NORTH CAROLINA DEPARTMENT OF ENVIRONMENTAL QUALITY
POLICY AND INNOVATION GROUP

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NORTH CAROLINA GEOLOGICAL SURVEY
OPEN FILE REPORT 2017-11

## Introduction

The Atlantic Coastal Plain of eastern North Carolina (Fig. 1) is poorly understood from scientific, stratigraphic, and mapping perspectives. It is mantled primarily by Pliocene and Pleistocene deposits that have map extents, allostratigraphy, and relationships to global sea level cycles that are mostly undefined. Outcrops are rare, and the new subsurface data necessary to define units and map this region is expensive. Except for recent STATEMAP (SM) deliverables, detailed geologic maps at 1:24,000-scale for the Coastal Plain do not exist. The current geologic map (NCGS, 1985) does not show surficial units for the Coastal Plain, it shows underlying subcrops (Fig. 1A). In recent SM areas (FY10-15), the Pliocene Yorktown Formation is supposedly the principal subcrop (NCGS, 1985); this unit is affiliated with a regional-scale shallow confining unit. Detailed mapping (FY10-15) shows that the Yorktown (Fig. 1A) is thin, absent, or misidentified. Isotopic age dates suggest that basal, clastic carbonate beds that define the base of the Plio-Pleistocene, correlate with the Chowan River Formation, rather than the Yorktown. If this is the case the Yorktown is essentially absent in this area of the NC Coastal Plain. The post-Chowan River section includes several early Pleistocene units in ramp or interfluve settings; younger terraces and alluvium occur in incised valleys.

## Location and Geologic Setting

The Coastal Plain, a relict, Plio-Pleistocene landscape (Fig. 1B), consists of a series of progressively younger scarps, or paleoshorelines, and intervening terraces that step down in elevation and age towards the coast (Fig. 2) and into river basins (Fig. 3). This is stairstep topography. Seven river basins dissect the Coastal Plain so that its low-relief, flat, eastward-dipping marine terraces (ramps) are separated by incised valleys with terraced borders. Over the past 5 Ma, glacio-eustatic changes in sea level drove the transgressive-regressive (T-R) cycles that sculpted this landscape. Fluvial, estuarine and marine deposits occur in the incised valleys. The stratigraphy in valley fills differs from that of the ramp or interfluve (Farrell and others, 2003), and forms the “alluvial aquifer system” (Tesoriero and others, 2005).

The Surry Scarp, a Pleistocene paleoshoreline complex, trends north through Fountain quad (Figs. 1, 4A). Regional-scale conceptual models (Mixon and others, 1989; Winker and Howard, 1977; Oaks and DuBar, 1974; Daniels and others, 1966) and NCGS SM data (Farrell and Crane, 2013) suggest that the Surry shoreline is the highstand position for the main early Pleistocene T-R cyclic event. Stratigraphic relationships near the scarp are complex and include several early Pleistocene units; each contains similar repeating facies, and fossils are rare. In Virginia (Mixon and others, 1989) these are the Moorings Unit and the Bacons Castle, Windsor, and Charles City Formations (Fig. 5). In NC and VA, these correlative units occur within the shoreline complex, and both landward and seaward of it. These are not lithologically distinct bodies of rock that are easily mappable; these are allo-units that are mapped by establishing bounding surfaces, their terminations, and the geologic facies above them. Our goal is to describe facies and establish units in a sequence stratigraphic context, and to determine the stratigraphy’s relationship to surficial landforms. Sequence stratigraphy emphasizes facies relationships and stratal architecture within a chronological framework (Catuneanu and others, 2009).

## Strategy for Performing the Investigation

Geologic mapping in the NC Coastal Plain requires a non-traditional method, called three-dimensional (3D) subsurface mapping (see Newell and Dejong, 2010; and Hughes, 2010), to define and map surficial geologic units. This method combines a geomorphic interpretation of the relict Quaternary landscape with targeted subsurface analysis along profiles that transect geomorphic features. It is useful because the NC Coastal Plain is notorious for its low relief, few outcrops, lack of defined units and type sections, recurring facies, colluvium on side slopes, and extensive wetlands cover, even on uplands: bedrock mapping methods do not apply.

To produce the map, landforms were interpreted from the highest resolution Light Detecting and Ranging (LiDAR) elevation data (20 cm). LiDAR tiles, as floating point ASCI files were downloaded from the Floodplain Mapping Program’s website (www.ncfloodmaps.com). These were transformed from ASCI files to raster grids, mosaiced into 10 X 10 rasters, and reprojected as State Plane Nad 1983 meters. Hillshade, slope, and contour lines (1.0, 0.5, and 0.25 meters) were constructed from the raster grids. Orthoimagery (2012, 2010) from the NCONEMAP was used in conjunction with elevation grid color ramps, contour lines, hillshade and slope to interpret landforms. Farrell and others (2003) summarize the method of comprehensive landscape analysis. A series of landform elements was interpreted and digitized starting with the Holocene depositional system and working backward in time into older landscapes. Key transects cross cutting the Surry paleoshoreline and other features were chosen for subsurface analysis. Geologic cores were acquired in plastic tubes with the Geoprobe drill rig. These are 1.5-inch diameter continuous cores (discrete sampling method) collected in 4-foot increments. Cores were logged using the methods of Farrell and others (2012, 2013). High-resolution photos of cores were compiled as photomosaics for archiving. Allostratigraphic units were defined on cross sections, and extrapolated regionally using geomorphic map. Data locations were collected using GPS.

## Geomorphic and Stratigraphic Description of Four Quadrangle Region (Figure 4)

The southwest quadrant is situated east of the Surry Palaeoshoreline Complex, mostly at elevations below 28 m, in a stratigraphically complex area on the boundary between the “Sunderland Terrace” (see Fig. 2) and the “Wicomico Terrace”. This geomorphically complex area includes a variety of relict coastal landforms and associated facies along its length. Associated features include barrier islands, beach and shoreface, beach ridge accretion plains, longshore bars, spits, embayed areas, lagoons, tidal channels, etc. (see Farrell et al., 2003). Near the Surry shoreline complex, four, surficial, early Pleistocene units occur beneath upland, predominantly marine flats: in adjacent Virginia, these are called the Bacons Castle Formation, Moorings Unit (informal), and the Windsor and Charles City Formations. All four units are Early Pleistocene in age (Mixon et al., 1989), becoming successively younger in age towards the east. These may be conformable as indicated by stratigraphic details observable in core and outcrop. All four units potentially include similar, repeating facies. The current study includes marine interfluve units associated with correlatives of the Windsor and Charles City Formations, and a number of terraces in the local incised drainages. The map deliverable shows two units, tentatively called Q wm (Windsor Formation, marine) and Q lzm (Lizzie Formation, marine; terraces are numbered in sequence. The nomenclature utilized here is considered draft only.

