

**GEOLOGY AND HEAVY-MINERAL EXPLORATION  
OF SEDIMENTARY DEPOSITS ALONG THE FALL  
ZONE OF NORTHAMPTON, HALIFAX, NASH, AND  
WILSON COUNTIES, NORTH CAROLINA**

**by**

**PATRICIA E. GALLAGHER and CHARLES W. HOFFMAN**

**OPEN-FILE REPORT 90-4**

**NORTH CAROLINA GEOLOGICAL SURVEY**

**DIVISION OF LAND RESOURCES**

**RALEIGH**

**1990**

**STATE OF NORTH CAROLINA  
JAMES G. MARTIN, GOVERNOR**

**DEPARTMENT OF ENVIRONMENT,  
HEALTH, AND NATURAL RESOURCES  
WILLIAM W. COBEY, JR., SECRETARY**

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## GEOLOGICAL SURVEY SECTION

The Geological Survey Section examines, surveys and maps the geology, mineral resources, and topography of the state to encourage the wise conservation and use of these resources by industry, commerce, agriculture and government agencies for the general welfare of the citizens of North Carolina.

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# CONTENTS

|  |    |
|--|----|
| Abstract .....                             | 1  |
| Introduction.....                          | 1  |
| Heavy-mineral exploration .....            | 2  |
| Recent activity.....                       | 2  |
| Economic heavy minerals.....               | 3  |
| General.....                               | 3  |
| Occurrence.....                            | 4  |
| Mining techniques .....                    | 4  |
| Titanium-bearing minerals.....             | 4  |
| Monazite.....                              | 5  |
| Zircon.....                                | 6  |
| Geology .....                              | 6  |
| State Geologic Map compilation .....       | 6  |
| Background .....                           | 6  |
| Mapping methods .....                      | 7  |
| State Geologic Map units .....             | 8  |
| Yorktown Formation.....                    | 8  |
| Terrace deposits and upland sediment ..... | 9  |
| Piedmont rocks .....                       | 9  |
| Summary of previous studies .....          | 9  |
| Conclusions .....                          | 13 |
| Acknowledgements .....                     | 14 |
| References cited.....                      | 14 |

## ILLUSTRATION

|   |   |
|---|---|
| Figure 1 Diagrammatic map and cross-sectional views of generalized geology<br>of northern inner Coastal Plain of North Carolina ..... | 8 |
|---|---|

# **Geology and Heavy-Mineral Exploration of Sedimentary Deposits Along the Fall Zone of Northampton, Halifax, Nash, and Wilson Counties, North Carolina**

## **ABSTRACT**

The report of potentially economic occurrences of titanium sand deposits in upland sediments along the Fall Zone in Virginia has resulted in active heavy-mineral exploration in North Carolina and Virginia. In North Carolina, exploration is concentrated in the "Terrace deposits and upland sediment" unit, an informal unit mapped along the Fall Zone for the 1985 Geologic Map of North Carolina. Two potentially mineable deposits have been delineated thus far in each of North Carolina and Virginia. This report includes background information on the geology and potential heavy-mineral resources for the Fall Zone area of North Carolina and is intended for use by landowners, exploration companies, and other interested parties.

Heavy minerals of economic interest in the upland sediments include the titanium-bearing minerals ilmenite, leucosene, and rutile, monazite and zircon. Increased demand from traditional uses and the development of new uses have spurred economic interest in these minerals.

Two sedimentary map units were delineated along the Fall Zone in Wilson, Nash, Halifax, and Northampton Counties on the 1985 Geologic Map of North Carolina. These units are the Yorktown Formation (Pliocene) and the Terrace deposits and upland sediment (Tertiary). The Yorktown Formation is a distinctive, fossiliferous sandy clay of marine origin. The terrace deposits and upland sediments consist of unfossiliferous sand, clayey sand, and gravel. The "Terrace deposits and upland sediment" unit is shown on the State Geologic Map only where it overlies rocks of the Piedmont Province; the mapping was a broad reconnaissance effort to delineate the distribution of the upland sediments as they occurred over the Piedmont. Working out the stratigraphy or deciphering the depositional environments of this unit were beyond the scope of the State Geologic Map project.

