project

The largest dam removal project ever in North Carolina, and the second largest in 2005 in the United States, took place in December 2005 on the Deep River in the central Piedmont region.

After five years in the planning and permitting stages, the Carbonton Dam, located 45 miles from Greensboro, Raleigh and Fayetteville, was removed to restore ten miles of the Deep River to a natural, free-flowing state last enjoyed by Native Americans. A new public river park has just been completed at its former location and is now open for public use and enjoyment.

The Carbonton Dam was the source of tremendous environmental damage. Over ten miles of the Deep River have been flooded for generations by the structure and its predecessor dams. As a result of Restoration Systems' work, the long stagnant lake behind the dam was drained and the river is restoring itself nicely, revealing rapids not seen since Woodrow Wilson was president.

The project is one of the largest rare and threatened species restoration projects of its kind in the U.S., with unprecedented benefits to rare mussels and the federally listed Cape Fear Shiner. Water quality, historically damaged by the dam, will also gradually improve over a large area with increased flow and rising oxygen levels.

The dam stood 17' high and 270' long, and spanned the storied Deep River. The current facility at Carbonton was built in 1921 as the first electrical power plant in the Sandhills. Earlier structures date back to the Evans Lock and Dam in the mid-19th century when attempts were made to move coal on barges down the river, hence the origin of the name Carbonton. The original power plant was a cornerstone of the Sandhills Power Company and ultimately became CP&L, now Progress Energy. Restoration Systems left the historic structure intact for future conversion to a public use facility, which is set to be completed by the Deep River Parks Association and funded by Restoration Systems, Inc.

The preceding section titled "Carbonton Dam Removal Project," was used with permission from Restoration System's web site. More information about Restoration Systems and their work can be found at:
www.restorationsystems.com

STOP 4:
Black Diamond Coal Mine
Cumnock Formation along Indian Creek, near Carbonton, NC
Stop Leader - Tyler Clark

Location: 35.535753° N, -79.332747° W

Features of Interest: Evidence of 19th-century coal mining, Cumnock Formation, coal seams, and drag folding along a normal fault.

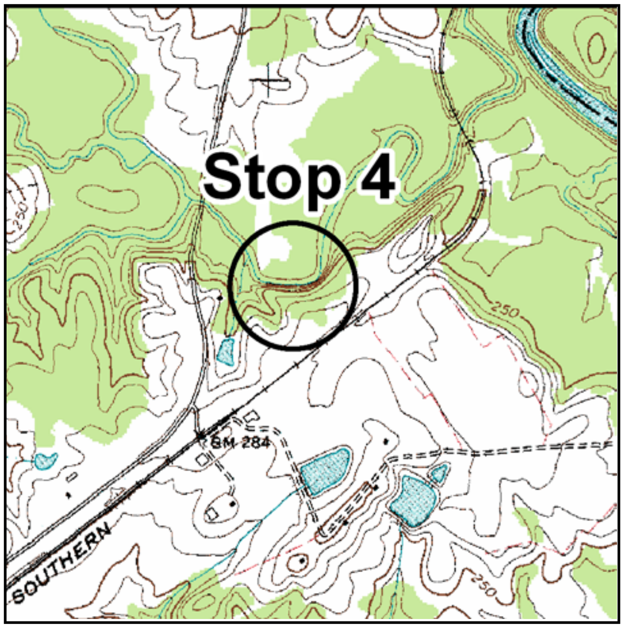

Figure 12. Black Diamond coal mine. Goldston 7.5-minute topographic map.

The Black Diamond coal mine and exposures of the Cumnock Formation occur in a heavily forested area on the top and side of a large bluff on the south side of Indian Creek (Fig. 12), approximately 300 meters east of the intersection of Indian Creek and SR 2306 (Goldston-Carbonton Rd.), and about 2 km NE of Carbonton, NC. Approximately 25 m of nearly continuous section, consisting of black and gray shales, coal beds, and a diabase intrusion, are exposed along the base of the bluff at the edge of the stream. Both the Gulf and the Cumnock coal beds are exposed. This is the largest natural exposure of the Cumnock Formation in the Deep River basin (O. F. Patterson, personal communication, 1988). The beds are steeply dipping, compared with most exposures in the basin, with a 42-degree southeastern dip. Evidence of extensive mine operations are present along the top of the bluff.

The coal exposed in this outcrop can be traced over 25 km across the northwestern part of the Sanford basin, along and near the Deep River. In total, seven beds of coal are present in the lower to middle Cumnock Formation. There are two main seams, the lower Gulf coal seam and the upper Cumnock coal seam, separated by 8.5 to 12 m of black to gray shale and siltstone (Robbins and Textoris, 1986). The Gulf coal seam typically consists of one bed ranging from a few centimeters to nearly 1 m thick, and in places it is underlain by a rooted underclay (Hope, 1975) or by sandstone. The upper Cumnock coal seam consists of three beds, together ranging from 1 to 3 m thick.

At the Indian Creek stream-cut near the Black Diamond Mine, a diabase intrusion (nearly 1 m thick) is present near the base of the section. The Gulf coal seam is exposed roughly 3 m above the diabase (measured section in Reinemund, 1955, plate 8). At this locality, the lower Gulf coal seam consists of approximately 40 cm of coal to bony or shaley coal, overlain and underlain by blackband (ferruginous black shale with siderite nodules). The blackband is overlain by shale and carbonaceous shale. About 2 m above the Gulf coal seam there are several thin beds of coal ranging from about 5 to 15 cm thick (Fig. 13).
About a meter above these thin beds (as measured within the mine nearby) is a west-dipping high-angle normal fault with associated drag folding (Fig. 14). Approximately 4 m above the fault, the Cumnock coal crops out in three main seams (meas. by John McIvor

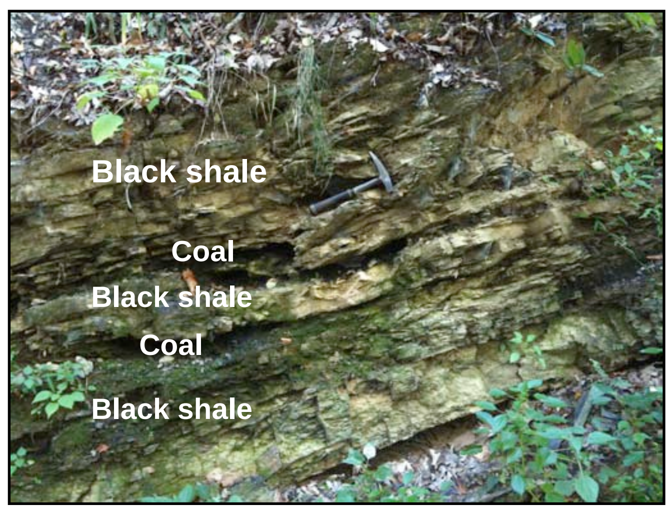

Figure 13. Outcrop of coal, shaley coal, and black shale along Indian Creek. Rock hammer for scale. Black shale weathers to a dull beige color on exposed surfaces. A small-scale reverse fault with associated drag folding is visible just below the rock hammer.