In the four quad area, coastal landforms are preserved geomorphically between elevations of 26 and 34 meters. The toe of the Surry paleoshoreface is at about 28 m; the main highstand elevation that explains most of the geomorphic features associated with the Surry Scarp is at about 30 m. Other landforms and surficial stratigraphy indicate slightly higher sea levels (34-35 m) associated with the shoreline complex. Two units are associated with the shoreline complex itself (28-34+ m): the Windsor Formation and the Moorings unit. The Moorings unit is locally associated with barrier island facies. The Windsor outcrops surfically, east of the 30 m contour. It is notched and overlain by the Lizzie Formation near the 26 m contour. This particular geomorphic boundary occurs in the current map area. The sea level maximum associated with the flooding event that formed the Surry paleoshoreline complex was likely at about 34 – 35 m, with a shoreline complex and embayed coast between 34 and 28 m. A second near-occupation of the same shoreline formed the shoreline features at about 26 m in the current map area, the boundary between “Windsor” and “Lizzie” Formations.

Incised Valley Units: Valleys incised into the marine Windsor (Q wm) and Lizze (Q lzm) units include six Pleistocene terraces that step down from 26 to 19 m. In Virginia, the 26 m shoreline marks the western extent of the Windsor Formation. The area east of this unnamed scarp is mantled by the Lizzie Formation (Farrell and Crane, 2013). Updip limits of valley fill terraces associated with the Lizzie Formation are called Qt6 (26 m maximum).

## FY 16 Results: Overview of Geomorphology and Stratigraphy in Falkland Quadrangle, Southwest Quadrant

The project deliverable is a PDF of the southwest quadrant of Falkland Quadrangle (1/4 quadrangle). This new map area is immediately east of Fountain (STATEMAP FY13, 14, 15), north of Farmville (STATEMAP FY 10 and 12), and northeast of Walstonburg (STATEMAP FY 11 and 12) Quadrangles. Mapping was conducted by one NCGS staff Geologist and two temporary STATEMAP-funded positions [one Temporary Geologist I (11-month appointment) and one part-time driller (320 hours per year)].

Geomorphic analysis began in July 2016 using high resolution LiDAR and 0.25 m contours derived from bare earth, floating point data. Using geomorphology, core locations were selected to develop two major cross sections: 1) a NW-SE profile that extended the existing cross section in adjacent Fountain Quadrangle; and 2) a new N-S trending cross section, approximately perpendicular to the SE trending regional cross section, across a drainage. Existing stratigraphic data in the map area included only 2 cores, collected previously by STATEMAP for correlation purposes; there are no outcrops. Signed permission forms were acquired from landowners prior to drilling. Coring with the Geoprobe extended from September, 2016 to August, 2017. New stratigraphic data was collected at 29 borehole locations, including a total of 1295.65 feet of continuous core (discrete sampling method), in coreholes that ranging from 28 to 56 feet in depth. Recovery was greater than 90 percent. Deepest cores bottomed out in Cretaceous “basement”. Cores Boswell-01 and Holland-01 were collected on adjacent Fountain Quadrangle for correlation purposes.

During drilling, cores were split, washed and described by using Farrell and others (2012, 2013) graphical logging methods. Cores were photographed in the field with a cell phone; this worked well as a first cut in core photography. Archival photography was started in the lab. Cross sections were constructed from the field sections.
As time permitted, high-resolution graphic logs (1 inch = 1 foot) of core stratigraphy were constructed in the lab; these logs are on par with methods of characterizing oil and gas reservoirs and permits direct correlation with gamma and resistivity logs. The overall goal is to describe sedimentary facies and the sequence stratigraphic framework, and integrate these with naming and identifying surficial geologic map units and geomorphic features.

## Falkland Quadrangle (1/4): Significant findings from the mapping include:

- Geomorphic analysis reveals that the map area is immediately east of the Plio-Pleistocene Surry Paleoshoreline complex (shore elevation ~ 30 m MSL). Interfluves range in elevation from ~ 28 m (northeast) to 25 m (southeast). Interfluves are separated by incised drainages which have a series of terraces that step down from 24 m to 19 m. The bottom of drainages includes a Holocene wetland flat at 17 to 22 m, that gradually rises in elevation in an upstream direction, and burying Early Pleistocene terraces.
- A significant shore parallel feature occurs at ~26 to 27 m. This elevation may correspond to a stratigraphic contact that separates a sand-rich shoreface unit (west) from falling-stage, finer-grained, highly variable deposits to the east. Tentatively this may be a “formation boundary”, i.e. separating correlative Moorings from Windsor units. Tentatively this boundary may separate normal from forced regressive deposits.
- Associated forced regressive deposits may consist of a series of continuously-deposited, terrace-defined units that step down in elevation from 26 to 20 m, at intervals of 1 to 2 m; these would generate parasequences about 1-2 m thick in the adjacent incised valleys.
- The Quaternary section is ~ 20 ft (6 m) thinner here than west of the Surry Paleoshoreline. Refusal depth ranged from 28-56 ft (8.5 – 17 m). Refusal was caused by encountering semi-consolidated substrate (Cretaceous), collapse of loose shells, sands and gravels into corehole, closing of hole by thixotropic marine units, and cemented zones and large inpenetrable shells.
- Details at corehole Tucker-03, elevation 25.61 ft MSL: Total depth is 53.5 ft; Cretaceous occurs at 53.0 ft. Above K, is a marine flooding surface overlain by a lag bed with phosphate and quartz pebbles. Above the lag is a dark greenish gray, marine, upward coarsening siliciclastic (<30% bioclastic) to mixed (30-70% bioclastic) to bioclastic (>70%) sequence (sequence 1). Gravel fraction is mostly shell hash. This marine sequence is silty gravelly sand (zgS) at its base, coarsening upward into a fully bioclastic gravel. This is overlain by large bivalve shell gravel that is cemented that marks the base of marine sequence 2 (?) and the base of the surficial map unit. The bioclastic gravel fines upward into a “black” phosphate-rich sand from which shell material is dissolved away. Above this are lithologically variable facies that are part of the surficial map unit.