## **INTRODUCTION**

Following publication of an article (Berquist, 1987), describing potentially economic concentrations of heavy-minerals along the Fall Zone of Virginia in 1987, numerous companies have initiated exploration programs. These programs generally encompass the Fall Zone of the southeastern United States, but are mainly concentrated north of the Neuse River in North Carolina (particularly in Wilson,

Nash, Halifax, and Northampton Counties) and south of the James River in Virginia. Consequently, the North Carolina Geological Survey has received many inquiries from citizens and exploration companies. This report provides general background information on the geology and potential heavy-mineral resources for this area; such information is not presently available in any single publication. The report is intended for use by landowners and other interested parties who want to better understand the geology and mineral resource potential of the area, and for use by explorationists as basic reconnaissance information.

North Carolina Geological Survey Open-File Report 90-5 (Gallagher and Hoffman, 1990), a companion map for this report, shows sedimentary deposits of the 1985 Geologic Map of North Carolina along the Fall Zone in Northampton, Halifax, Nash, and Wilson Counties at a scale of 1:125,000 on a base that includes the state secondary road network. The map was produced from file materials generated during State Geologic Map compilation. No new mapping is represented by Open-File Report 90-5.

The Fall Zone (also commonly referred to as the "Fall Line") is a 10- to 20-mile-wide area where the wedge of sediments of the Coastal Plain Province overlap crystalline rocks of the Piedmont Province and thin to a feather edge. Stream gradients decrease and floodplains widen dramatically as streams and rivers fall from the relatively more resistant surface of the Piedmont Province onto the relatively flat-lying and easily eroded sedimentary rocks of the Coastal Plain Province. Thus the easternmost part of Piedmont is marked by rapids, and hence, the area became known as the Fall Zone. The Fall Zone extends along most of the eastern seaboard and has affected the cultural development through this region. Cities such as Richmond, Roanoke Rapids, and Rocky Mount developed along the Fall Zone because the rapids marked the upstream extent of navigable waters and provided power for industrial development.

## **HEAVY-MINERAL EXPLORATION**

### **RECENT ACTIVITY**

Terrace deposits of the Fall Zone region are the primary target of ongoing heavy-mineral exploration activity. C. R. Berquist, Jr., of the Virginia Division of Mineral Resources first recognized heavy-mineral concentrations in the high-level gravels of the Fall Zone. During a regional mapping project, he noticed dark bands of sand concentrated in drainage ditches after rainfalls. He sampled several locations and reported his findings in a short paper titled "Minerals in High-Level Gravel Deposits Along the Fall Zone of Virginia" (Berquist, 1987). This report is credited with attracting industry interest.

At least eight companies, and perhaps more, including several major

international heavy-mineral producers, initiated exploration programs in this area. Exploration activity intensified during 1989 after discovery and announcement of the Old Hickory deposit located about 60 miles southwest of Richmond in Sussex and Dinwiddie Counties along the Fall Zone of Virginia. This deposit was discovered by Renison Goldfields Consolidated, an Australian firm with U. S. operations based in Green Cove, Florida. Mining Journal (October, 1989) reported that the Old Hickory deposit is estimated to contain 210 million tons of sand averaging 6.5 percent heavy minerals which consist mainly of ilmenite and zircon. A second deposit has been delineated in southern Virginia about 6 miles west of Emporia near Brink, Greensville County, by a joint venture of Becker Minerals of Cheraw, South Carolina, and Consolidated Rutile Limited of Australia. The joint venture is called South East TiSand. A small-scale pilot operation was initiated at the Brink deposit in March 1990 to test mining and land restoration techniques. Two prospective areas have been identified thus far in North Carolina; one is east of Bailey, in Nash County, the second is east of Aurelian Springs, in Halifax County.

Once a deposit is identified, considerable evaluation, lasting perhaps several years, will be undertaken to determine if it is economically viable to extract the heavy minerals. Numerous factors, including land acquisition costs, market conditions and trends, the costs of mining, processing, and shipping the materials, and mitigating environmental impacts all go into calculating the viability of opening and operating a mine.

## ECONOMIC HEAVY MINERALS

### General

Heavy minerals is a term used to group several mineral species that have higher densities (specific gravities) than the common or light minerals such as quartz and feldspar. Ilmenite, magnetite, staurolite, epidote, garnet, aluminosilicates, tourmaline, monazite, various pyroxene and amphibole minerals, and zircon are examples of heavy minerals that occur in sedimentary rocks. Among the different heavy-mineral species, the titanium-bearing minerals (ilmenite, leucoxene, and rutile), monazite, and zircon are most commonly extracted. The titanium-bearing minerals, because of their relative abundance and their economic value, are usually the main exploration target. Zircon, monazite, and perhaps other heavy-mineral species, depending on their abundance and specific characteristics in a given deposit, are extracted as byproducts. Heavy minerals are minor constituents in sedimentary deposits and, under most circumstances, make up one percent or less of a sand deposit. Under rare circumstances, however, these minerals occur in sufficient concentrations to be of economic interest. Given appropriate size, location, and thickness, a deposit averaging about three to six percent heavy minerals, of which half are economic minerals, can be viable to mine (Grosz, 1987).

