

York River Geology

Carl Hobbs

Virginia Institute of Marine Science
Gloucester Point, VA 23061 U.S.A.

ABSTRACT

The four separate sites of the Chesapeake Bay National Estuarine Research Reserve in Virginia are within the Coastal Plain province of the mid-Atlantic. The surficial geology at each site is of Quaternary age, primarily Holocene wetlands. The site at Taskinas Creek is set into Tertiary age strata. The underlying strata increase in age up-stream. Regionally, the Late Tertiary and Quaternary geology is a function of the series of major transgressions and regressions, during which the successively more recent high stands of sea level generally have not reached the level of the preceding high stand. As a consequence, stratigraphically higher, younger deposits occur topographically below exposures of the older strata. The two down-stream reserve sites are within the area of the Eocene age Chesapeake Bay Impact Crater. Also at these two sites, the tidal marshes are superimposed on a ridge and swale topography. The local rate of sea-level rise, approximately 4 mm/yr, is the underlying process driving changes to the tidal marshes at all four sites. The Goodwin Islands, at the mouth of the York River with exposure to Chesapeake Bay, can be severely impacted by storm waves and surge. Future research should include a program of coring to develop the time-history of recent rise of sea level and assist on-going efforts toward mapping the regional geology and toward understanding the local and regional ground-water systems. In addition, establishment of permanent benchmarks to document elevation would enable long-term monitoring of subsidence and facilitate differentiation of the eustatic and isostatic components of changes in relative sea-level rise relative to climate change or other factors.

INTRODUCTION

All four separate sites of Chesapeake Bay National Estuarine Research Reserve in Virginia (CBNERRVA) are within the Coastal Plain province of the mid-Atlantic along the York River and its tributaries. The surficial geology at each of the locations is of Quaternary age, primarily Holocene wetlands that formed within the past few thousand years. The underlying strata increase in age up-stream. Additionally, the two down-stream reserve sites, Goodwin and Catlett Islands, are within the area of the approximately 35 million year old Chesapeake Bay Impact Crater.

THE CHESAPEAKE BAY IMPACT CRATER

During the Eocene Epoch, approximately 35.5 million years ago (KOEHLER *et al.*, 1996), a comet or meteor struck the earth at what today is the southern part of Chesapeake Bay (Figure 1). At that time, sea level was a hundred or so meters higher than today. Chesapeake Bay did not exist, and the area hit by the bolide was a continental shelf, marine environment. Poag (1996) characterizes the resulting crater as “the seventh largest impact crater on Earth.” The roughly circular crater is approximately 90 km (56 miles) in diameter and nearly 2 km (1.2 miles) deep (POWERS and BRUCE, 1999, among others.) According to Poag *et al.* (1994), the crater was filled extremely rapidly with a breccia, composed of clasts of the disrupted strata. Poag *et al.* (1994) named the fill deposit the Exmore breccia and consider it to be an impact tsunami deposit.

The excavation cut strata down through the Lower Cretaceous and into the Paleozoic basement rocks. As several of the strata are aquifers, the crater and its fill disrupt the regional, deep ground-water-system. Water presently flowing in the aquifers flows around the crater while the crater itself is “a single huge reservoir ... (in which) pore spaces are filled with briny water that is 1.5 times saltier than normal seawater” (USGS, 1998).

Probably because of its rapid deposition, the Exmore breccia compacted more rapidly than the surrounding, older, strata with the result that its upper surface has dropped or sagged through time. Poag *et al.* (1999) state that “the crater is buried under 300-1,000 m of post impact late Eocene to Quaternary sedimentary strata.” The overlying, post-impact strata thicken slightly in the area over the crater as shown by Powers and Bruce (1999), among others, as the sediments attempted to fill the shallow basin, with the consequence that there is differential compaction between the slightly thicker strata over the crater and the surrounding sediments. The compaction likely was the cause of the apparent tectonic activity that, ac-