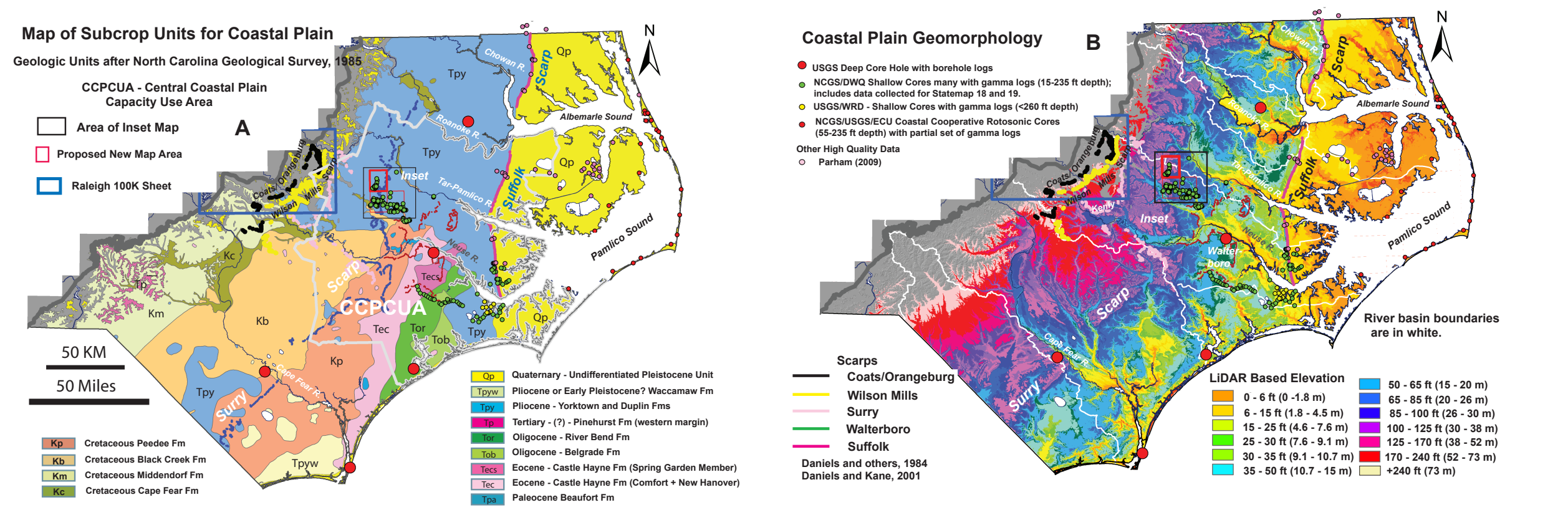


Figure 1. A. Geologic map for the Coastal Plain of NC (NCGS, 1985) shows the Yorktown Formation as principal surficial unit in STATEMAP FY10-16 study areas. B. LiDAR elevation model with color ramps emphasizing marine terraces and incised valleys; the locations of high quality core data (recently collected by NCGS and USGS, post 2000) are shown.

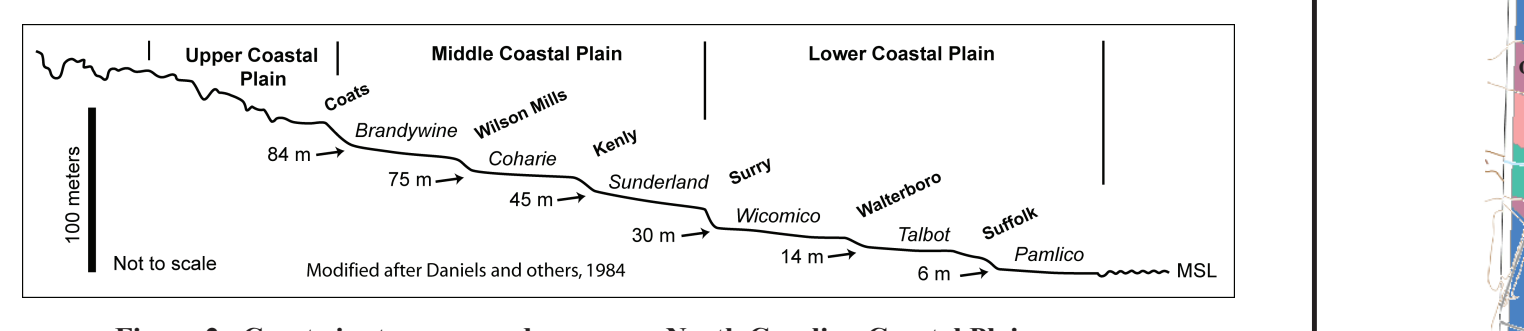


Figure 2. Coastwise terraces and scarps on North Carolina Coastal Plain.

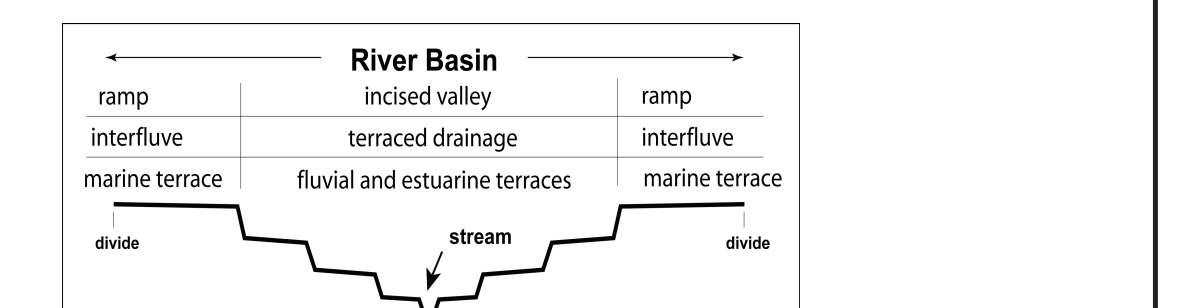


Figure 3. Stairstep topography bordering river basins and terminology.

Table 1. Locations of cores collected in Falkland Quadrangle prior to the current fiscal year’s data collection, collected for STATEMAP FY14 data deliverables.

| HOLE_ID | DATE_DRILLED | GEO_IN_FIELD | QUAD | COUNTY | NORTHING_M | EASTING_M | LAT_DD | LONG_DD | DEPTH_FT | DEPTH_M | ELEVATION_FT | ELEVATION_M | CORING METHOD | DRILLERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NORVILLE-01 | 12/5/2014 | K.Farrell, B.Harris, K.Cummings | Falkland | Pitt | 213304.3890 | 735731.2520 | 35.664867 | -77.606780 | 46.00 | 14.02 | 85.56 | 26.08 | Geoprobe Discrete Sampling | D. Foyles |
| NORVILLE-03 | 12/15/2014 | K.Farrell, B.Harris, K.Cummings | Falkland | Pitt | 213915.5400 | 735003.5320 | 35.670467 | -77.614723 | 47.00 | 14.33 | 90.32 | 27.53 | Geoprobe Discrete Sampling | D. Foyles |
| | | | | | | | | | | | | | | |
| | | | | | | | | TOTAL FOOTAGE | 93.00 | 28.35 | | | | |

Table 2. Locations of new geoprobe cores collected during SM FY16. These are located in the Southwest Quadrant of Falkland Quadrangle except for Boswell-01 and Holland-01, which extend an important transect and are positioned in Southeast Quadrant of the Fountain Quadrangle.