## **Occurrence**

In some circumstances, heavy minerals are concentrated into placer deposits by flowing water, such as in rivers or along ocean margins. Alternatively, blowing wind may concentrate heavy minerals in areas where sand dunes form. The Trail Ridge deposit in Florida is the richest known heavy-mineral deposit in the United States and is interpreted as an ancient sand dune detached from, but associated with, a beach system (Force and Rich, 1989). Heavy-mineral production from Western Australia (the world's leading source of rutile, ilmenite, and monazite) is also derived from similar beach sands. The barrier island system is thought to be the most favorable mechanism for concentrating heavy minerals.

## **Mining Techniques**

Heavy minerals are typically excavated by means of a dredge or bucket wheel system which removes large volumes of loose sediment at the mine site. The sediment is screened to remove gravel and is mixed with water to create a slurry. The slurried material is passed through a gravity spiral which separates and concentrates the heavier minerals. The heavy-mineral concentrate from the spiral is dried and passed through electromagnetic or electrostatic separators which sort minerals into individual species on the basis of their distinctive magnetic qualities. Electromagnetic or electrostatic separators are capable of producing "industry standard" separates of relatively pure mineral concentrates. The light minerals, principally quartz and clay, are then used to backfill the mine.

The Mining Act, administered by the Land Quality Section of the Division of Land Resources, requires that mining permits must be obtained and a reclamation plan must be approved before mining can commence. Mine operators must adhere to air, water, and erosion control practices in accordance with state regulations (administered by various divisions within the Department of Environment, Health, and Natural Resources) during the course of mining a deposit.

## **Titanium-bearing Minerals**

The titanium-bearing minerals ilmenite, leucoxene, and rutile are the primary mineral resource derived from heavy-mineral sands. Ilmenite ( $\text{FeTiO}_3$ ) is the most common of the titanium minerals. Leucoxene is a leached or altered ilmenite; the leaching removes the iron from the original ilmenite thereby enriching the titanium content of the mineral. Leucoxene is generally less abundant than ilmenite. Rutile ( $\text{TiO}_2$ ) has the highest titanium content of the titanium-group minerals but is almost always less abundant. Based on the occurrence of these minerals in a given deposit, ilmenite, leucoxene, and rutile are combined to achieve a certain grade of titanium dioxide ( $\text{TiO}_2$ ); this product is called synthetic rutile. Rutile is the preferred titanium mineral because it is relatively pure  $\text{TiO}_2$ , and

because it may be processed into a soluble product using a chloride process. The chloride process is less expensive and less environmentally damaging than the alternative sulfide process (Lynd, 1980). Australia is currently the world's largest producer of natural rutile and ilmenite. Production is from ancient beach sand deposits.

Titanium is used to produce paint pigment, welding-rod coatings, lightweight titanium metals, fiberglass, and chemicals. Titanium dioxide pigment production accounts for most titanium consumption. Demand for titanium dioxide pigment is expected to stay strong. Titanium metal use has increased in response to higher production of commercial aircraft and other applications for lightweight metals are being developed which will further increase the demand for titanium metals.

As demand for titanium dioxide pigment has grown steadily so has the price of ilmenite. The price increased from \$40 per metric ton in 1985 to \$70 per metric ton in 1989. Rutile increased in price from \$358 per metric ton in 1985 to \$525 per metric ton in 1989 (U.S. Bureau of Mines, 1990).

### **Monazite**

Monazite ((Ce,La,Y,Th)PO<sub>4</sub>) is a yttrium phosphate mineral that is normally recovered as a byproduct of heavy-mineral sand production. Monazite is a source of rare-earth elements (metallic elements with atomic numbers that range from 57 to 71) plus thorium, scandium, and yttrium. Australia is the world's leading producer of monazite, where it is recovered as a byproduct of ilmenite sands.

The world's first commercial monazite production was from Burke County, North Carolina, in 1887; thorium produced from the monazite was used in manufacturing mantles for gas lamps (Moore, 1980). Monazite is currently being recovered as a byproduct of gold-bearing and industrial sands from a mine near Marion, North Carolina.