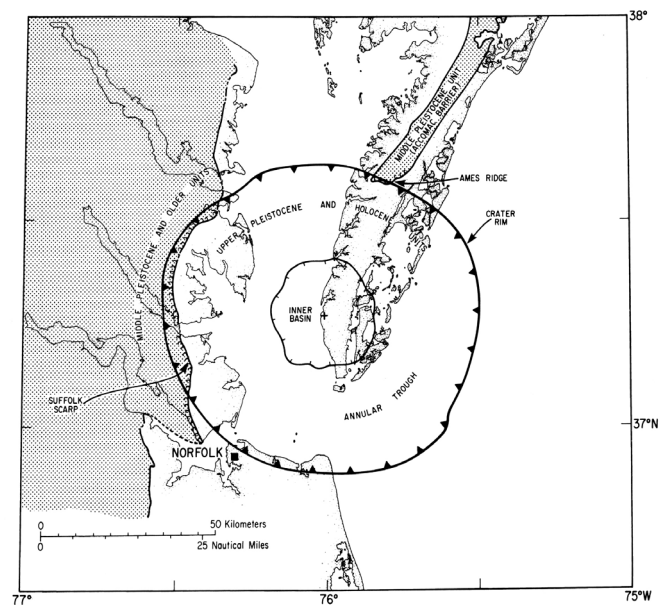


Figure 1. Map depicting the extent of the Chesapeake Bay Impact Crater (Figure 23 from POAG *et al.*, 1994).

ording to Ramsey (1992), writing before the recent series of crater-related studies, effectively ended by Bacons Castle time. However, the presence of small, near surface growth-faults suggests that the process might continue today and be the cause of the small earthquakes associated with the outer rim of the crater (JOHNSON *et al.*; 1998). The Catlett Islands essentially sit above the crater rim, near the small faults observed by Johnson *et al.* (1998).

REGIONAL LATE TERTIARY AND QUATERNARY GEOLOGY

The later Tertiary and Quaternary strata of the Coastal Plain result from deposition in shallow marine or estuarine environments accumulated during a series of marine transgressions. Substantial, hundred meter scale, variations in sea level were caused by climate driven changes in the volume of the ice caps. As sea level rose, the surf-zone moved across and eroded the gently sloping land surface. When sea level was nearly static, the erosion of the shoreline and near shore zone sculpted a distinct steeper slope. The eroded sediments along with material supplied by river input were deposited somewhat further offshore. As it happened, each successively younger, sea-level high stand was somewhat lower than its predecessor. This probably occurred as a result of several factors including a long-term decrease in global average temperature beginning in the Cretaceous and an increase in ocean basin volume that accompanied the growth of the Atlantic. Hobbs (2004) reviews the regional correlation of strata and history of the stratigraphic nomenclature.

The deposition of thin, roughly tabular beds followed by a regression and subsequent transgression has resulted in the stair-step geological framework of the mid-Atlantic Coastal Plain (Figure 2). The upper Pliocene and Pleistocene strata rest upon older Tertiary strata that outcrop in valley walls cut into the inland portion of the coastal plain. Because the younger units were formed by the erosion and redeposition of the older units and because of a paucity of fossils in many strata, identification of specific formations often is difficult requiring, in addition to an understanding of the regional stratigraphic setting, local experience and knowledge of elevation. Most formations are separated by unconformities. The older Tertiary units have a better preserved fauna, listed by Ward (1985) who also provides descriptions of the older strata of the Pamunkey River area. Most of the Pleistocene stratigraphic section is weakly cemented and poorly indurated. As a consequence, when exposed in steep faces, the sediments are easily eroded. Ward and Blackwelder (1980) named the Eastover Formation in their revised interpretation and nomenclature for the Upper Miocene and Lower Miocene strata. Johnson and Berquist (1989) indicated that the lower Eastover contains few fossils though there are fairly abundant ghosts and molds. The upper

Eastover is fossiliferous and is separated from the overlying Yorktown Formation by an unconformity. In areas where fossils and other identifying features are absent, it is difficult to distinguish between the Eastover and the Yorktown.