Figure 14. Outcrop of Cumnock Formation with pronounced drag folding. The normal fault responsible for the folding is poorly exposed just to the left of the photograph under the roots of a large tree. The regional dip of the rocks is from right to left. Units are drag folded to a steep angle in the left side of photograph.

in 1933, as reported by Reinemund, 1955, plate 8). The lower of the three coal seams is 50 cm thick, overlain by about 10 cm of black shale. This is overlain by about 30 cm of coal, topped by 50 cm of blackband. The upper bed of the three (main bench of the Cumnock coal) overlies the blackband and is about 50 cm thick. The main bench of the Cumnock coal seam is overlain by several meters of shale, which contains two thin (less than 10 cm) coal beds associated with blackband and carbonaceous shale (section description based on measured section from Black Diamond Mine, in Reinemund, 1955, plate 8).

Coal in the Cumnock Formation is interpreted as evidence for a tropical paleoclimate with high precipitation and/or humidity in a lake-fringing swamp environment with low rates of clastic sedimentation (Hope, 1975; Gensel, 1986; Textoris and others, 1989). The blackband siderite deposits associated with the coal indicate anoxic, low sulfate waters (Berner, 1981). The black shales are interpreted as offshore lacustrine deposits in a large, hydrologically-open, perennially-stratified lake (Gore, 1986, 1989).

Many of the mines in this area operated intermittently and unsuccessfully due to a complex system of faults which have displaced the coal, and related diabase intrusives, which have metamorphosed it from bituminous coal to anthracite or semianthracite, locally associated with natural coke (Reinemund, 1955, p. 101-104). Anthracite and coke are most extensive near Carbonton (approximately 2 km SW of the Black Diamond mine) where the diabase intrusives are largest and nearest the coal (Reinemund, 1955, p. 104).

Reinemund (1955) summarized the history of coal mining in the Sanford basin. The coal has been used locally since Revolutionary War times. By 1850, many prospects and small mines had opened along the coal outcrop. The first commercial shaft mines were opened in the 1850's. The Cumnock (or Egypt) Mine (located approximately 10 km to the northeast) penetrated the coal at a depth of 430 feet (Campbell and Kimball, 1923). The plan was to haul the coal to the Deep River and ship it downstream on barges, however the Civil War broke out just as the construction of locks and dams along the Deep River was completed. During the Civil War, the Confederate Army took over some of the mines, and the Black Diamond mine (among others) supplied coal for ships of blockade runners in Wilmington, NC. Some of the mines were sealed near the end of the Civil War to prevent the Union armies from exploiting the coal.

Reinemund (1955, p. 91) stated that the Black Diamond mine was referred to by Chance (1885, p. 43) as the 'slope at the Evans place'. It has also been called the Carbonton mine. Chance (1885) stated that all of the workings of the Black Diamond mine were confined to the lower two benches of the Cumnock coal bed. The mine was worked during the Civil War, but was not used much afterward. The mine was opened several times during the 1930's, but it has been closed since then. The combined production of the Black Diamond mine and some other pits in the area probably did not exceed 15,000 or 20,000 tons, according to estimates (Reinemund, 1955, p. 94). Reinemund (1955, p. 93) apparently visited the site in 1949 and issued the following assessment of the mine. “The workings consist of an old slope (now caved), a shaft, and an airway; all of these are connected by a gangway that joins the slope at a slant depth of about 93 feet. The airway was open in 1949, but it was flooded to within 10 feet of the portal. There are a great many surface prospect pits in the vicinity” (Reinemund, 1955, p. 93).

Disclaimer: *The previous field stop was originally published as part of a Field Trip Guide for the 50th Annual meeting of the Southeastern Section of the Geological Society of America, April 2001, p. 27-50. It has been included in this guidebook as is, without any editorial changes to the text. However, all the figures were replaced with new photographs. Please reference as Clark and others (2001).*

STOP 5:
Endor Iron Furnace
Sanford Formation
near Cumnock, NC
Stop Leaders – Tyler Clark,
Phil Bradley, and John Hairr

Location: 35.553178° N, -79.218764° W

Features of Interest: View the ruins of the Endor Iron Furnace and discuss the link between the regions natural resources and its historic economic development.

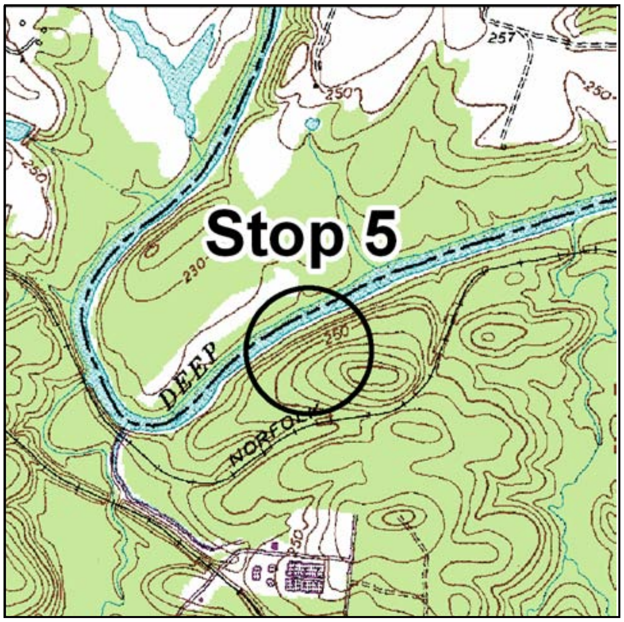

Figure 15. Location of the Endor Iron Furnace. Colon 7.5-minute topographic map.

The Endor Iron Furnace (Figs. 15 and 19) is a historic site administered by the NC Division of State Historic Sites. The furnace structure is constructed of sandstone of the Sanford Formation (Figs. 16 and 17) quarried from a nearby "brownstone" quarry. The Endor Iron Furnace site is an excellent location to discuss the link between the regions natural resources and its historic economic development. The Endor Iron Furnace as well as other furnaces in the region relied upon the coal resources of the Sanford basin and the iron deposits of Harnett County (Fig. 20). An outcrop of sandstone and siltstones of the Sanford Formation is present in the slope adjacent to the furnace. Discarded piles of slag from the smelting of iron (Fig. 18) are present throughout the grounds of the furnace.

Figure 16. Coarse-grained to pebbly, arkosic sandstone quarried locally for the blocks of the furnace.

Figure 17. Detailed stoneworking of the keystones above the furnace arched openings.

Figure 18. Discarded piles of slag from the melting of iron.

Figure 19. Wide view of the ruins of the Endor Iron Furnace. The cliffs above contain large layers of reddish-brown, medium- to coarse-grained sandstone with thin interbeds of reddish-brown, fine-grained siltstone.