Monazite is processed to produce a number of rare-earth elements and compounds which have various applications in the manufacturing of petroleum refining catalysts, metallurgical alloys, electronics, ceramics, glass polishing compounds, permanent magnets, phosphors, and lasers. New applications are in modern ceramics and color television picture tubes (Robjohns, 1989). High-purity rare-earth products are used to manufacture specialty magnets.

Demand for monazite is expected to increase with the development of new uses in the electronic, computer, and communication industries. The 1988 year-end price of monazite concentrate was \$632 per metric ton (U.S. Bureau of Mines, 1990).

## **Zircon**

Zircon ( $ZrSiO_4$ ) is recovered exclusively as a byproduct of heavy-mineral beach sands and is used to produce zirconium. Zirconium has applications in foundries as a refractory material, as an abrasive, and has other industrial uses in ceramics, alloys, and chemicals. Because of its corrosion resistance, zirconium has special applications in the chemical processing and aerospace industries. Zirconium chemicals are used for adhesives, antiperspirants, catalysts, fiber optics, and synthetic gems. Advanced engineering applications are being developed for zirconium chemicals.

During 1988, there was a worldwide shortage of zircon, and an associated increase in the price. In 1989, the price of zircon was \$468 per metric ton, a significant increase from \$193 per metric ton in 1985 (U.S. Bureau of Mines, 1990). The supply deficit is expected to continue for some time and the demand for zircon should remain high. Mining Journal (February, 1990) reported that demand for zircon could increase by 31 percent by 1993.

## **GEOLOGY**

### **STATE GEOLOGIC MAP COMPILATION**

#### **Background**

The State Geologic Map (North Carolina Geological Survey, 1985) was compiled in 1983 and 1984 from existing maps and reports supplemented by reconnaissance field surveys. The State Map Advisory Committee, consisting of industry, academic, and government geologists with experience in North Carolina, was assembled to provide guidance and expertise during the compilation process. Conventions and guidelines for the map were developed jointly by the Geological Survey compilers and the State Map Advisory Committee to deal with specific map problems. One such convention was to not show alluvium and other surficial sediments at elevations above 25 feet (Suffolk scarp of the northeastern Coastal Plain). This decision had the greatest affect on the Coastal Plain, which is extensively covered by largely unmapped and poorly understood surficial sediments. This approach was used because there was no comprehensive or suitable mapping of the surficial deposits from which to compile the State Geologic Map.

A problem arose in compiling the geology of the Fall Zone area of the northern inner Coastal Plain. The surficial sediments, thought to be pre-Quaternary in age, overlying rocks of the Piedmont Province are of sufficient thickness and aerial extent to mask the underlying crystalline geology. Also, the distribution of the Yorktown Formation through this area, as depicted on then existing maps for

Wilson, Nash, and Halifax Counties (Wilson and Spence, 1979; Wilson, 1979; 1981) was judged by committee members to be unsuitable for compilation on the State Geologic Map. Thus, it was necessary to undertake some new work in this area to meet the needs of the State Geologic Map project.

## Mapping Methods

Initially, several days were spent in the field determining potential approaches to mapping and defining possible map units to be shown on the 1985 State Geologic Map. County roads were driven and outcrops were examined. To characterize the geology, several auger holes were drilled and logged with a gamma tool. Gamma logs were used to determine lithology, thickness, and location of beds down-hole. Materials from newly dug water wells were inspected and gamma logs were run on several existing water wells for subsurface control. This preliminary work suggested that two sedimentary units were readily mappable in the area: the Yorktown Formation and undifferentiated surficial sediments of the "Terrace deposits and upland sediment" unit.

The Yorktown Formation was recognized and mapped primarily by the presence of fossiliferous material. Unfossiliferous sand and gravel directly overlying crystalline rock was placed in the "Terrace deposits and upland sediment" unit. It was also recognized that the "Terrace deposits and upland sediment" unit tended to cover divides and that, in these areas, there was a subtle, yet distinctive, topographic expression or signature. Where sand and gravel like that of the "Terrace deposits and upland sediment" unit was found to overlie fossiliferous material, Yorktown Formation was mapped. This followed the convention of not showing surficial deposits that overlay "bedrock" units above 25 feet elevation. Figure 1 shows generalized map and cross-sectional views of typical northern inner Coastal Plain geology as it would be portrayed based on conventions used for the State Geologic Map.