Across the outer coastal plain, the Pliocene age Yorktown Formation is widespread and easily identifiable strata. Krantz (1990, 1991) places its age as between 4.8 million and 2.8 million years before present. According to Cronin *et al.* (1984) it was deposited during three transgressive episodes. The depositional environment was shallow marine: inner shelf, barrier island, estuarine, lagoon. Ward and Blackwelder (1980), Johnson and Ramsey (1987), and Johnson and Berquist (1989) suggest that the fossils indicate a subtropical setting for the upper portion of the formation. The Yorktown is widespread, occurring from Maryland to North Carolina.

According to Johnson and Peebles (1985) and Ramsey (1987) the Yorktown and Eastover formations are cut by an angular unconformity; thus the Bacons Castle Formation, named by Coch (1965), sits disconformably atop the Yorktown. Ramsey (1987, 1988) subdivided the Bacons Castle into tidal flat deposits (Barhamsville member) and fluvial and estuarine gravel and sand (Varina Grove member). In some areas, Bacons Castle sediments fill channels that were cut into underlying deposits. The formation contains a wide variety of sediments and sedimentary structures but is lacking in usable fossils or other dateable materials. Primarily because of its stratigraphic position, the Bacons Castle Formation has been assigned to the Late Pliocene.

Oaks and Coch (1973) used the Moorings unit for an informal stratigraphic unit west of the Surry Scarp. Johnson and Berquist (1989) characterized the Moorings unit as having an eastern sand facies and a western clay facies; both of which usually are less than 3 m thick. They described the clay fa-

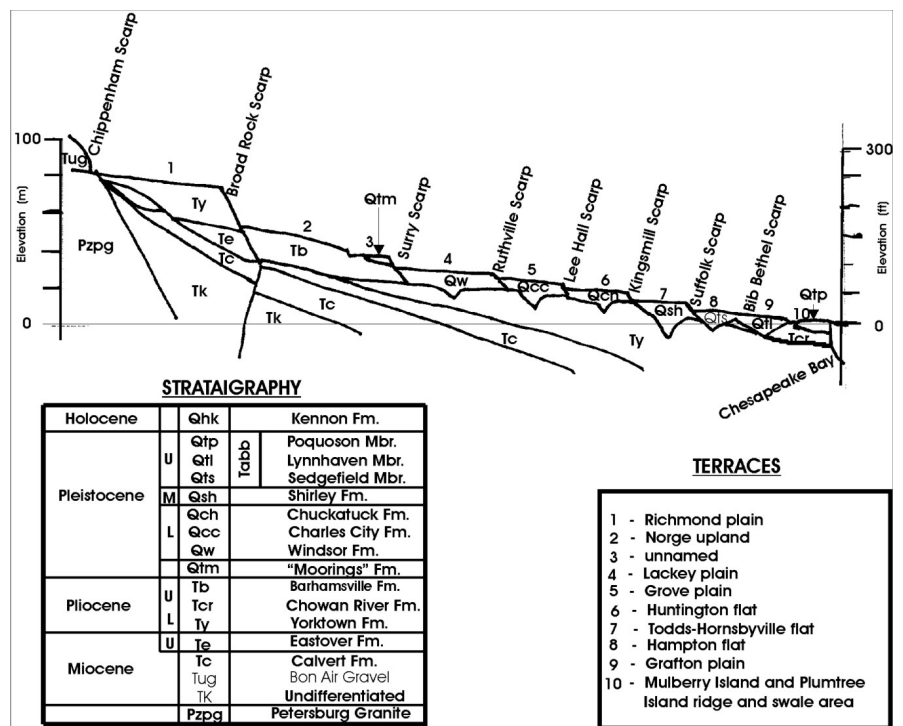


Figure 2. A schematic cross section of geologic framework of the York River area of the mid-Atlantic Coastal Plain (after JOHNSON and HOBBS, 1990; and HOBBS, 2004).