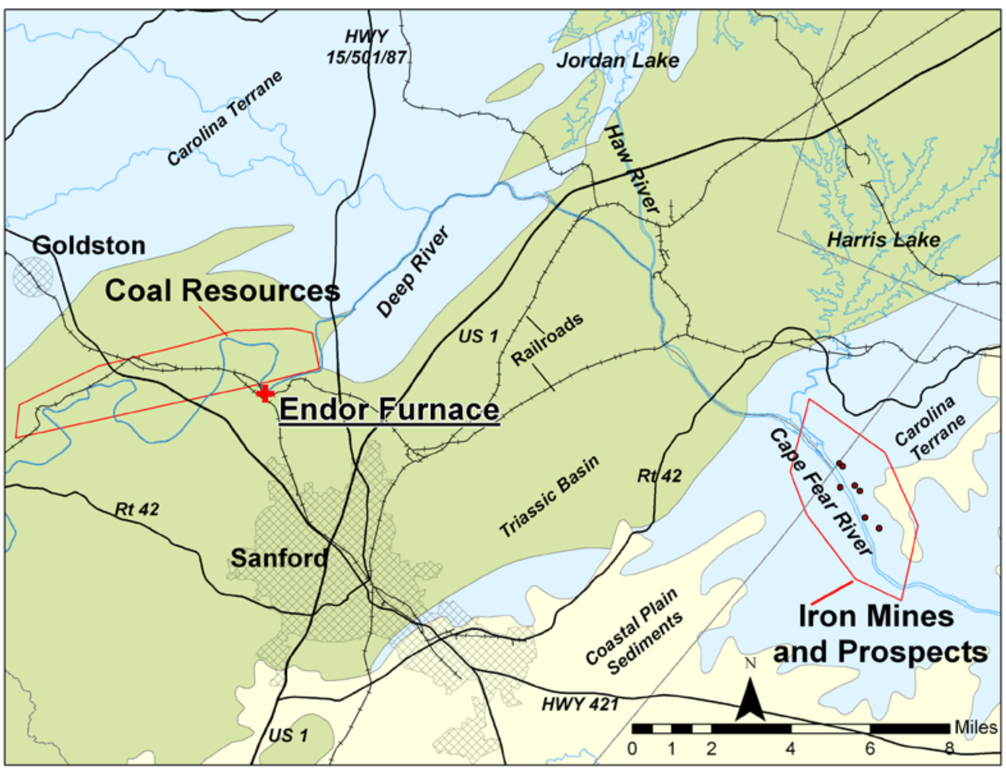

Figure 20. Location of the Endor Iron Furnace in relation to the coal resources of the Triassic basin and the iron deposits of the Carolina Terrane.

Notes on the History of the Endor Iron Works

by John Hairr, Site Manager, House in the Horseshoe State Historic Site,

Rising nearly forty feet above the surface, the stone ruins of the Endor Furnace stand along the south bank of the Deep River in Lee County. Built in 1862, the Endor Iron Works was part of an industrial complex that utilized the natural resources of the Deep River Coal Field and iron deposits along the Cape Fear River to make war materiel for the Confederate war effort during the War Between the States. Later the iron works produced iron for a mining and manufacturing conglomerate that used Endor as a part of their iron operations which they hoped would lure international investors. There were other iron operations in North Carolina during the nineteenth century, but few gained the notoriety of Endor due in large part to the strength and resilience of the iron produced by this furnace utilizing iron from the Buckhorn region of Harnett County.

The iron ore for the Endor Furnace came mainly from the Buckhorn Iron Mine, located 22½ miles downstream on the north bank of the Cape Fear River. The primary ore deposit lay at the top of a large eminence called Ore Hill, where miners extracted the ore from the earth, placed it in a tram and sent it down to the base of the hill. Here it was loaded onto flats which were towed upstream by steamboats that utilized the various canals and navigational structures then present in the Cape Fear and Deep Rivers. An example of one of these navigational works, Farish's Lock & Dam, was built by the Cape Fear and Deep River Navigation Company upon what had been a century before the site a Native American fish dam, and is located within the bounds of the proposed Endor Iron Works State Historic Site.

Interest in developing the iron resources of the Deep River valley date back to 1768, when John Willcox began operating the state's first iron works along the Deep River at Gulf (Willcox, 1988). Interest in the iron resources of the area waned after Willcox's death, but by the middle of the 1850's industrialists once again began looking into the resources of the region. The development of these resources went hand in hand with the extension of navigation along the Cape Fear and Deep Rivers above Fayetteville. The lure of mineral wealth also led to the construction of the Western Railroad from Fayetteville to the Egypt Coal Mine. The Western Railroad would prove to be a more reliable mode of transportation than the lock and dams on the rivers, which were frequently out of commission due to damage suffered during floods and freshets. During the war, the railroad was an integral part of the transportation network that combined river born transportation of raw materials and pig iron from Buckhorn upstream to Endor and Egypt, and then down the Western Railroad to Fayetteville, thus avoiding the hazardous rapids along the Cape Fear where navigational improvements had failed.

The mineral related activities were not a localized affair, and drew interest from people all over the country. State Geologist Ebenezer Emmons (Emmons, 1858) proposed that the area would be an ideal location for the building of a national foundry. Federal legislation actually sent Commodore Charles Wilkes, famous for exploration of Antarctica and numerous islands in the Pacific, into the Deep River country to examine its suitability as a site for a national foundry (Wilkes, 1858). The War Between the States broke out before this could be put into place, but the notion lived on. Several prominent North Carolinians supported the idea, and eventually a bill was passed by the Confederate Congress establishing a Confederate Foundry on the Deep River. The bill was signed into law by President Jefferson Davis just a few weeks before the collapse of the Confederate government.

There were two phases of operations for the ironworks at Endor. The first phase began when the Endor Iron Company was incorporated in April of 1862 by several men from a Wilmington mercantile firm including John MacRae, Donald MacRae, John W.K. Dix, John C. MacRae and W.H. MacRae, along with Benjamin Jordan of Virginia (Articles, 1862). An ironmaster from Virginia who had been convinced to bring his iron-making skills to North Carolina by Governor John W. Ellis, Jordan oversaw initial construction of the furnace, which was completed later that same year. The furnace was described in 1868 as being 35 feet tall, and 35 feet square at the base. Though it was built in close proximity to several coal mines, the Endor Furnace was fueled mainly by charcoal, although records do speak to the presence of coke ovens on the property. Shells from the Tertiary materials exposed in bluffs along the Cape Fear between Wilmington and Fayetteville were used as a fluxing material. Iron produced here was shipped south to Fayetteville via the Western Railroad, with a spur line from Endor intersecting the main line near McIver's Depot. In

Fayetteville, the iron could be manufactured into weapons at the Fayetteville Arsenal, or shipped downstream to Wilmington.

The ironworks at Endor covered several acres of ground well beyond the furnace structure itself. Exactly how extensive the operation was is unknown, and will require a great deal of archeological work in the future to determine. In addition to the furnace and ancillary structures, there would have been rail terminus facilities, docking facilities for loading and offloading cargo along the river, and transportation improvements for moving men and equipment between the base of the hill and the bluff overlooking the furnace. In addition, there would have been housing needed for the workmen, which included both free and enslaved labor during the early years of the furnace's operation.

The scope of the Civil War era iron operations at Endor is not well understood, but later reports note the presence of various buildings and machinery at the site, including an assortment of engines, a rolling mill, a foundry, a Cumberland coal stove, heavy tilt hammers and a blacksmith shop (Endor Iron Works Ledger, 1864-69) . In the summer of 1871, George H. Elliott (1872) made an examination of the Cape Fear and Deep Rivers for the U.S. Army Corps of Engineers, and in his report gives some interesting hints to the extent of the iron operations at Endor that were still visible six years after the end of the fighting. "Two miles below Egypt are the Endor iron-works, built by the confederate [sic] government during the late war; they are quite extensive, and the buildings, furnaces, engines, and other machinery are apparently in good condition."

There were several types of ore available in the area, including blackband ore which was extracted from the coal mines nearby. Kerr (1875) wrote of these ores, "The next ores demanding our attention are the *Black Band* and *Ball Ore*, or 'kidney ore' of the coal measures. These are earthy and calcareous carbonates of iron, imbedded in the black, carbonaceous shales which enclose the coal, or are interstratified with the coal itself. These ores seem to be co-extensive with the coal in Deep river, outcropping everywhere with it at several places outside of its limits." There was also, "…a bed of brown hematite…" on the McIver property adjacent to Endor (Nitze, 1893).