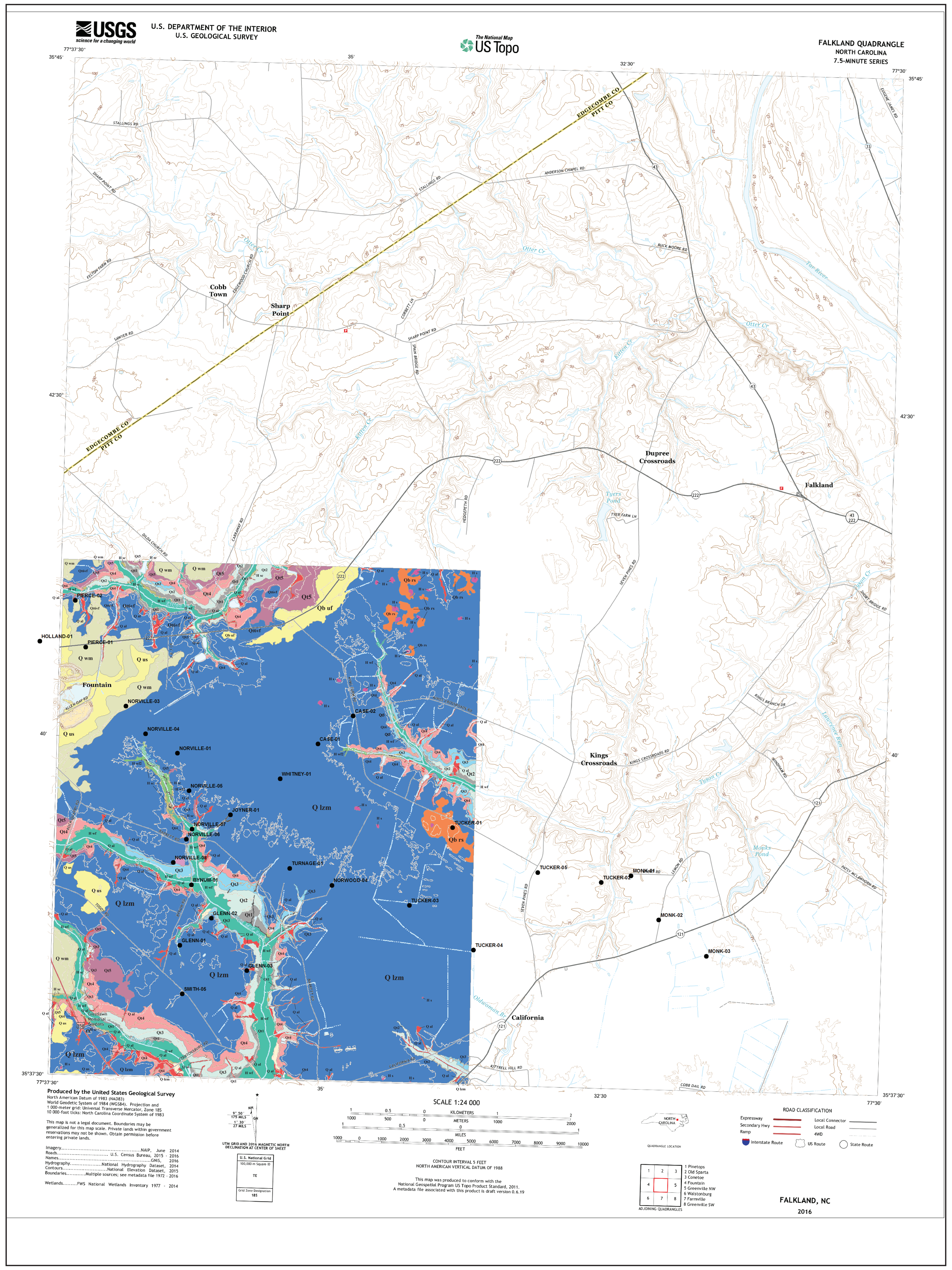
| HOLE_ID | DATE_DRILLED | GEO_IN_FIELD | QUAD | COUNTY | NORTHING_M | EASTING_M | LAT_DD | LONG_DD | DEPTH_FT | DEPTH_M | ELEVATION_FT | ELEVATION_M | CORING METHOD | DRILLERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NORVILLE-04 | 9/7/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 213551.0960 | 735286.4880 | 35.667147 | -77.611654 | 50.50 | 15.39 | 86.18 | 26.27 | Geoprobe Discrete Sampling | D. Foyles |
| NORVILLE-05 | 9/8/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 212800.2800 | 735907.7370 | 35.660301 | -77.604909 | 39.00 | 11.89 | 84.95 | 25.89 | Geoprobe Discrete Sampling | D. Foyles |
| NORVILLE-06 | 9/14/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 212134.4450 | 735899.0620 | 35.654301 | -77.605108 | 47.40 | 14.45 | 81.72 | 24.91 | Geoprobe Discrete Sampling | D. Foyles |
| NORVILLE-07 | 9/16/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 212277.7910 | 735972.4550 | 35.655584 | -77.604275 | 44.00 | 13.41 | 71.13 | 21.68 | Geoprobe Discrete Sampling | D. Foyles |
| JOYNER-01 | 9/30/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 212491.9550 | 736485.2370 | 35.657449 | -77.598579 | 36.00 | 10.97 | 84.22 | 25.67 | Geoprobe Discrete Sampling | D. Foyles |
| TUCKER-01 | 10/1/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 212441.7180 | 739522.7750 | 35.656605 | -77.565043 | 48.00 | 14.63 | 85.25 | 25.98 | Geoprobe Discrete Sampling | D. Foyles |
| TUCKER-02 | 10/2/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 211777.3330 | 741578.1420 | 35.650347 | -77.542453 | 44.00 | 13.41 | 76.84 | 23.42 | Geoprobe Discrete Sampling | D. Foyles |
| MONK-01 | 10/18/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 211884.8940 | 741981.2400 | 35.651263 | -77.537984 | 51.50 | 15.70 | 77.91 | 23.75 | Geoprobe Discrete Sampling | D. Foyles |
| MONK-02 | 10/20/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 211298.3890 | 742381.6690 | 35.645924 | -77.533658 | 56.00 | 17.07 | 81.97 | 24.98 | Geoprobe Discrete Sampling | D. Foyles |
| MONK-03 | 10/26/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 210829.8980 | 743050.7810 | 35.641612 | -77.526347 | 48.00 | 14.63 | 81.78 | 24.93 | Geoprobe Discrete Sampling | D. Foyles |
| NORVILLE-08 | 11/1/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 211810.6340 | 735734.4970 | 35.651403 | -77.606976 | 49.25 | 15.01 | 81.39 | 24.81 | Geoprobe Discrete Sampling | D. Foyles |
| TUCKER-03 | 11/2/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 211358.3310 | 738977.2280 | 35.646911 | -77.571240 | 53.50 | 16.31 | 84.04 | 25.61 | Geoprobe Discrete Sampling | D. Foyles |
| TUCKER-04 | 11/9/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 210785.6230 | 739872.2280 | 35.641633 | -77.561449 | 46.50 | 14.17 | 83.73 | 25.52 | Geoprobe Discrete Sampling | D. Foyles |