Nash County was chosen as a pilot county to map. The flat-lying upland areas were delineated and other information including soil types and Department of Transportation bridge and road boring information were plotted on 7.5-minute topographic quadrangle maps. Preliminary maps and cross-sections were developed from surface and subsurface information such as geophysical logs from water wells and interviews with water well drillers and county personnel. Descriptions of bridge foundation borings along Interstate 95 and U.S. 64 were particularly useful during this project and provided good subsurface control. The preliminary maps and cross-sections were field tested and modified as needed during several weeks of field work. The final product proved to be adequate and representative of the geology. Thus, the same mapping techniques were applied to the other counties, although with less time spent in the field.

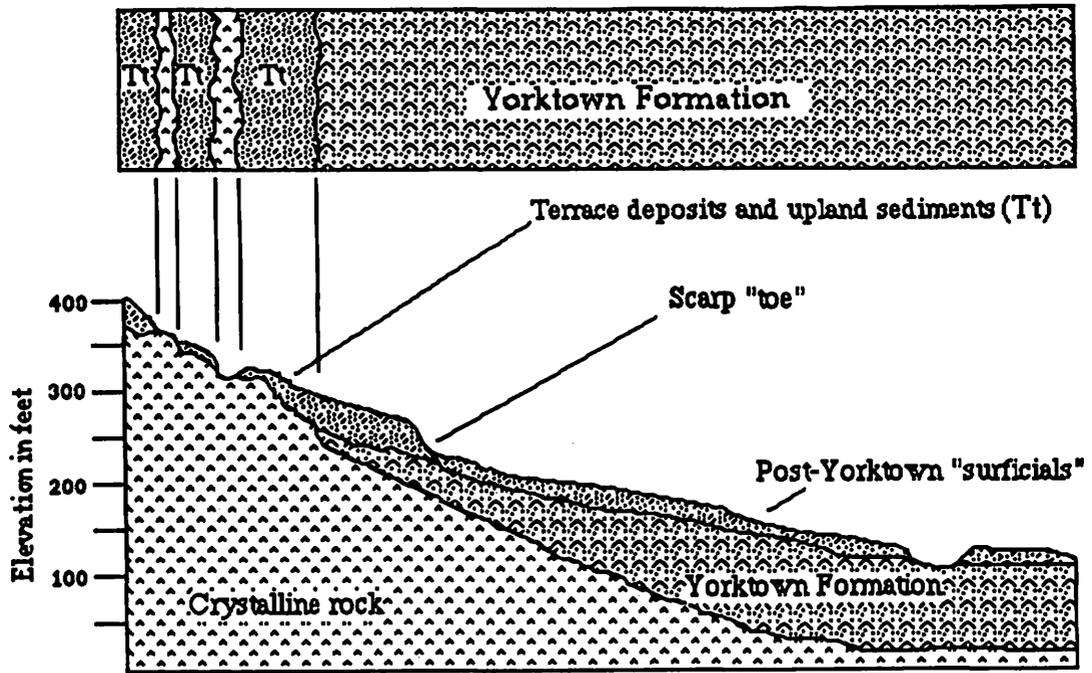


Figure 1 Diagrammatic map (upper) and cross-sectional (lower) views of the generalized geology of the northern inner Coastal Plain of North Carolina. Sketch not drawn to any specific scale but vertical exaggeration is considerable.

## STATE GEOLOGIC MAP UNITS

### Yorktown Formation

The Yorktown Formation is a distinctive marine unit that was deposited throughout northeastern North Carolina and southeastern Virginia during an early to middle Pliocene rise in sea level. The unit consists of bluish-gray, fossiliferous sand with varying amounts of clay. It contains abundant mollusk shells that persist to the updip edge of the formation (the westernmost limit where the formation thins and disappears); large pecten shells are scattered upon crystalline rocks in the vicinity of the Benevue Country Club northwest of Rocky Mount. A coating of black, hard phosphate and marine animal borings into granite are also good indicators of the Yorktown transgression onto Piedmont rocks. The Yorktown Formation typically weathers to reddish-orange and, with close scrutiny, burrows, altered shell material, and molds of leached shells can be observed in weathered exposures. To the east, through the northeastern North Carolina and southeastern Virginia Coastal Plain, the Yorktown Formation thickens and is covered by younger late Pliocene and Pleistocene units. Ward and Blackwelder (1980), described the Yorktown Formation, interpreted its depositional history, and divided it into four members. Other recent studies of the Yorktown Formation include Ward and

Strickland (1985) and Bailey (1987).  
**Terrace Deposits and Upland Sediment**

Terrace deposits and upland sediment consist of gravel, clayey sand, clay, and sand with minor iron-cemented sandstone. The unit typically is reddish-brown. Gravel ranges from granule to cobble-sized and is generally rounded. Angular gravel occurs at contacts with Piedmont bedrock and, locally, the contact with the Piedmont is a scour surface. Gravel may exhibit crude cross bedding. Sand generally consists of variably sorted quartz with common to abundant amounts of feldspar. Grain size ranges from coarse to very fine. Sedimentary structures are generally not apparent in the sand, but this may be because outcrops are small and deeply-weathered.