By far, the vast majority of the ore used at Endor came from Buckhorn, where a deposit of iron ore was discovered by William McClane in 1856. As superintendent of the Egypt Coal Mine, McClane was well acquainted with the blackband ore that was found with the coal, but the ore he found downstream at Buckhorn was unlike any he had seen along the Deep River. Commodore Wilkes (Wilkes, 1858) described the iron as "remarkable ore," and wrote of the deposit, "There is another locality of iron ore lying without this coal formation, and rising through the older slate rocks, on the Cape Fear river, at Buckhorn Falls. Although it was not immediately connected with the district to which our examination was directed, yet it was visited. It lies some 9 miles below the junction of the Haw and Deep rivers, immediately on the east bank of the Cape Fear river. This ore hill rises about 300 feet in height. It passes in a southeast direction for nearly a mile, and covers a surface of over 300 acres. It is somewhat dome-shaped, and appears to be one mass of very rich ore, having a solid vein of pure peroxide, which is 8 feet in width, while ores containing manganese and siliciuos [sic] matter extend beyond it on each side…It is a massive peroxide of iron in composition, similar to the well known specular ore—is of a dull reddish brown color—has bright streak—is not crystallized, but very heavy, tough, but not difficult to break."

The pig iron produced at Endor, as well as that produced by a rival company downstream at the Ocknock Furnace at Buckhorn, was used to produce implements of war, but the iron was also used to make railroad car wheels, which were found to be among the most durable wheels made anywhere in North America. A correspondent for the *Weekly Standard* (Anonymous, 1863) described the resilience of one of these wheels made from Buckhorn iron that was produced at Endor, "…which required forty vigorous blows of the sledge hammer to crack, and even then the outer circle was not affected. This severe test satisfies the workmen that the Endor iron is the best ever made in this State."

The furnace operated sporadically during the five years after the war, manufacturing iron mainly used for local consumption. On June 8th, 1866, the Lockville Mining & Manufacturing Company took over the operation of the furnace. Their first item of business was to sign an agreement with John A. Smith to produce iron. The agreement stated that the company was to supply, "wood and Iron," while Smith supplied the "Coke and Labor, each to have half of iron castings and one half the bills for Special casting." (Endor Iron Works Ledger, 1864-69).

George G. Lobdell, an ironmaster from Delaware who owned an ironworks that manufactured railroad car wheels, became acquainted with the resilience of the iron produced from the ore extracted from the Buckhorn Mine during the war, and set about obtaining the source of this iron for his company. Lobdell learned of the existence of the iron thanks to a series of tests he performed on wheels from a captured Confederate railroad car, which outperformed the wheels produced in his own ironworks, which were considered to be the best in the country. Intrigued, he set about trying to track down where the wheel came from, a five year search that finally led him to Endor and Buckhorn (Fowler, 1967). On August 6th, 1870, he paid $1,000.00 for the Endor Iron Furnace property, which was being auctioned off by the sheriff of Chatham County (Lobdell, n.d.).

After chartering a new corporation, the Cape Fear Iron and Steel Company, Lobdell and his partners began the work of exploiting the mineral resources of the upper Cape Fear and Deep Rivers in earnest. They obtained the rights to the various navigation company works along the rivers, purchased coal mines and other mineral deposits, and repaired the locks and dams between Battles Lock & Dam and Carbonton so they could efficiently transport their raw materials (Lobdell, n.d.). Kerr (1875) wrote of these efforts, "They have already expended upwards of $300,000 in opening the navigation of the river for a distance of some 40 miles above the ore bank, through the coal deposits, and have also repaired the Endor furnace and put it in blast, and have been making a very superior car-wheel iron." He also noted that the ore from Buckhorn was exceptionally pure and free from phosphorus and sulphur, and the iron produced using this ore was, "…mostly a spiegeleisen…" (Kerr, 1875).

At the heart of their ambitious undertaking was the construction of ironworks at both Endor and Buckhorn. At Endor, several expensive modifications were made to convert the furnace from a cold blast furnace into a more efficient hot blast operation. When they were finished, Lobdell's workers had raised the height of the Endor Furnace to 39 feet and increased the furnace's annual capacity to 2,500 tons (Swank, 1880). Fortunately, there exists an eyewitness account of the modifications made to the Endor Furnace. The writer, a correspondent for the *New York Times*, was not impressed with the remodeled furnace. "At the Endor Works, an old furnace used during the war with poor success has been refitted and not improved. It was calculated to make about ten tons per day. After chilling up twice it was finally got to work, and at the time of my visit was making one ton per day of white iron. It is illy [sic] constructed and badly planned. The best blast pipes are on top, and the blast passes thence down exposed through the air to the *tuyeres*. The blast is driven by an engine, the steam boiler of which are also heated by the waste gases. As the gas to heat the hot blast is lighted the moment it leaves the furnace, it is evident that the top of the furnace must be very hot, and the bottom disproportionately cool." (Anonymous, 1873)

Meanwhile, at the site of an earlier ironworks at Buckhorn, Lobdell erected the most elaborate furnace of the entire operation. Lobdell (n.d.) later noted that the Buckhorn Furnace was among the best equipped in the South. At 54 feet tall and an annual capacity of 4,500 tons, it was the largest iron furnace in the state (Swank, 1880). But it was plagued with many problems, and was in use for less than a year. The same correspondent from the *New York Times* commented upon these works, "That the plans were well drawn there is no doubt, but it would be hard to find a more ill-judged affair. The blowing cylinders were perched fifteen to twenty feet above the ground on a trestle-work made of timber about 10 by 12. If they had intended to rock the workmen's babies to sleep they could have hardly fixed a better place. The furnace itself was modeled by a very excellent engineer of Pennsylvania, but without the slightest knowledge of the ore to be used, which is probably one of the most intractable in this country." The correspondent then made the following ominous prediction. "From present appearances it will take full four months of hard work to put this furnace in blast; it is calculated to make twenty tons per day, and will probably make one-fourth that amount, or none at all." (Anonymous, 1873)

The exact reasons for the failure of the iron operations at Endor and Buckhorn are uncertain. Although many claim that the ore ran out shortly after the Buckhorn Furnace went into operation in 1874, this was not the case, as ore was still being transported from the mines along the Cape Fear upstream to Endor for several years afterward. In addition to the mechanical problems mentioned above, contemporary observers noted that the problems had more to do with financial speculation than lack of raw materials. Another factor that has to be considered is the availability of inexpensive iron produced from Pennsylvania which flooded the market after the war, thus making iron operations in North Carolina such as those along the Deep River financially unviable. Regardless of the reason, the last load of ore from Buckhorn was transported along the river to Endor in 1880, and the massive stone furnace has remained silent ever since.

STOP 6 (OPTIONAL):
Deep River fault
Sanford and Cumnock Formations
near Cumnock, NC
Stop Leader – Tyler Clark

Location: 35.553178° N, -79.218764° W

Features of Interest: Sandstone and siltstones of the Sanford Formation in fault contact with the Cumnock Formation across the Deep River fault, also diabase.