cies as commonly bioturbated, massively bedded, silty clay to muddy sands. The sand facies is massively bedded and generally lacking sedimentary structures except for local clay laminations and drapes. According to Johnson and Berquist (1989), "the Moorings unit formed as a barrier-beach (sand facies) and back barrier lagoon or bay (clay facies) couplet. The sand (barrier-beach) facies, which lies to the east of the clay facies, is at slightly higher elevations and grades laterally into the fine-grained sediments at lower elevations." This is exactly as would be expected with the barrier beach seaward, east, of and topographically above the bay or lagoon. By virtue of being stratigraphically above the Windsor Formation and below the Bacons Castle and being west of the Surry Scarp, Johnson and Berquist (1989) place the Moorings unit in the Late Pliocene or Early Pleistocene.

The Windsor Formation rests uncomfortably atop the Yorktown and immediately seaward of the Surry Scarp. As reviewed in Hobbs (2004), the Surry Scarp clearly crosses North Carolina and Virginia and has been mapped as far south as Florida. The terrace below the Surry Scarp is the Lackey Plain (JOHNSON, 1972) and is upper surface of the Windsor. According to Johnson and Berquist (1989) no diagnostic fossils have been described from the Windsor. They also describe the sedimentary sequence as fining upward from coarse, fluvial sediments to bioturbated, massively bedded, muddy sands and sandy muds of estuarine origin. Mostly because of its stratigraphic position, the Windsor Formation generally is considered to date from the early Pleistocene.

The Charles City Formation (JOHNSON and BERQUIST, 1989) sits below the Ruthville Scarp which separates the Lackey Plain from the younger Grove Plain. The Ruthville Scarp (JOHNSON and BERQUIST, 1989) was cut during deposition of the Charles City Formation. They describe its sediments as fining upward from gravelly sands to silty to clayey sands with very coarse sediments, pebbles, cobbles, and boulders, at the basal contact. They describe the Charles City Formation as being severely eroded and preserved only as isolated sections which often outcrop in stream banks and terraces. According to Johnson and Ward (1990), datable fossils have yet to be found in the Charles City. Based on its stratigraphic position beneath the Middle Pleistocene Chuckatuck and Shirley Formations, Johnson and Berquist (1989) place the Charles City Formation in the Early Pleistocene.

The Lee Hall Scarp (JOHNSON, 1972) has just over 4 m (12 ft) of relief above its toe at about 17 m (58 ft). It has a shallow rise and has been sufficiently cut by erosion in some areas as to be unrecognizable. It separates the Grove and Grafton Plains. The Chuckatuck Formation (JOHNSON and PEEBLES, 1985, 1987; JOHNSON and BERQUIST, 1989) underlies the Grafton Plain. According to Johnson and Berquist (1989) relative sea level reached about 19 m (60 ft) above present during Chuckatuck time. As with the other Pleistocene sedimentary units, the Chuckatuck Formation was formed from sediments eroded from older strata and has not yielded any age-definitive fossils or fossil assemblages. Johnson and Berquist (1989) state, "The lowermost beds for the Chuckatuck occupy channels cut at least 25 feet deep into older Pleistocene and Tertiary Sediments. The channel deposits commonly contain poorly sorted, basal pebbly-to cobbly-sand that is less than 6 inches thick." Because it is separated from the overlying Late Middle Pleistocene Shirley Formation by an unconformity, the Chuckatuck Formation likely is of Middle Pleistocene age.

Along the York River, the Camp Peary Scarp (JOHNSON, 1972) separates the Grafton Plain from the Huntington Flat which is the upper surface of the Shirley Formation (JOHNSON and BERQUIST, 1989). According to Johnson and Berquist (1989) the Shirley Formation contains fluvial, estuarine, marsh, shallow marine, and similar deposits. Based on dates (MIXON *et al.*, 1982 and CRONIN *et al.*, 1984) of correlative deposits along the Rappahannock River, Johnson and Berquist (1989) indicate that the Shirley Formation has a Late Middle Pleistocene age of about 185,000 year (late in Oxygen Isotope Stage 7). The Shirley varies in thickness from a thin, feather edge at the Kingsmill Scarp, a Camp Peary correlative (HOBBS, 2004) to more than 16 m in paleochannels cut into the Eastover and older strata (JOHNSON and BERQUIST (1989).