Terrace deposits and upland sediments are unfossiliferous but are inferred to be of Tertiary age. Equivalent deposits continue east of their mapped distribution where it becomes difficult to distinguish them from surficial sediments of the Coastal Plain. Working out the stratigraphy or deciphering the depositional environments of the terrace deposits and upland sediments were beyond the scope of the 1985 State Geologic Map compilation; however, recent work in Virginia (Berquist and Goodwin, 1989; Mixon and others, 1989) and a review of other literature offers some insight into this problem. This is discussed below.

### **Piedmont Rocks**

Rocks of the Eastern slate belt and, to a lesser extent, the Raleigh belt, crop out in the northern part of the Fall Zone of North Carolina. The Eastern slate belt is a metamorphosed volcanic terrane thought to be related to the Carolina slate belt to the west. The Raleigh belt is a northeast-southwest-striking anticlinorium (a convex-up fold) in which granitic rocks are exposed along the core. Metamorphic rocks surround the core of the anticlinorium and become progressively lower-grade away from the axis (North Carolina Geological Survey, 1985). In western Northampton and northwestern Halifax Counties, the Eastern slate belt consists of foliated granitic rock, metamorphosed quartz diorite, and minor felsic metavolcanic rocks and metamudstones. In southwestern Halifax, western Nash and western Wilson Counties, rocks of the Eastern slate belt consist of felsic, intermediate, and mafic metavolcanic rocks, and metamudstones. Foliated granitic rock occurs in eastern Nash County, west of Rocky Mount. Granitic rock is also exposed along Contentnea Creek west of Wilson, in an active quarry at Sims, and in an abandoned quarry north of Elm City. Raleigh belt rocks occur in west-central Nash County and consist of granite. Injected gneiss of the Raleigh belt crops out in western Northampton County.

### **SUMMARY OF PREVIOUS STUDIES**

Scarps and terraces have been recognized and mapped in many previous

geologic investigations in the Atlantic Coastal Plain. As a result, they are implicitly accepted in most Coastal Plain interpretations and their existence as distinctive, easily recognized features is commonly taken for granted. Actually, they are quite subtle, discontinuous, and often barely recognizable, even to a trained geologist. (The scarps that appear on the 1985 Geologic Map are shown only where they were easily discernible on 7.5 minute topographic maps). While there is little doubt that these are "real" geomorphic features, their role as geologic boundaries is of considerable disagreement among geologists. However, the terrace concept is a valuable tool for heavy mineral exploration and a review of the pertinent literature is provided in this report. More specifically, a terrace with surface elevations ranging from 170 to 250 feet is the host of the two heavy-mineral deposits discovered in Virginia.

McGee (1888) was one of the earliest workers to recognize terraces in the Coastal Plain province. He believed that they were constructional marine features. He mapped inland gravels and sands as the Appomatox Formation and sediments overlying the eastern portion of the Coastal Plain as the Columbia Formation. McGee (1891) later renamed the Appomatox Formation the Lafayette Formation.

Stephenson (1912a; 1912b), utilizing limited topographic control, mapped surficial sediments of the Coastal Plain at a scale of 1:1,000,000. He divided sediments of the upper Coastal Plain into the Lafayette Formation and the Coharie and Sunderland Formations of the Columbia Group. He restricted the Lafayette Formation to sediments west of a seaward-facing scarp at an elevation of approximately 230 feet and he thought the age of the Lafayette was Pliocene. Stephenson mapped the Coharie Formation between elevations of 160 to 235 feet and the Sunderland Formation from 110 to 150 feet. He thought the Columbia Group was Quaternary in age.

Cooke (1931) delineated seven Pleistocene marine terraces along the Atlantic Coastal Plain based on elevations. These are the Brandywine (270 feet), the Coharie (215 feet), the Sunderland (170 feet), the Wicomico (100 feet), the Penholoway (70 feet), the Talbot (42 feet), and the Pamlico (25 feet). Cooke interpreted these terraces to be formed by still stands of a regressing sea. Thus, each successive terrace to the east was younger than the adjacent one lying to the west.