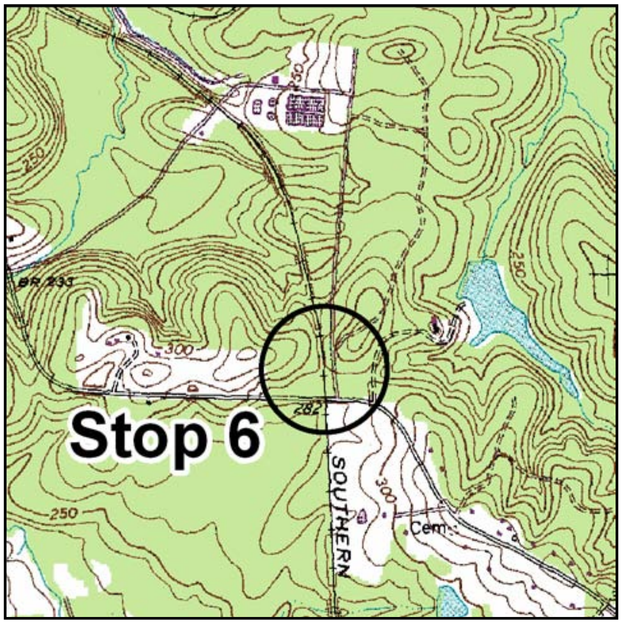

Figure 21. Location of the Deep River fault along railroad cut, just north of Cotton Road. Colon 7.5- minute topographic map.

Stop 6 is along an active railroad just north of Cotton Road (Fig. 21), therefore care should be taken in the case of trains. The majority of the rocks exposed in this cut are reddish-brown sandstones and interbedded siltstones of the Sanford Formation. These units are excellently exposed along the north end of the cut. However, careful examination of the southern end of the cut will reveal grey shales of the Cumnock Formation. The boundary between the two units is the Deep River fault, which at this location has been intruded and partially replaced by a Jurassic-age diabase dike. The best description of the Deep River fault is provided by Reinemund (1955) and is republished here:

"The Deep River fault is a regionally- important structure in the Deep River coal field. It has produced horizontal offsets in the coal outcrops, southwest of Carbonton and north of the McIvor Mine, amounting to about a mile and a half at each locality, and it has raised the coal in the center of the field from a depth of more than 3,000 feet below sea level on the northern side of the fault to a depth of less than 2,000 feet below sea level on the southern side of the fault. Near the McIvor Mine the vertical displacement in the coal beds along this fault is about 2,200 feet, and south of the Murchison Mine it is about 2,000 feet."

"The best exposure of this fault in the entire field is in a cut on the Atlantic and Yadkin Railroad near the McIvor Mine, where it separates red and brown sandstones of the Sanford formation from gray shales of the Cumnock formation and is followed for a short distance by a diabase dike."

Figure 22. Panoramic mosaic view of the Sanford Formation exhibiting massive to well-bedded, reddish-brown sandstone dipping approximately 15-20 degrees to the south-southwest. View is to the west.

Figure 23. Interbedded, reddish-brown sandstone and siltstone of the Sanford Formation. View is to the west.

STOP 7:
Standard Minerals Pyrophyllite Mine
Glendon, NC

Stop Leader – Phil Bradley

Location: 35.503548° N, -79.425273° W

Features of Interest: Active pyrophyllite mine in deformation zone of Glendon fault, hydrothermally altered rock types, deformation features along the Glendon fault, and pyrite.

Background and Regional Overview

The Glendon, NC area (Fig. 25) is home to several economic deposits of pyrophyllite that were first documented in the early to mid 1800's (Olmstead, 1822 and Emmons, 1856). Stuckey (1928 and 1967) and Conley (1962) conducted investigations into the structure and characteristics of the deposits. McDaniel (1976) and Spence (1975) interpreted the origin of the pyrophyllite deposits as being related to ancient hydrothermal (hot spring) activity. Green et al. (1982) presented the results of geologic mapping, interpretations of the stratigraphic sequence and depositional framework of the rocks within the region (Fig. 25). Moore (1980) investigated the rocks immediately southwest of the Glendon pyrophyllite mines and documented the structural complexity of the area due to over-printing faulting. Klein (1985), as part of a detailed field trip guide, described aspects of the geology, mineralogy and structure of the Glendon pyrophyllite deposits.

The Glendon pyrophyllite deposits are located in northeast Moore County within the Virgilina sequence (Harris and Glover, 1988; Hibbard et al., 2002; and Hibbard et al 2006) of the Carolina terrane. Available age dates from the northern portions of the Virgilina sequence indicate a ca. 633 to 612 Ma age for the Hyco Formation portion of the sequence (Wortman et al., 2000; Bowman, 2010; and Bradley and Miller, 2011) and a ca. 588 to 578 Ma age from youngest detrital zircons from the Aaron Formation portion of the sequence (Samson et al., 2001 and Pollock, 2007). There is no geochronologic data from the areas surrounding the Glendon deposits and the region has not been mapped in detail scale (1:24,000).

In southern Orange County, Hyco Formation units are intruded by the ca. 579 Ma (Tadlock and Loewy, 2006) East Farrington pluton and associated West Farrington pluton. The Virgilina sequence was folded and subjected to low grade metamorphism during the ca. 578 to 554 Ma (Pollock, 2007) Virgilina deformation (Glover and Sinha, 1973; Harris and Glover, 1985; Harris and Glover, 1988; and Hibbard and Samson, 1995). In general, layering of Virgilina sequence lithologies are interpreted to range from shallowly to steeply dipping due to open to isoclinal folds that are locally overturned to the southeast. In the Roxboro, NC area, folded Virgilina sequence lithologies are intruded by the ca. 546 Ma Roxboro pluton (Wortman et al., 2000).

Lithologies of the Virgilina sequence are unconformably overlain by the Albemarle sequence in the Carolina terrane. Rocks of the Albemarle sequence have been overprinted by upright folding with an axial planar cleavage accompanied by greenschist facies metamorphism. Timing of this deformation has been interpreted as ca. 450 ma (summarized in Hibbard et al., 2002). Folds associated with Virgilina deformation may have been tightened and experienced reverse faulting during the ca. 450 Ma or later event.

The Glendon Pyrophyllite Deposits

The Glendon pyrophyllite deposits consist of four mines, from southwest to northeast they are the; Bates (inactive), Phillips (inactive), Womble (active Standard Minerals mine) and White (inactive for pyrophyllite) Mines (Fig. 25). Pyrophyllite is used to manufacture a variety of products for the refractory, ceramics and filler industries. Some of the early mining in the Glendon area was underground; mining is presently from open pits (Fig. 24).

Figure 24. Panoramic view of the Standard Minerals pyrophyllite mine. View is to the northeast, directly along the strike of the Glendon fault.