The Suffolk Scarp (Figures 1 and 2) has been mapped for about 200 miles (300 km). Johnson (1972) considered it the most prominent scarp on the York James peninsula with 10 m (30 ft) of rise as it separates the Grafton Plain from the Hornsbyville Flat and correlatives. These plains are the surface of the Sedgefield Member of the Tabb Formation (JOHNSON, 1976, JOHNSON and BERQUIST, 1989). The Big Bethel Scarp marks the lower edge of the Hornsbyville Flat and the upper limit of the Hampton Flat. The Mulberry Island Flat is lower than the Hampton but the two are not separated by a well defined scarp. The Hampton and Mulberry Island Flats likely are the surface expression of the Lynnhaven and Poquoson Members of the Tabb Formation and were deposited during the last above present stand of sea level, on the order of 100,000 years ago, Oxygen Isotope Stage 5. Indeed each of the three members might represent one of the mini high stands during Stage (TOSCANO, 1992; TOSCANO and YORK, 1992). Holocene sediments, primarily marsh or swamp, colluvium, and alluvium, unconformably overlie older strata. The modern sediments occur filling and fringing flooded channels and at the foot of steep slopes.

The underlying process driving changes today, as it has been in the past, to the surficial geology is sea-level rise. According to the NOAA (2008) using data from a now discontinued tide gage at Gloucester Point, the average rate of sea-level rise from 1950 through 1999 at Gloucester Point was 3.95 mm/yr (1.3 ft/century). A longer record, 1929-1999, at Sewells Point in Hampton Roads, about 40 km (25 miles) to the south, yields a rate of 4.42 mm/yr (1.45 ft/century) (NOAA website, 2008). On areas with a shallow slope, sea-level rise causes a transgression of the water over the land, moving the shoreline landward. If the rate is not too great, sea-level rise also encourages the upward and, perhaps, outward growth of marshes in areas otherwise conducive to marsh growth. This progradation opposes the simultaneous marine transgression.

GEOLOGIC SETTING OF THE RESEARCH RESERVE SITES

Goodwin Islands

Johnson (1972) mapped the Pleistocene outcrops on the Goodwin Islands (Figure 3) as the Norfolk Formation, an earlier term for the Tabb Formation (JOHNSON and BERQUIST, 1989). He described the ridges as being "composed of fine to medium sand, with less than 10 percent silt and clay. Small quantities of gravelly sand occur locally on the ridges. On the broader ridges sediments are slightly finer on the west side of



Figure 3. An oblique, aerial photograph of the Goodwin Islands (from CBNERRVA).

the ridges. The sand on the crest of the ridge lacks distinctive primary sedimentary structures and shows shallow weathering profiles.” According to Johnson (1972) there is a possibility that the lowest ridges were formed by progradation accompanying the most recent rise of sea level. The ridges on the Goodwin Islands are part of the Plum Tree Island Ridge and Swale Area (JOHNSON, 1972). The surficial deposits are relatively thin, perhaps indicating deposition during a relatively short and shallow submergence. Figure 4 is a geological map of the area. As a consequence of their low elevation and open exposure both to Chesapeake Bay, Mobjack Bay, and somewhat west along the York River, the Goodwin Islands are severely impacted by storm tides and waves.

