National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Colonial National Historical Park

Paleontological Resource Inventory (Public Version)

Natural Resource Report NPS/COLO/NRR—2022/2361

ON THE COVER
A collection of fossil scallops (*Chesapecten*) sampled from the beaches along Colonial National Historical Park. Photo by Rowan Lockwood (William & Mary).

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Paleontological Resource Inventory (Public Version)

Natural Resource Report NPS/COLO/NRR—2022/2361

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February 2022

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Chriscoe, M., R. Lockwood, J. S. Tweet, and V. L. Santucci. 2022. Colonial National Historical Park: Paleontological resource inventory (public version). Natural Resource Report NPS/COLO/NRR—2022/2361. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/nrr-2291851.

NPS 333/179631, February 2022

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Executive Summary

Colonial National Historical Park (COLO) in eastern Virginia was established for its historical significance, but significant paleontological resources are also found within its boundaries. The bluffs around Yorktown are composed of sedimentary rocks and deposits of the Yorktown Formation, a marine unit deposited approximately 4.9 to 2.8 million years ago. When the Yorktown Formation was being deposited, the shallow seas were populated by many species of invertebrates, vertebrates, and micro-organisms which have left body fossils and trace fossils behind. Corals, bryozoans, bivalves, gastropods, scaphopods, worms, crabs, ostracodes, echinoids, sharks, bony fishes, whales, and others were abundant.

People have long known about the fossils of the Yorktown area. Beginning in the British colonial era, fossiliferous deposits were used to make lime and construct roads, while more consolidated intervals furnished building stone. Large shells were used as plates and dippers. Collection of specimens for study began in the late 17th century, before they were even recognized as fossils. The oldest image of a fossil from North America is of a typical Yorktown Formation shell now known as *Chesapecten jeffersonius*, probably collected from the Yorktown area and very likely from within what is now COLO. Fossil shells were observed by participants of the 1781 siege of Yorktown, and the landmark known as “Cornwallis Cave” is carved into rock made of shell fragments. Scientific description of Yorktown Formation fossils began in the early 19th century. At least 25 fossil species have been named from specimens known to have been discovered within COLO boundaries, and at least another 96 have been named from specimens potentially discovered within COLO, but with insufficient locality information to be certain. At least a dozen external repositories and probably many more have fossils collected from lands now within COLO, but again limited locality information makes it difficult to be sure.

This paleontological resource inventory is the first of its kind for Colonial National Historical Park (COLO). Although COLO fossils have been studied as part of the Northeast Coastal Barrier Network (NCBN; Tweet et al. 2014) and, to a lesser extent, as part of a thematic inventory of caves (Santucci et al. 2001), the park had not received a comprehensive paleontological inventory before this report. This inventory allows for a deeper understanding of the park’s paleontological resources and compiles information from historical papers as well as recently completed field work.

In summer 2020, researchers went into the field and collected eight bulk samples from three different localities within COLO. These samples will be added to COLO’s museum collections, making their overall collection more robust. In the future, these samples may be used for educational purposes, both for the general public and for employees of the park.

Acknowledgments

The authors acknowledge the Indigenous peoples who are the original inhabitants of the lands that COLO occupies today, and we pay our respects to their tribal members past and present.

The land on which COLO is situated is part of a complex history of colonization that devastated Virginia Indian tribes and must be understood and explicitly acknowledged. Acknowledgment is a first step in ending the history of exclusion and promoting awareness of and respect for Indigenous culture.

We would like to acknowledge the help of the William & Mary faculty and students who assisted with this project. The paleontology lab provided support and joined us for field work collections. We thank Rosemary Guardado and Colleen Norton for assistance in the field, as well as Kate Dean-McKinney, Edward Clarke, Olivia Falb, Veronica Mantha, Kara Morien, Megan Sidlo, Tim Speedy, Meg Taylor, and Emily Topness, all of whom are valuable members of the paleontology lab at William & Mary.

We thank the landowners who allowed us to access the park from their private land. Robert and Polly Krause provided us with access to the Moore House Type Section on the York River, and we extend our thanks to the landowners at Mount Pleasant, located along the James River.

We recognize the valuable support provided by the National Park Service staff at Colonial National Historical Park including Dorothy Geyer, Melanie Pereira, and Dwayne Scheid. We share a special thanks to Tim Connors, from the National Park Services Geologic Resources Division, for reviewing this document and for preparing the geological and paleontological resource sensitivity maps used in this inventory report for COLO.

We appreciate the assistance from Seth Lerman in the Northeast Regional Office of the National Park Service for his role as the peer review coordinator for the COLO Paleontological Resource Inventory Report. We give special thanks to Carl R. Berquist (W&M, formerly with the Virginia Division of Geology and Mineral Resources), Lucy E. Edwards (USGS, Emeritus), and Robert E. Weems (USGS, Emeritus), who provided formal peer review for this report. We would also like to thank Kelvin W. Ramsey and Lauck W. Ward for providing incredibly useful informal critiques of the manuscript, as well as photos of Cornwallis Cave and Thomas Say's type specimens, respectively. Lucy Edwards and David Powars gave permission to reuse several figures from Powars et al. (2016).