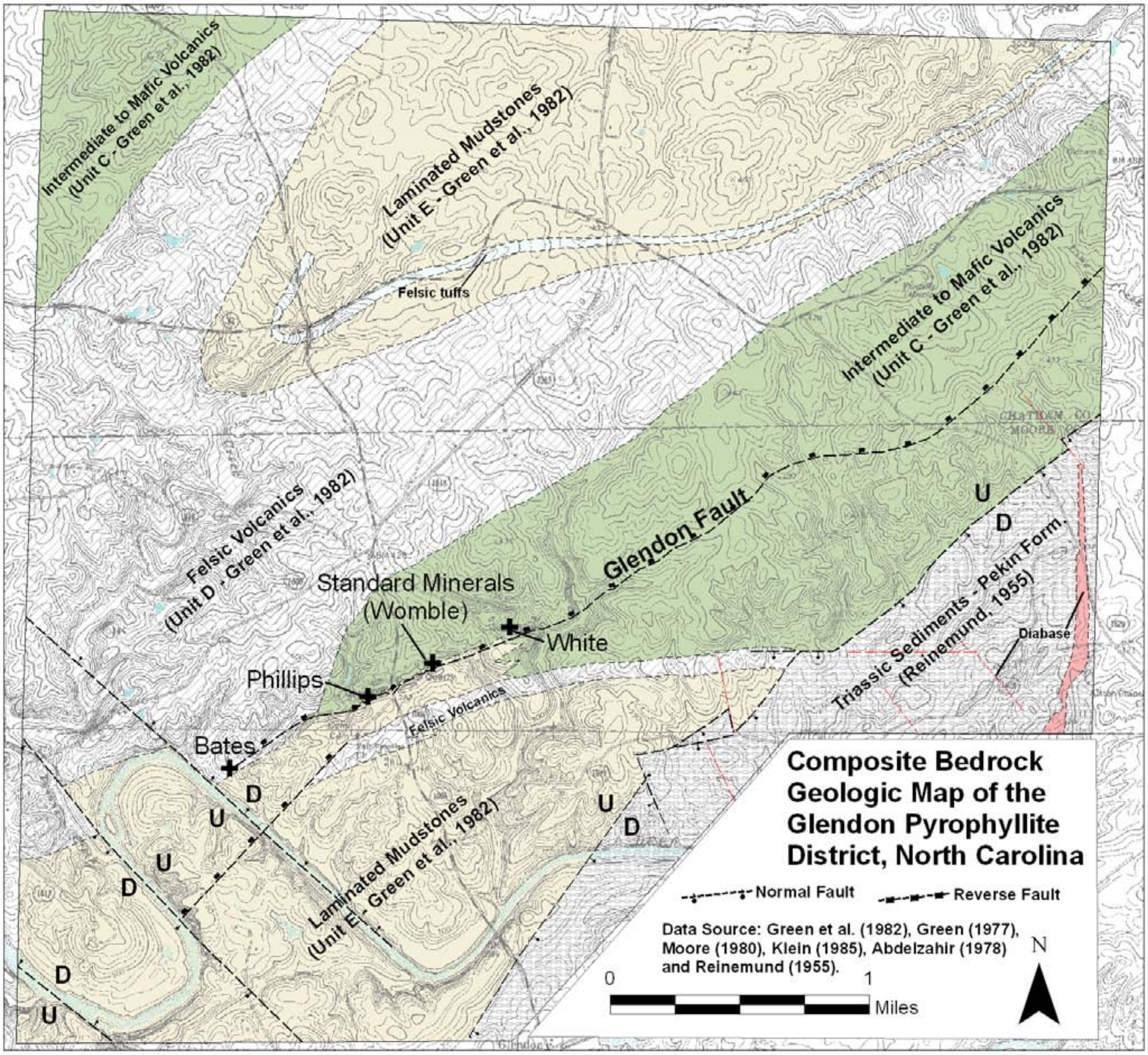

Figure 25. Composite geologic map of the Glendon pyrophyllite district, North Carolina. Data Source: Green et al. (1982), Green (1977), Moore (1980), Klein (1985), Abdelzahir (1978) and Reinemund (1955).

The mines are located along the Glendon fault (Stuckey, 1928 and Conley, 1962). The Glendon fault is a high angle reverse fault that is a locus of pyrophyllite alteration for a distance of over 30 km (18 miles) in northeast Moore County and into southern Chatham County. The Glendon fault is interpreted to be parallel to the axial surfaces of regional-scale overturned folds and disrupts an anticline near its crest (Green et al., 1982 and Klein, 1985). In general, the fault is a zone of intense deformation ranging from 10 to 50 meters wide with abundant small scale folds, fractures and deformed and undeformed quartz veins indicating a complicated movement history (Klein, 1985). Quartz veins may be folded and high strain foliations present within the fault zone overprint and/or transpose primary bedding and regional foliation. Northwest-trending faults of probable Mesozoic aged cut the Glendon fault.

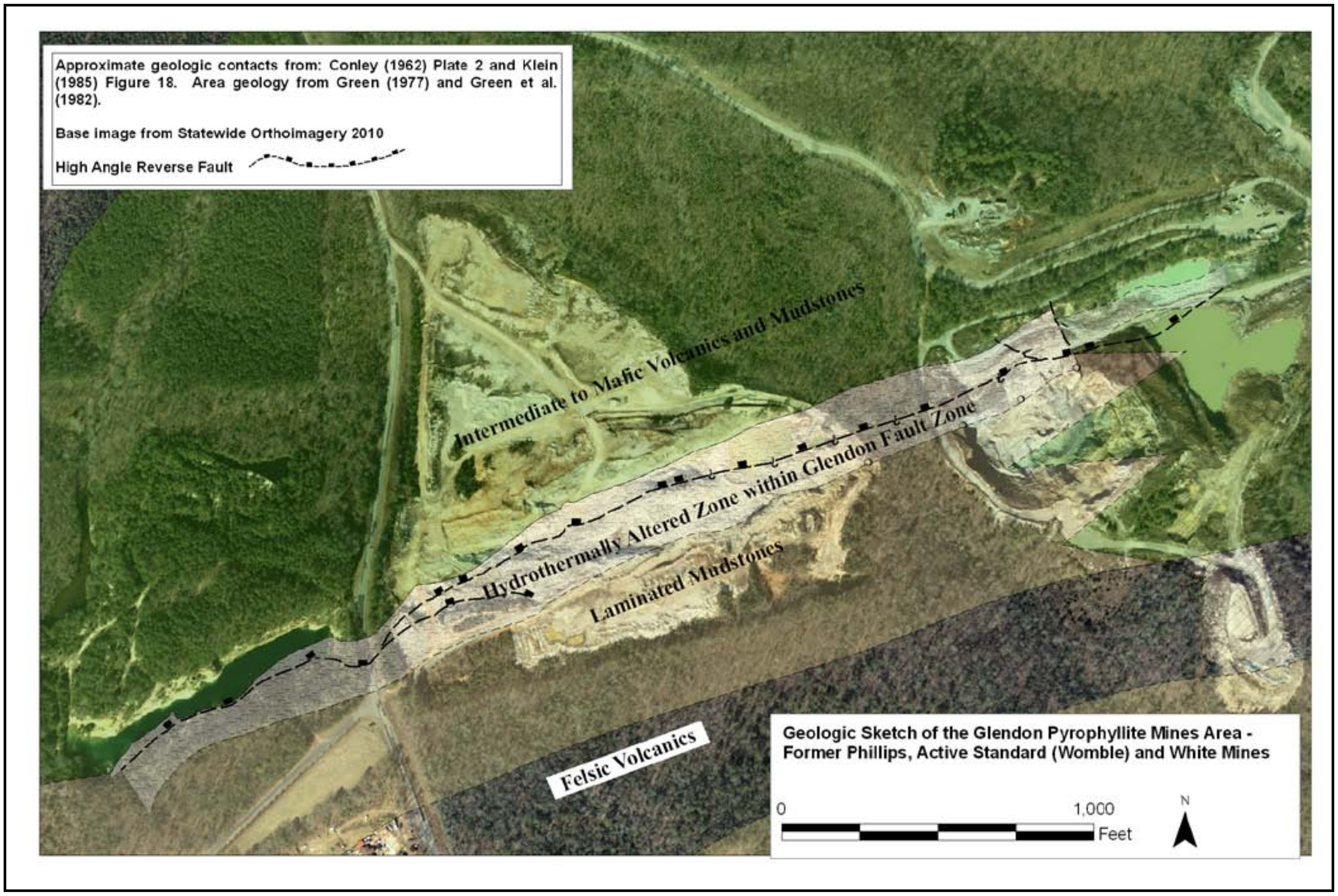

Figure 26. Geologic Sketch of the Glendon Pyrophyllite Mines Area - Former Phillips, active Standard (Womble) and White Mines. Approximate geologic contacts from: Conley (1962) Plate 2 and Klein (1985) Figure 18. Area geology from Green (1977) and Green et al. (1982).