| TUCKER-05 | 11/10/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 211877.6290 | 740707.7610 | 35.651366 | -77.552048 | 54.20 | 16.52 | 83.10 | 25.33 | Geoprobe Discrete Sampling | D. Foyles |
| GLENN-01 | 11/29/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 210687.6510 | 735870.4470 | 35.641265 | -77.605649 | 40.75 | 12.42 | 83.13 | 25.34 | Geoprobe Discrete Sampling | D. Foyles |
| GLENN-02 | 12/1/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 211074.4870 | 736283.4430 | 35.644699 | -77.601028 | 46.00 | 14.02 | 82.43 | 25.13 | Geoprobe Discrete Sampling | D. Foyles |
| GLENN-03 | 12/1/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 210380.0630 | 736795.9900 | 35.638375 | -77.595478 | 39.00 | 11.89 | 77.04 | 23.48 | Geoprobe Discrete Sampling | D. Foyles |
| SMITH-05 | 12/7/2016 | K.Farrell, E.Thornton | Falkland | Pitt | 210025.7940 | 735928.0290 | 35.635292 | -77.605115 | 46.30 | 14.11 | 85.06 | 25.93 | Geoprobe Discrete Sampling | D. Foyles |
| TURNAGE-01 | 1/17/2017 | K.Farrell, E.Thornton | Falkland | Pitt | 211797.3560 | 737324.3590 | 35.651081 | -77.589422 | 52.00 | 15.85 | 83.04 | 25.31 | Geoprobe Discrete Sampling | D. Foyles |
| BOSWELL-01 | 1/19/2017 | K.Farrell, E.Thornton | Fountain | Pitt | 214715.1900 | 733087.0260 | 35.677913 | -77.635770 | 54.90 | 16.73 | 93.92 | 28.63 | Geoprobe Discrete Sampling | D. Foyles |
| NORWOOD-04 | 1/25/2017 | K.Farrell, E.Thornton | Falkland | Pitt | 211589.3080 | 737909.3390 | 35.649131 | -77.582995 | 44.00 | 13.41 | 81.37 | 24.80 | Geoprobe Discrete Sampling | D. Foyles |
| PIERCE-01 | 2/1/2017 | K.Farrell, E.Thornton | Falkland | Pitt | 214697.8930 | 734422.3330 | 35.677591 | -77.621022 | 52.00 | 15.85 | 91.58 | 27.91 | Geoprobe Discrete Sampling | D. Foyles |
| HOLLAND-01 | 2/2/2017 | K.Farrell, E.Thornton | Fountain | Pitt | 214752.5730 | 733792.3940 | 35.678163 | -77.627972 | 54.50 | 16.61 | 91.78 | 27.98 | Geoprobe Discrete Sampling | D. Foyles |
| CASE-01 | 2/16/2017 | K.Farrell, E.Thornton | Falkland | Pitt | 213506.6340 | 737639.9740 | 35.666446 | -77.585667 | 47.85 | 14.58 | 85.60 | 26.09 | Geoprobe Discrete Sampling | D. Foyles |
| CASE-02 | 2/23/2017 | K.Farrell, E.Thornton | Falkland | Pitt | 213907.4020 | 738105.1740 | 35.669999 | -77.580466 | 28.00 | 8.53 | 84.35 | 25.71 | Geoprobe Discrete Sampling | D. Foyles |
| WHITNEY-01 | 6/22/2017 | K.Farrell, E.Thornton | Falkland | Pitt | 213010.6200 | 737144.1160 | 35.662047 | -77.591224 | 39.50 | 12.04 | 86.29 | 26.30 | Geoprobe Discrete Sampling | D. Foyles |
| PIERCE-02 | 8/16/2017 | K.Farrell, E.Thornton | Falkland | Pitt | 215331.0870 | 734251.8350 | 35.683326 | -77.622811 | 48.00 | 14.63 | 87.66 | 26.72 | Geoprobe Discrete Sampling | D. Foyles |
| BYNUM-01 | 8/24/2017 | K.Farrell, E.Thornton | Falkland | Pitt | 211516.1070 | 735993.1700 | 35.648723 | -77.604167 | 35.00 | 10.67 | 70.18 | 21.39 | Geoprobe Discrete Sampling | D. Foyles |
| | | | | | | | | | | | | | | |
| | | | | | | | | TOTAL FOOTAGE | 1295.65 | 394.91 | | | | |