Flint (1940) dealt primarily with scarps east of the Fall Zone area, but his work is an important contribution because he critically analyzed preceding work and pointed out many inconsistencies with regard to investigations of the higher-elevation terraces and scarps.

Mundorff (1946) described the geology of Northampton, Halifax, Edgecombe, Nash, and Wilson Counties in a regional ground water report. He grouped upland sediments above the 270-foot elevation as "unclassified high-level gravels, sands and clays of Tertiary and Cretaceous (?) age" and informally referred to them as

"high-level gravels" (a term that is still commonly used). Mundorff believed that these sediments were fluvial in origin and speculated that they could be different ages—some being as old as Cretaceous. Mundorff followed Cooke's (1931) scheme for surficial sediments below the 270-foot elevation.

Doering (1960) extended work done by Matson (1916) in Florida, Alabama, and Mississippi and correlated sediments that were formerly mapped as Lafayette Formation in Georgia, South Carolina, North Carolina, and Virginia to the Citronelle Formation of the Gulf Coast region. In southern North Carolina, with the exception of an area around Lumberton, Robeson County, Doering restricted the Citronelle Formation to sediments west of the Citronelle escarpment (elevation approximately 250 to 270 feet) and combined sediments east of the Citronelle escarpment (previously mapped by Stephenson (1912b) as Coharie and Sunderland Formations) into the Sunderland Formation. In central North Carolina, along a transect from Fuqua (now part of Fuquay-Varina in southern Wake County) to Magnolia, Duplin County, Doering (1960) included sediments of the Lafayette and Coharie Formations in the Citronelle Formation. His transect placed Citronelle deposits as low as the 100-foot elevation and included Stephenson's (1912) type area for the Coharie Formation. Doering's map shows the Citronelle in northern North Carolina restricted to sediments overlying rocks of the Piedmont. In southern Virginia, Doering correlated gravelly sands that capped the Piedmont in the Fall Zone to the Citronelle Formation. Doering interpreted the Citronelle Formation as a fluvial deposit laid down in response to uplift in the mountains and Piedmont during the earliest Pleistocene. Doering thought later movement (still preglacial Pleistocene) resulted in the erosion of the Citronelle Formation and deposition of the Sunderland Formation as a series of coalescing alluvial fan deposits below the Citronelle escarpment. Doering also interpreted sediments east of the Sunderland as nearshore and marine deposits of Pleistocene age which were deposited in response to glacially-driven sea level changes.

Colquhoun (1965), who worked in South Carolina, referred to the Citronelle escarpment as the Orangeburg scarp. "Orangeburg" remains in use for the distinctive scarp at the 250- to 270-foot elevation that occurs through South Carolina and the Sandhills region of North Carolina.

Daniels and others (1966) mapped the Macks, the Pinehurst, and the Brandywine Formations across the Cape Fear-Neuse River divide in the vicinity of Benson. They thought that the Macks Formation was a marine unit and speculated that the Macks and Yorktown Formations could be lateral equivalents or could be separated by an unconformity. Blackwelder and Ward (1979) demonstrated that the Macks Formation of Daniels and others (1966) are simply nearshore deposits of the Yorktown Formation and recommended that the name Macks Formation be abandoned. This recommendation has been followed by most subsequent workers. Daniels and others (1966) named the Coats scarp (with a toe elevation of 275 feet) and thought that the Coats and the Orangeburg scarps were possibly correlative but

acknowledged problems with such a correlation. The "toe elevation" equals the lowest elevation of the scarp feature.

Daniels and Gamble (1974) continued work in the area north of the Neuse River to the Nash County line near Bailey and restricted their Macks Formation (updip Yorktown Formation) to west of the Coats scarp and lumped the surficial deposits east of the Coats scarp into one unnamed unit. They placed the eastern boundary of the unnamed unit at the Surry scarp with a toe elevation of 100 feet. They suggested an age of Pliocene to Pleistocene for the unnamed unit and mapped two major facies within it: a mixed sand with clay facies (with clay lenses, pebbles and a few cobbles), and a medium to fine sand facies (with basal pebbles and some coarse sand). Additionally they identified two scarps in the middle Coastal Plain, the Wilson Mills scarp (toe elevation of 215 feet) and the Kenly scarp (toe elevation of 145 feet); but they observed no lithologic change in the surficial sediments across these scarps.