Catlett Islands

The geology of the Catlett Islands (Figures 4 and 5) is similar to that of the Goodwin Islands. The islands themselves are

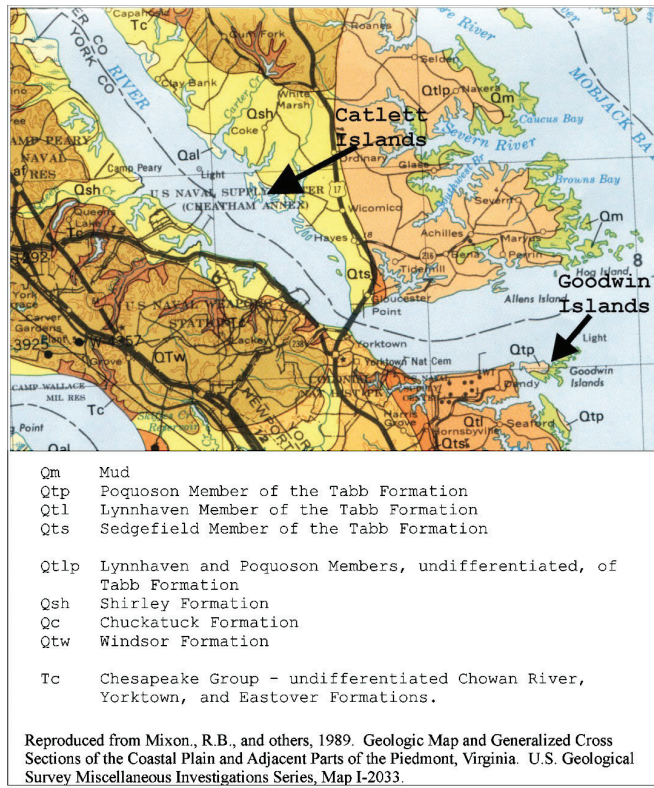


Figure 4. Geologic map depicting the Goodwin Islands and the Catlett Islands reserve site (from MIXON and others 1989).



Figure 5. An oblique, aerial photograph of the Catlett Islands (from CBNERRVA).

the surface expression of low ridges comprised of Late Pleistocene deposits of the Tabb Formation (MIXON *et al.*, 1989). The primary differences are that the Catlett Islands are in a much more protected setting, on the north bank of the York River and that they abut a relatively steep river bank in which older strata (Shirley Formation) are exposed. Holocene marshes are growing on the fringes of the ridges. The islands are subject to inundation during storm tides, however the shelter provided by the adjacent mainland protects them from north, northeast, and east winds and, thus, also from many waves. The long fetch up the York River allows for substantial wave action along the Catlett Islands with the northwest winds that accompany some cold front and often occur with the passage of storms.

Taskinas Creek/York River State Park

The Taskinas Creek estuarine reserve site (Figure 6) has a much different setting than the other Reserve sites in the system. It is a small stream and tidal marsh system cut into the older sediments of the south bank of the York River. The 397 ha (980 acres) of the Reserve are within York River State Park and contain both tidal and non-tidal elements. The geology of the Taskinas Creek site (Figure 7) consists of modern swamp deposits, the Pleistocene deposits over which they are deposited, and older Tertiary strata into which the stream valley is cut. Although the geologic map does not differentiate the components of the Chesapeake Group, it most probably is



Figure 6. An oblique, aerial photograph of Taskinas Creek (from CBNERRVA).