# GEOLOGIC MAP WITH GEOMORPHIC LANDSCAPE ELEMENTS OF THE FALKLAND 7.5 MINUTE QUADRANGLE, SOUTHWEST QUADRANT, NORTH CAROLINA

By
Kathleen M. Farrell and Erik D. Thornton

Geology mapped from July 2016 to September 2017. Landscape analysis, map preparation, digital cartography and editing by Kathleen M. Farrell.

2017



Produced by the United States Geological Survey

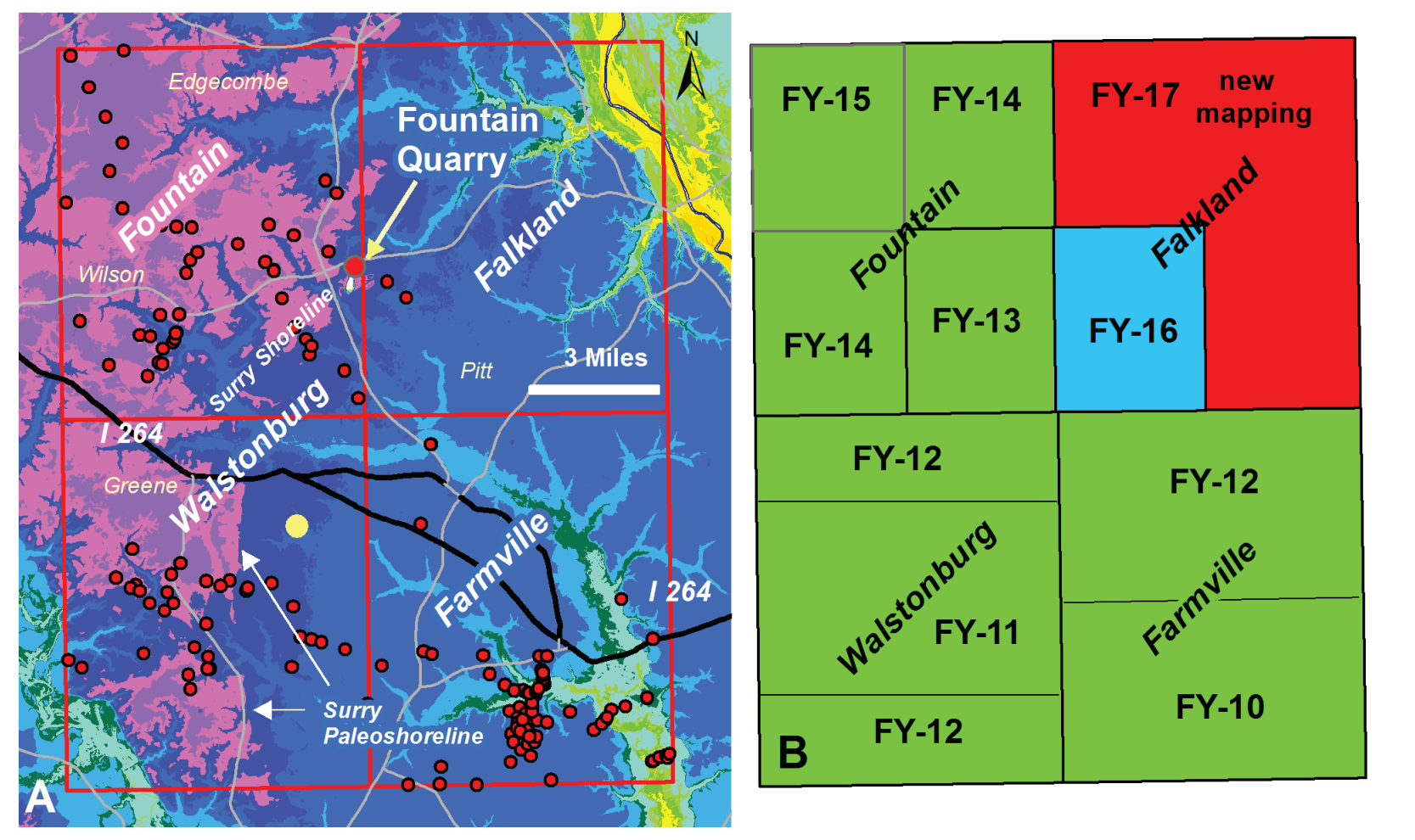


Fig. 4. Data distribution in the key 4 quad map area (Farmville, Walstonburg, Fountain and Falkland quads) that includes the Early Pleistocene Surry Paleoshoreline complex on a LiDAR basemap. County boundaries and I264 transportation corridor are shown. B. Recent and newly proposed STATEMAP deliverables. Falkland quad (SW 1/4) is the new FY16 map area.

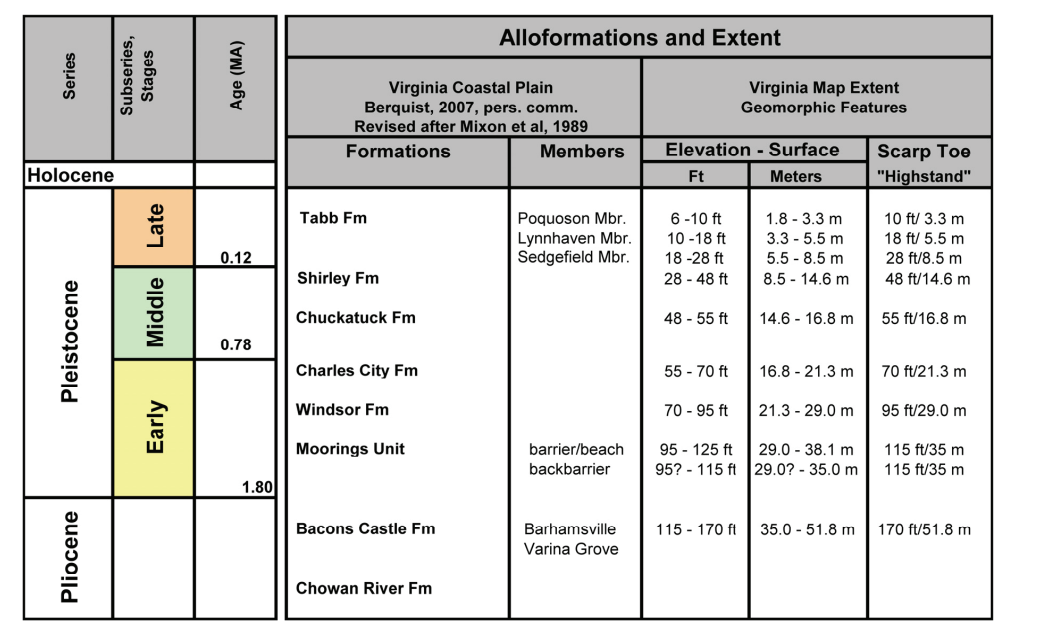


Figure 5. Chart showing relative ages and map units for Virginia’s Coastal Plain Map (Mixon and others, 1989) This diagram does not incorporate revisions to the Pleistocene proposed by Gibbard and others (2010).