Daniels and others (1978) who re-examined the inner Coastal Plain through Wilson County and into Nash County, extended the Macks Formation (updip Yorktown Formation) east of the Wilson Mills scarp and show it to interfinger with the Yorktown Formation. They reported that the Macks (Yorktown) Formation is exposed along the Coats scarp immediately south of Bailey.

The work by Daniels and his co-workers through the late 1960's to middle 1970's is clearly the published work specific to North Carolina that is most relevant to the inner Coastal Plain surficial sediments north of the Neuse River. Problems encountered with trying to apply this work, however, include the lack of cultural features and topography on the base maps, the small size of the published maps (typically page-size or less), and the use of soil-science terms to define and describe geologic units. Similar problems are involved when trying to critically examine and apply much of the early literature as well.

Blackwelder and Cronin (1981) published a computer-generated block diagram of the Coastal Plain from Virginia to northeastern Florida. Through the Fall Zone of Virginia and northeastern North Carolina they delineated a feature named the Petersburg scarp with toe elevations of about 140 feet and upper elevations that range from 250 to 350 feet. The relatively flat area between the Surry scarp (100 feet) and the toe of the Petersburg scarp was called the Hopewell Plain. Gravels overlying the Yorktown Formation across this plain were interpreted as regressive deposits laid down during retreat of the Yorktown sea. Blackwelder and Cronin (1981) thought that central North Carolina, north of the Cape Fear Arch and in the vicinity of Johnston County, has been a positive topographic feature since the Miocene and noted that the area is underlain by more resistant bedrock than the area to the north. Blackwelder and Cronin (1981) observed that the Yorktown Formation is thin across this area and concluded that the Yorktown transgression was limited because of the high topography and resistant bedrock. They also noted that in

central North Carolina, the Yorktown occurred at the base of a distinct scarp with a toe elevation of 250 feet and thought that this scarp was correlative to the Petersburg scarp. Blackwelder and Cronin (1981) connected the Orangeburg and the Petersburg scarps.

Weems (1986) mapped upland gravels in Virginia and placed them in his "g1" unit. He interpreted the gravels to be fluvial and of late Miocene to early Pliocene age. Johnson and others (1987) recognized an unnamed marine sand overlain by gravels in the Fall Zone of Virginia and suggested that the lower marine unit was middle Miocene or older. They named the overlying gravels the Bon Air Gravel and correlated them to Weems' (1986) "g1" unit.

Berquist and Goodwin (1989) mapped two Coastal Plain units in the Fall Zone of Virginia, designating them as "G1" and "G2". The "G1" unit includes the unnamed marine unit and the Bon Air Gravel of Johnson and others (1987). It reportedly occurs above an elevation of 250 feet and consists of marine sand overlain by gravels that grade upward into loamy sand. Berquist and Goodwin (1989) considered the "G1" unit to be of Tertiary age. Mixon and others (1989) mapped the "G1" unit as "Tmsg" (Miocene sand and gravel) through the inner Coastal Plain of Virginia and tentatively correlated it with the middle Miocene Choptank Formation. The "G2" unit of Berquist and Goodwin (1989) includes sediments occurring between 175 and 240 feet. It consists of a basal, muddy, pebbly sand overlain by sandy to clayey sediments. The "G2" unit was interpreted to have been deposited in shallow marine, beach, and other nearshore environments. Mixon and others (1989) show the "G2" unit as "Tpsg" (Pliocene sand and gravel) on their map and describe the lower part of the unit as the nearshore equivalent of the Yorktown Formation and the upper part of the unit as regressive deposits of the Yorktown sea. Based on elevations, geologic setting, and lithology, the "Tmsg" and "Tpsg" units of Mixon and others (1989) (Berquist and Goodwin's "G1" and "G2" units, respectively) are loosely correlative with the "Terrace deposits and upland sediment" unit shown on the 1985 Geologic Map of North Carolina.

## CONCLUSIONS

Heavy-mineral exploration activity is concentrated in Tertiary terrace deposits along the Fall Zone of Virginia and North Carolina. Potentially economic titanium sand deposits have been delineated in North Carolina near Bailey in Nash County and near Aurelian Springs in Halifax County. These titanium sand deposits occur within the unit mapped as "Terrace deposits and upland sediment" unit on the 1985 Geologic Map of North Carolina. The geology of these sediments is not well understood but they are thought to be mainly marine deposits of late Tertiary age. Additional, more detailed work is required to better understand the sedimentary deposits of the Fall Zone of North Carolina and to relate occurrences of potentially economic heavy-mineral deposits to these sediments.

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