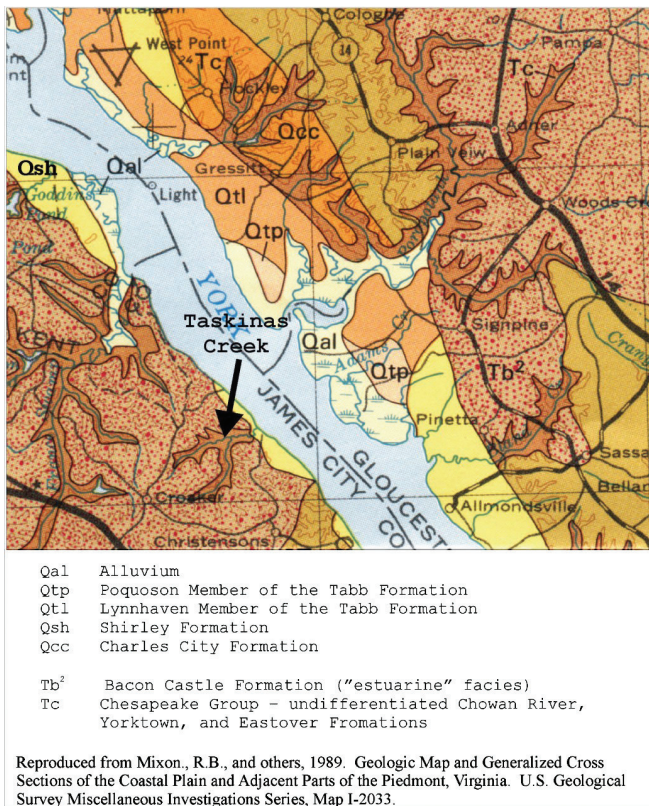


Figure 7. Geologic map depicting the Taskinas Creek reserve site (from MIXON *et al.*, 1989).

the Yorktown Formation exposed in the banks as the Bacons Castle Formation never is found below 60 ft in the vicinity of York River State Park (C.R. BERQUIST, JR., pers. comm. 2005) and the site is north of any mapped occurrences of the Chowan River Formation.

Sweet Hall Marsh

Sweet Hall Marsh is the lower-most extensive tidal fresh water marsh located in the Pamunkey River. The marsh is the area bounded a tight meander of the Pamunkey and the adjacent upland (Figure 8). A small marsh creek runs across the base of the marsh separating much of it from the mainland. The marsh itself is a modern deposit sitting atop older strata (Figure 9). Outcrops of the Late Pleistocene Tabb Formation abut the marsh (MIXON *et al.*, 1989). Depths in the creek reach 4 m (12 to 13 ft) (NOS, 1980) whereas depths in the main channel reach 17 m (56 ft) and commonly run in excess of 7 m (22 ft). These perhaps surprisingly great depths might indicate that the river remains in a channel that was excavated during a low stand of sea level. Thus the channel is cut into older, more indurated sediments. The Pamunkey River's average annual discharge rate from 1972 to 2006 recorded at Hanover was 1,085 ft³/s (USGS, 2005). The river's record peak flow was 40,300 ft³/s which occurred with Hurricane Camille in August 1969. The second highest flow was 29,900 ft³/s accompanied Hurricane Agnes in June 1972 (USGS, 2005). Although the river is unlikely to erode a comparably deep, new channel, it is possible that the cut-off creek might widen sufficiently to capture a larger portion of the river flow. Sweet Hall Marsh is



Figure 8. An oblique, aerial photograph of Sweet Hall Marsh (from CBNERRVA).

near the center of an area of relatively rapid subsidence. Holdahl and Morrison (1974) calculated that region traversed by the lower portions of the Pamunkey and Mattaponi Rivers was sinking at a rate of 3.2 mm/yr (1.05 ft/century). By comparison, the same study depicted subsidence rates of nearly 3.0 mm/yr (0.98 ft/century) at Taskinas Creek and just under 2.8 mm/yr (0.92 ft/century) at the Goodwin Islands.

SUMMARY AND CONCLUSIONS

All four sites of the Chesapeake Bay National Estuarine Research Reserve in Virginia are within the Coastal Plain geological province. Regionally, the Late Tertiary and Quaternary geology has been controlled by the series of major marine transgressions and regressions, in which successively