## Legend for Geologic Map Units - Geomorphic Landscape Elements

### Holocene

| | |
|---|---|
| ■ | Stream Channel |
| ■ | Man-Made Excavation - Pond or Lagoon, Mining Operations. |
| ■ | Man-Made Earthenware Structures - such as Spoil Piles from Mining and Dredging, Dams, Causeways through Wetlands. |
| H wf | H wf--Wetland Flat (Holocene): Wetland flat at base of incised valleys; commonly with anastomosed channel network activated during flood stage, or a single main channel, which is commonly trenched and straightened by human activity; may exhibit lacustrine conditions. Basal quartz sand fines up into organic-rich sand and mud. Deposits are typically less than 3 m thick. Flat is typically flanked by colluvium, alluvial fan, and partly buried channel belts. It is partly incised into pre-existing deposits, and may be separated in stepwise fashion from other active wetland flats. Upstream, the flat narrows and is replaced by channel deposits or undifferentiated Quaternary alluvium. Typical facies include: muddy and sandy peat, gravelly sand and other facies. |
| H wf2 | H wf2--Wetland Flat 2 (Holocene - reactivated Pleistocene flat): Wetland flat that merges with the Hwf in upstream reaches of incised valleys. In some cases, H wf2 is separated vertically by a step-like feature from H wf. An incised channel may connect the two wetland flats. In other cases, the two flats gradually merge in upstream reaches. H wf2 is dryer than H wf; it may be continuous with a set of valley fill terraces. |
| H sc | H sc--Side valley colluvium, slightly higher Holocene facies, positioned marginal to wetland flat; may include side bars and lunate bars associated with channels. |
| H s | H s--Sinkhole (Holocene): Incipient ovate depression that is lower than surrounding landscape, and commonly infilled with wetland. |

### Undifferentiated Quaternary Deposits:

| | |
|---|---|
| Q urs | Q urs: Undifferentiated remobilized sands that usually on interfluve flats such as the 24-26 m marine terrace. |

### Undifferentiated Pleistocene Valley Fill Deposits

| | |
|---|---|
| Qal | Qal Undifferentiated Quaternary Alluvium - currently active landscape. Includes all the Holocene material in side valleys and on alluvial fans and colluvium on side slopes. |
| Qt1 | Qt1 Pleistocene Stream Terrace @ 19-20 m. |
| Qt2 | Qt2 Pleistocene Stream Terrace @ 20-21 m. |
| Qt3 | Qt3 Pleistocene Stream Terrace @ 22-23 m. |
| Qt4 | Qt4 Pleistocene Stream Terrace @ 23-24 m. |
| Qt5 | Qt5 Pleistocene Stream Terrace @ 24-25 m. |
| Qt6 vf | Qt6 Pleistocene Valley Terrace @ 25-26.5 m; merges with marine terrace equivalent that is seaward (east) of ~26 m shoreline (Q lzm). |

### Early Pleistocene Units - Interfluve Regions:

| | |
|---|---|
| Q lzm | Q lzm: Informal Lizzie Formation, marine interfluve deposits; occur beneath marine flat east of 26 m shoreline. |
| Q us | Q us: Undifferentiated shoreline and barrier islands sands that usually occur at 28-30 m and 26-27m. These help define the shorelines at 30 m and 26 m. |
| Qwm | Qwm: Windsor Formation: Seaside marine unit that mantles the Wicomico plain seaward of the Surry paleoshoreline at elevations of ~26 to 28 m. In the Fountain quarry, the unit consists of S lam, a laminated sand facies. In this case, distal shoreface deposits. |

## Sr Isotopic Stratigraphy

Strontium isotopic stratigraphy utilizes variations of the 87Sr/86Sr ratio in seawater to date the time of sedimentation. Variations in 87Sr/86Sr ratios are recorded in authigenic calcium-bearing minerals because of the similarity in the ionic radius of Sr (1.13 Å) to Ca (0.99 Å) (McArthur et al., 2001; Veizer et al., 1997). Calcium carbonate minerals such as calcite and aragonite exclude 87Rb, the parent of 87Sr, during authigenesis, thus the 87Sr/86Sr ratio preserved in fossil tests should reflect the seawater composition at the time of formation. Carbonate minerals must meet criteria to assure their chemical makeup reflects authigenesis rather than diagenesis for them to be suitable for 87Sr/86Sr ratio analysis and dating the time of sedimentation. Although there have been recurring fluctuations in 87Sr/86Sr ratios through time, as long as another method such as biostratigraphy allows the approximate point in time to be determined, the 87Sr/86Sr ratio can provide a numeric solution (McArthur et al., 2001).

87Sr in seawater is derived from two main sources, the weathering of continental crust and hydrothermal activity in the oceans. Strontium derived from the continental crust reaching the ocean through rivers has an average 87Sr/86Sr ratio of 0.716, while strontium supplied by hydrothermal circulation at mid-ocean ridges has a 87Sr/86Sr ratio of 0.703 (Elderfield, 1986). Hence, the 87Sr/86Sr ratio of seawater at any specific geologic time has depended primarily upon the variations in the rates of input from these sources as well as the rate of removal by deposition. Because the residence time of Sr in ocean water (approximately 106 yrs) is longer than the time it takes for currents to mix the oceans (103 yrs), the oceans are thoroughly mixed with respect to the Sr isotopes (McArthur, 1994). As the “present is the key to the past” and the residence time of Sr in ancient oceans was longer than the mixing time, the global ocean should have had the same 87Sr/86Sr for specific geologic intervals, thus permitting the dating of geologic events. There are some limitations to the method. First problems may arise when the 87Sr/86Sr ratio in carbonate samples differs from the 87Sr/86Sr ratio of the world oceans at the time of deposition. Although this is very rare in marine settings (McArthur et al., 2001), the 87Sr/86Sr ratio of a very restricted basin can be altered by local fluxes from rocks with significantly different 87Sr/86Sr ratios. A lower 87Sr/86Sr ratio may be induced by increased input from e.g. continental flood basalts or mid-ocean ridge volcanism. Similar problems arise when diagenetic fluids alter the original 87Sr/86Sr ratio (McArthur and Howarth, 2004). The bias towards higher or lower ratios depends on the 87Sr/86Sr ratio of the rocks or sediments through which fluids travel. There is no reason to expect that the 87Sr/86Sr ratio differs in sediments preserved in the Atlantic Coastal Plain from the global marine ratio.

## 87Sr/86Sr Analyses

Carbonate samples containing various molluscan types were collected from the cores listed in Table 3 and several other cores in related datasets. Although Sr isotopic dating of various fossils such as foraminifera and ostracods is used in dating marine sediments, in nearshore deposits articulated thick-valve molluscan shells are commonly used. They are commonly used because of the general lack of abundant microfossils and their presence suggests little lateral transport and reworking. In this study, only one articulated, thin-walled bivalve was found in the cores. Consequently, samples separated and prepared for dating were not ideal but they represented the best material available. All samples were examined under a binocular microscope for characteristics of diagenetic alteration, i.e. recrystallization, dissolution, and presence of carbonate precipitates that may affect the 87Sr/86Sr ratio. In addition, other parameters of preservation including shell colour and opacity, chalkiness, and the presence infilling of borings were also accessed. Those shell samples that had no visual evidence of diagenetic alteration were selected for further study. Samples selected for further study were sonicated in demineralized water in an ultrasonic cleaner to remove contaminants, air-dried, and re-examined under a binocular microscope. Only those molluscan samples deemed to have the greatest potential of providing Sr dates representing the time of sedimentation were selected for dating; the samples and dates are provided in Table 3.