Figure 27. Sericite altered – andesitic lithic tuff of the north side of the Standard Minerals mine. Relict lithic clasts and bluish-gray color is typical of unaltered rock.

Figure 28. Relict layering, interpreted as primary sedimentary bedding, is locally visible in outcrop and float blocks from the south side of the Standard Mine. Photograph is of a float block of strongly altered sericite-pyrophyllite phyllite.

Rock Types within the Mine

According to Klein (1985), rock types on the north side of the Standard Minerals mine consist of sericite-altered andesitic lithic tuffs and tuff breccias (Fig. 26). The rocks become progressively schistose and sericitized toward the Glendon fault (Fig. 27). Green et al. (1982) designated these rocks as part of their unit C – Intermediate to mafic volcanic and sedimentary rocks consisting of: 1) interbedded, intermediate to mafic lava flows, volcanic breccias and tuff; and 2) volcanic greywacke sandstone interbedded with laminated mudstone and local andesitic tuff.

Rock types on the south side of the Standard Minerals mine are interpreted as mainly laminated mudstones with lesser amounts of andesitic to basaltic rocks. Relict layering is present locally (Fig. 28). The south wall within the White mine has a distinctive volcanic breccia between the mudstone and andesitic basalt that consists of basalt and mudstone clasts in a red, very fine-grained, siliceous matrix with sub-millimeter color banded laminations. A similar rock type is present near the southeast wall of the active Standard Minerals mine (Fig. 29). Klein (1985) indicated that this deposit might be exhalative and formed by surficial hot spring activity.

Rocks in the altered zone at the Standard Mine are interpreted as laminated mudstones that show graded bedding and locally contain thin interbeds of felsic tuffs. Klein (1985) correlated the mudstones with Unit E of Green et al. (1982). Complex isoclinals folds of relict mudstone bedding and foliation (Fig 30) are present. According to Klein (1985), "folding and fracturing of quartz veins, silicified breccias and strained pyrite cubes in the foot wall of the Glendon fault suggest that deformation continued after early, fracture controlled high-alumina alteration and sulfide deposition."

High-grade pyrophyllite is white to light gray, strongly foliated and commonly contains relict mudstone layering. Pyrophyllite occurs as parallel flakes and locally as randomly oriented or radiated aggregates. Chloritoid in the form of prisms and rosettes is common in small amounts throughout. According to Klein (1985): 1) small amounts of sericite and moderate amounts of kaolinite accompany pyrophyllite; 2) veins and disseminated grains of pyrite are widespread; 3) other minerals reported or observed in the Glendon deposit are diaspore, apatite, zircon, ilmenite, rutile, epidote and fluorite; and 4) silicified zones are present locally with abundant disseminated pyrite (Fig. 31).

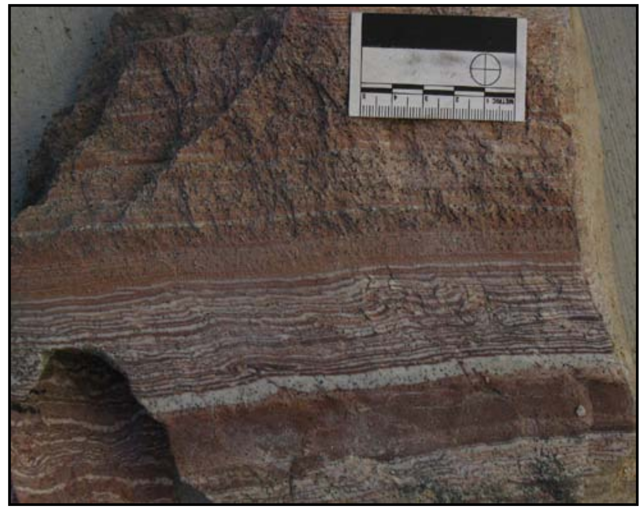

Figure 29. Boulder exhibiting alternating red and white bands from the south side of the Standard Minerals mine.

Figure 30. Folded and faulted foliation from the central portion of the altered zone of the Glendon fault.

Figure 31. Abundant pyrite cubes are in localized sulfide rich zones within the altered zone of the Glendon fault.

Presence of Gold in Pyrophyllite Deposits

The hydrothermal alteration associated with the formation of pyrophyllite deposits may be linked to the hydrothermal alteration associated with gold deposits and has been studied in detail by Powers (1993) at the pyrophyllite deposits in nearby Robbins. Recent work in Moore County by Rapprecht (2010) investigated the Deep River Gold Prospect, in northern Moore and southern Randolph Counties to determine the geologic setting, stratigraphy and patterns of alteration. The Deep River Prospect was interpreted as a porphyry–type deposit by Rapprecht (2010), that is flanked by gold–pyrophyllite and pyrophyllite deposits.

Teseneer (1978) analyzed gold and other trace elements content of pyrite from 21 locations within the Piedmont of North Carolina. Teseneer found gold content ranging from 33 to 167 parts per million (ppm) for all samples. A sample of pyrite from the Womble mine (active Standard Minerals mine) had a gold content of 43 ppm.

Lesure (1981) presented the results of the analyses of 244 samples collected from old gold mines, pyrophyllite deposits and road outcrop throughout northwestern Moore County. One hundred and ninety four (194) of the rock samples contained gold in quantities ranging from 0.02 to 2.4 ppm. Twenty-six (26) samples were collected from the Glendon pyrophyllite deposits and vicinity. Gold values ranged from 0.02 to 0.04 ppm.