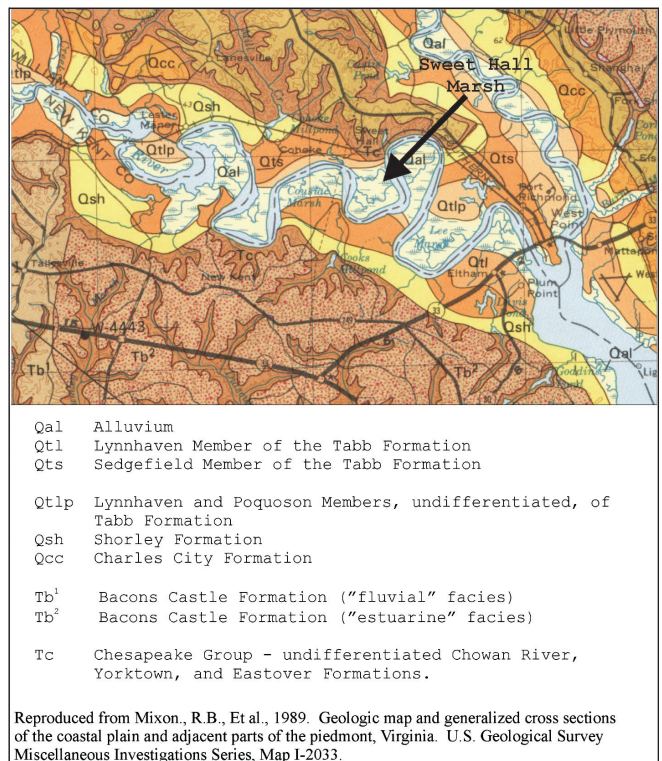


Figure 9. Geologic map depicting the Sweet Hall Marsh reserve site (from MIXON *et al.*, 1989).

more recent high stands of the sea have not reached the level of the preceding high stand. As a result, while stratigraphically above older units, younger beds may be physically lower. Except where filling channels cut into the underlying strata, the formations tend to be tabular and nearly horizontal. Because younger beds are comprised of sediments eroded and reworked from older, it often is difficult to distinguish one from the other without knowledge of elevation. Several of the formations lack fossils or other time specific characteristics; thus assignment of geologic age is dependent upon other factors. Earlier researchers have inferred age based on relative stratigraphic age. More recently, researchers have attempted to fit the stratigraphy to the continually improving model of gross sea-level change, e.g. oxygen isotope stages.

The Catlett and Goodwin Islands reserve sites consist of modern marshes growing a Late Pleistocene substrate. Sweet Hall Marsh occupies the area inside a tight meander of the Pamunkey River and is adjacent to Late Pleistocene outcrops, thought the specific strata beneath the marsh are not known. The Taskinas Creek site is the valley of a small tributary of the York River. It too consists of Holocene marshes and late Pleistocene strata but also includes exposures of the older formations into which the valley is cut. The two downstream Reserve sites, the Catlett Islands and Goodwin Islands, lie above the thirty five million year old Chesapeake Bay Impact Crater. Author's Note: substantial portions of this report are rewritten from Hobbs (2004), Johnson and Berquist (1989), and an unpublished contract report.

RESEARCH NEEDS

There are several avenues of geological research that should be advanced in the Research Reserve sites and adjacent areas of the York River system. There should be a coordinated program of coring through the marshes in the four sites in order to date the basal peats and develop the time-history of the recent rise of sea level. Comparing the differences between sites would provide information concerning relative rates of subsidence (or uplift) during the past several thousand years over the entire reserve system. Differentials in the local tectonic changes might result from different underlying conditions as a result of the Chesapeake Bay Impact Crater. Additionally, there are regional questions concerning potential high-stands of sea level through the past few thousand years. The ridge-and-swale geography of parts of the Goodwin and Catlett Islands suggests that they might be prime sites for further geological studies focusing on questions related to the history of sea level transgressions in the York region.

An enhanced knowledge of the underlying stratigraphy of the Research Reserve sites, obtained through deeper coring, would contribute both to the on-going efforts toward mapping the regional geology and toward understanding the local and regional ground-water systems. The geometry of the shallowest aquifers and aquacludes influences the pathways available for the transport of nutrients and other compounds. It already is known in general terms that the Impact Crater disrupted the deeper aquifers; however, post-depositional changes within crater-fill and overlying strata are less well known.

Establishment of suitable, permanent benchmarks to document elevation would enable long-term monitoring of subsidence. This monitoring would be in the form of precision leveling every few years. This knowledge of change in

elevation when compared to measurements of local relative sea level would facilitate differentiation of the eustatic and isostatic components of changes in relative sea level and assist in quantifying local sea-level rise relative to climate change or other factors.

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