Samples prepared for dating were submitted for isotopic analyses to the Department of Geological Sciences at the University of North Carolina at Chapel Hill. At Chapel Hill a VG (MicroMass) Sector 54 thermal ionization mass spectrometer in under the supervision of Dr. Drew Coleman was used for isotopic analyses. The methodology for the analysis of 87Sr/86Sr followed that of Harris and Self-Trail (2006). Three to five mg of each sample was dissolved and Sr separated from the matrix using EiChrom SrSpec resin and standard chromatographic techniques. In order to correct for instrumental mass bias, measured strontium isotope ratios were normalized to a value of 0.1194 for 86Sr/88Sr. The long-term normalized 87Sr/86Sr value for the Sr isotopic standard SRM 987 (U.S. National Institute of Standards & Technology, NIST) in the laboratory at Chapel Hill averages 0.710252 ±0.000015. All 87Sr/86Sr values of samples in Table 1 have been adjusted by the amount needed to change the average value for SRM 987 to 0.710250. This value varies slightly from the 87Sr/86Sr value of 0.710248 ± 0.000006 used by McArthur et al. (2001), resulting in only a negligible difference in dates.

Dates were determined using LOWESS 4B-08/04 and a preliminary revision (LOWESS 5 Fit 26 03 13) to the 2004 and 2009 LOWESS tables; this revision was provided by John McArthur (2014, personal communication).The look-up tables of Howarth and McArthur (1997) use a Locally Weighted regression Scatterplot Smoother (LOWESS) method, which is a nonparametric regression technique to produce a best-fit model for the 87Sr/86Sr curve. This procedure involves a point by point evaluation of the seawater curve. Due to the complexity of the nonparametric methods, they provided a look-up table with 87Sr/86Sr ratios in 0.000001 increments for date interpolation. Based on replicate sample analyses, the two-standard deviation internal precision for the Sr carbonate analyses is about 14x10-6 for a single determination and 11x10-6 for duplicate determinations. This analytical error was combined with uncertainty in the LOWESS fit to the secular 87Sr/86Sr curve for seawater at the 95% confidence level (McArthur et al., 2001) to yield the total uncertainty in dates given in Table 3.

## Interpretation of Sr Dates

To interpret the dates it is important to look at the range of the dates based on the analytical precision rather than the date for the corrected 87Sr/86Sr value; these are shown in Table 3. Considering the range, the dates of the ten samples cluster into two distinct groups (Table 3). A group of older dates occur in core samples Norville #3, 43.4’, Norville #2, 58.7’, Woodland #1, 37.2’ and Woodland #1, 38.8’and a group of younger dates occur core samples Norville #2, 56.95’, KE-C-10, 17.3-17.4’, KE-C-10, 15.9-16.0’, CBC-03, 47.2-47.3’, Ham -01, 38.3’, and Ham-01, 38.7’. The older dates indicate a Piacenzian or late Pliocene age for the samples and the younger dates indicate a Gelasian or early Pleistocene age for the samples (Table 3). When the dates are plotted an east-west cross section (Woodland #1, to Ham-01, to Norville #2, and CBC-03) datumed on sea-level they occur in the same lithologic unit from the lower member of the Chowan River Formation at the stratotype on the Chowan River, and dates from a fossiliferous unit in the Fountain Quarry located just north interpreted to be the Chowan River Formation. The Pliocene dates occur within the same lithostratigraphic unit and are interpreted to be from shells reworked into the Chowan River Formation from the underlying Pliocene Yorktown Formation.

Table 3. Results of Sr 87/86 isotopic analyses.

| Sample | Core Hole, Depth | Corrected 87Sr/86Sr | % Std Err | Error (2 σ) | + Ratio | - Ratio | LOWESS 5 26-03-13 Date | LOWESS 4 V4B-08/04 Date | LOWESS 5 Date Error (Range) | Age |
|---|---|---|---|---|---|---|---|---|---|---|
| HS2085S | Norville #3, 43.4' | 0.709053 | 0.0007 | 0.000010 | 0.709063 | 0.709043 | 4.00 | 4.00 | 1.80 (2.95-4.75) | Zanclean |
| HS2084S | Norville #2, 58.7' | 0.709062 | 0.0006 | 0.000009 | 0.709071 | 0.709053 | 3.03 | 2.93 | 1.55 (2.45-4.00) | Piacenzian |
| HS2083S | Norville #2, 56.95 | 0.709091 | 0.0007 | 0.000010 | 0.709101 | 0.709081 | 1.85 | 1.80 | 0.47 (1.63-2.10) | Gelasian |
| H2081-10S | KE-C-10, 17.3-17.4' | 0.709080 | 0.0007 | 0.000010 | 0.709090 | 0.709070 | 2.13 | 2.18 | 0.63 (1.875-2.50) | Gelasian |
| H2080-10S | KE-C-10, 15.9-16.0' | 0.709067 | 0.0007 | 0.000010 | 0.709077 | 0.709057 | 2.65 | 2.63 | 1.35 (2.225-3.575) | Piacenzian |
| H2076-10S | CBC-03, 47.2-47.3' | 0.709094 | 0.0006 | 0.000009 | 0.709103 | 0.709085 | 1.78 | 1.73 | 0.38 (1.60-1.975) | Gelasian |
| H2091 | Ham-01, 38.3’ | 0.709078 | 0.0007 | 0.000010 | 0.709088 | 0.709068 | 2.20 | 2.25 | 0.685 (1.917-2.60) | Gelasian |
| H2092 | Ham-01, 38.7’ | 0.709082 | 0.0005 | 0.000007 | 0.709089 | 0.709075 | 2.08 | 2.10 | 0.40 (1.90-2.30) | Gelasian |
| H2094 | Woodland, 37.2’ | 0.709060 | 0.0007 | 0.000010 | 0.709070 | 0.709050 | 3.23 | 3.15 | 1.85 (2.50-4.35) | Piacenzian |
| H2095 | Woodland, 38.8’ | 0.709065 | 0.0006 | 0.000009 | 0.709074 | 0.709056 | 2.80 | 2.70 | 1.325 (2.35-3.675) | Piacenzian |

Note: Values for 87/86 is reported relative to 0.710250 for standard NBS-987 (this is approximately the average obtained by all labs).

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