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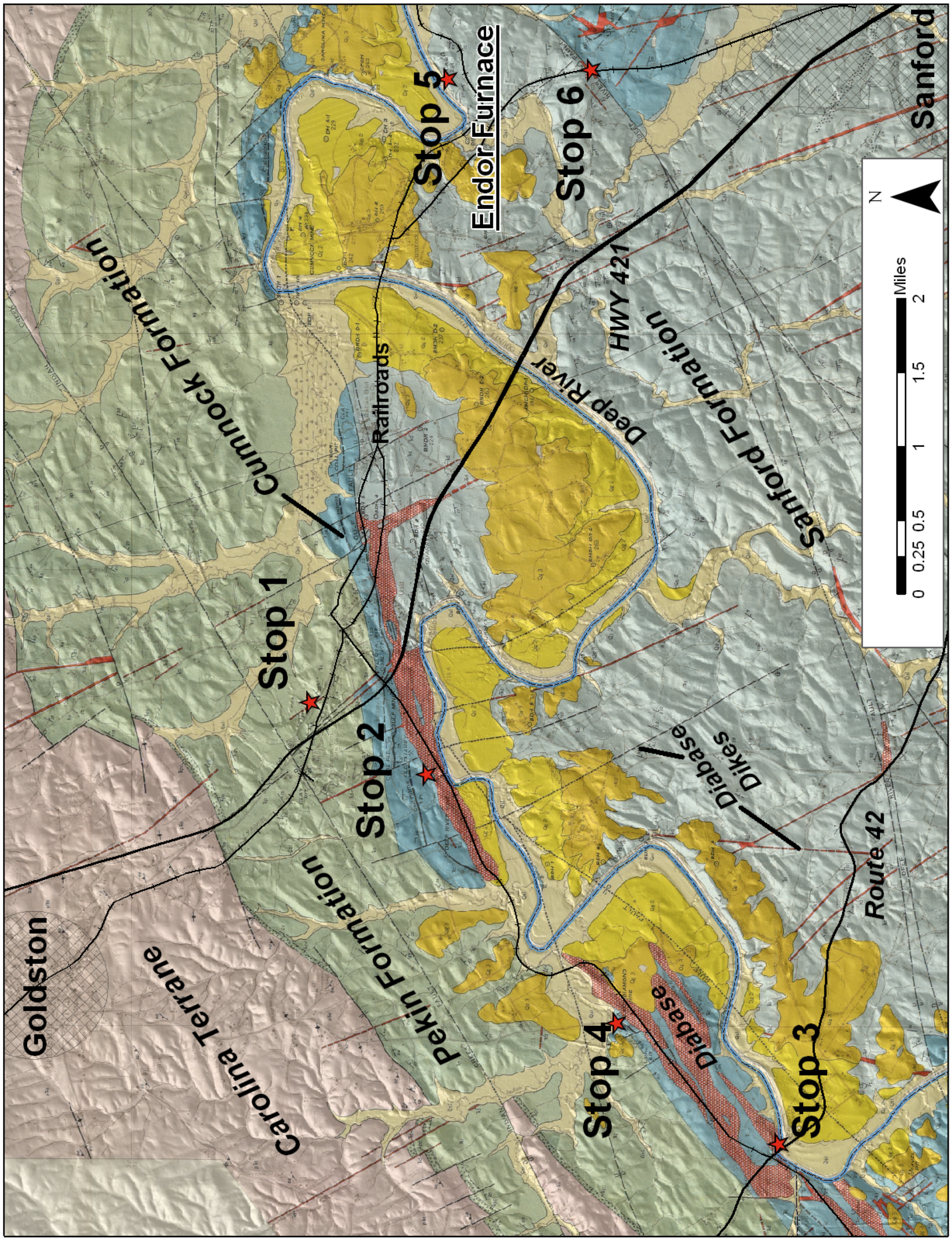
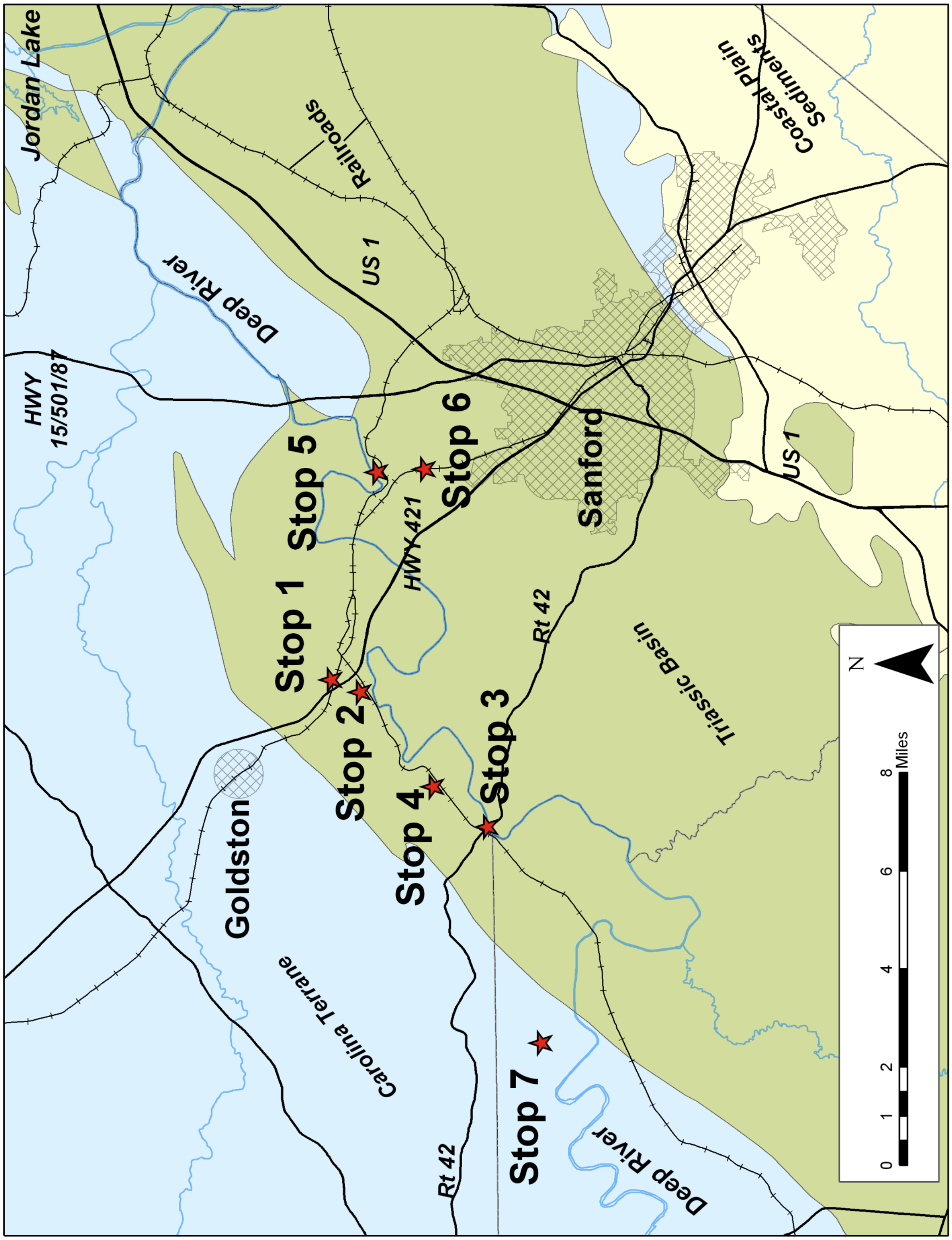


Locations of Field Trip Stops 1 through 6. Crystalline basement rocks of the Carolina terrane shown in pink, Late Triassic Pekin Formation in green, Late Triassic Cumnock Formation in dark blue, Late Triassic Sanford Formation in light blue, Jurassic diabase (dikes and sills) in red, and Cenozoic surficial deposits in yellow. Base map is from Reinemund (1955) with LiDAR shaded relief overlay.



Locations of Field Trip Stops 1 through 7. Crystalline basement rocks of the Carolina terrane shown in blue, Late Triassic sedimentary rocks of the Deep River basin shown in green, and Cretaceous and Cenozoic Coastal Plain deposits shown in light yellow.