Finally, we extend our thanks to Chelsea Bitting, Kiersten Jarvis, and Melanie Wood from the National Park Service Scientists in the Parks Program (SIP). The SIP Program is a partnership venture between the National Park Service, Conservation Legacy—Stewards Individual Placement Program, and the Geological Society of America which supports science-based internships for students and youth across the United States. Therefore, we also thank the many individuals and partners associated with the SIP Program.

Dedication

The authors would like to dedicate this inventory to two giants of the Virginia Coastal Plain—Gerald "Jerre" H. Johnson and Lauck "Buck" W. Ward. Dr. Johnson, Professor Emeritus of Geology at William & Mary, dedicated his life to mapping, drilling, and describing Coastal Plain units in Virginia, including those exposed in COLO. He delighted in sharing his enthusiastic passion for earth sciences with generations of students and Williamsburg community members. His intuitive understanding of the geological history of the Coastal Plain is documented in several fieldtrip guidebooks, required reading for anyone who wants to understand this geological province in Virginia.

Dr. Lauck Ward, a Curator Emeritus of Invertebrate Paleontology at the Virginia Museum of Natural History, is one of the world's foremost experts on Cenozoic fossil mollusks along the Atlantic and Gulf Coasts. Dr. Ward, in collaboration with Blake Blackwelder, is responsible for naming several of the geological units and fossils described in this inventory. He has amassed a truly invaluable collection of bulk sampled materials from historically important Virginia Coastal Plain localities before they were destroyed. Over the past 15 years, Dr. Ward has acted as a mentor to Rowan Lockwood, very generously providing his time, knowledge, collections, taxonomic opinions, boat access, locality info, map data, and unparalleled sense of humor on multiple field expeditions with countless W&M students.

This inventory truly could not have been possible without the unparalleled intellectual contributions of both of these gentlemen to Virginia geology and paleontology.

Introduction

Colonial National Historical Park (COLO) is located in southeast Virginia between the York and James Rivers (Figures 1a and 1b). This region is a coastal plain, with broad tidal rivers that flow to the Chesapeake Bay. The area surrounding COLO has been inhabited by humans for more than 16,000 years (McAvoy and McAvoy 1997; Feathers et al. 2006), and the park protects resources originating from the American Indians of the Powhatan Paramount Chiefdom. Additionally, COLO protects sites from the history of the British colonial period in North America, including the first permanent English settlement in Jamestown (JAME). A large portion of COLO contains the Yorktown Battlefields (YONB), which preserves the majority of ground over which the last major engagement of the American Revolutionary War took place (National Park Service 2018).

Park lands include forested areas, beaches, and historic sites. The Colonial Parkway (COLP) is a 37-km (23-mi)-long road that connects Jamestown, Yorktown, and Williamsburg. The parkway was designed to look like a colonial-era dirt road using aggregate and brushed concrete and is partially underlain by fossil marl. Its alignment provided a scenic experience of the historic views over the rivers and the park's main sites. The park was established on July 3, 1930 (Public Law 71-510, 46 Stat. 855, HR12235) and has expanded from that time to include 3,511 hectares (8,677 acres) of land that protect the historic and natural resources of the area (National Park Service 2018).

This report provides detailed information on the paleontological resources of COLO, including the history of paleontological work in the lands now within the historical park, source geologic units, taxonomic groups, localities, museum collections, research, interpretation, and management and protection. In addition to the main body of text, there are nine appendices: Appendix A, tables of paleontological species arranged by stratigraphy; Appendix B, plates of common COLO fossils; Appendix C, taxa named from COLO fossils; Appendix D, taxa potentially named from COLO fossils; Appendix E, contact information for repositories and photos of several historic type specimens; Appendix F, paleontological resource law and policy; Appendix G, selected paleontological locality data; Appendix H, a series of photos documenting the exterior of Cornwallis Cave; and Appendix I, a geologic time scale.

Significance of Paleontological Resources at COLO

The underlying geology of COLO includes the densely fossiliferous Yorktown Formation and other fossiliferous units (Figures 2 and 3). Paleontological resources from this area have been described and collected for hundreds of years, and likely longer. The first illustrated fossils from North America came from this region (see "History of Paleontological Work at COLO" below), and historic documents contain descriptions of many fossil localities before they became inaccessible due to human interference, invasive plants, or other factors. A number of Pliocene mollusk species have been named from specimens found within land that is likely part of COLO. Say (1824), Gardner (1943, 1948), and Campbell (1993) wrote important monographs on bivalves and gastropods that include specimens collected from COLO. Paleontological resources from within COLO were also used in the construction of historic buildings outside the park, including the original Grace Episcopal Church in Yorktown (Roberts 1932; Johnson et al. 1981).

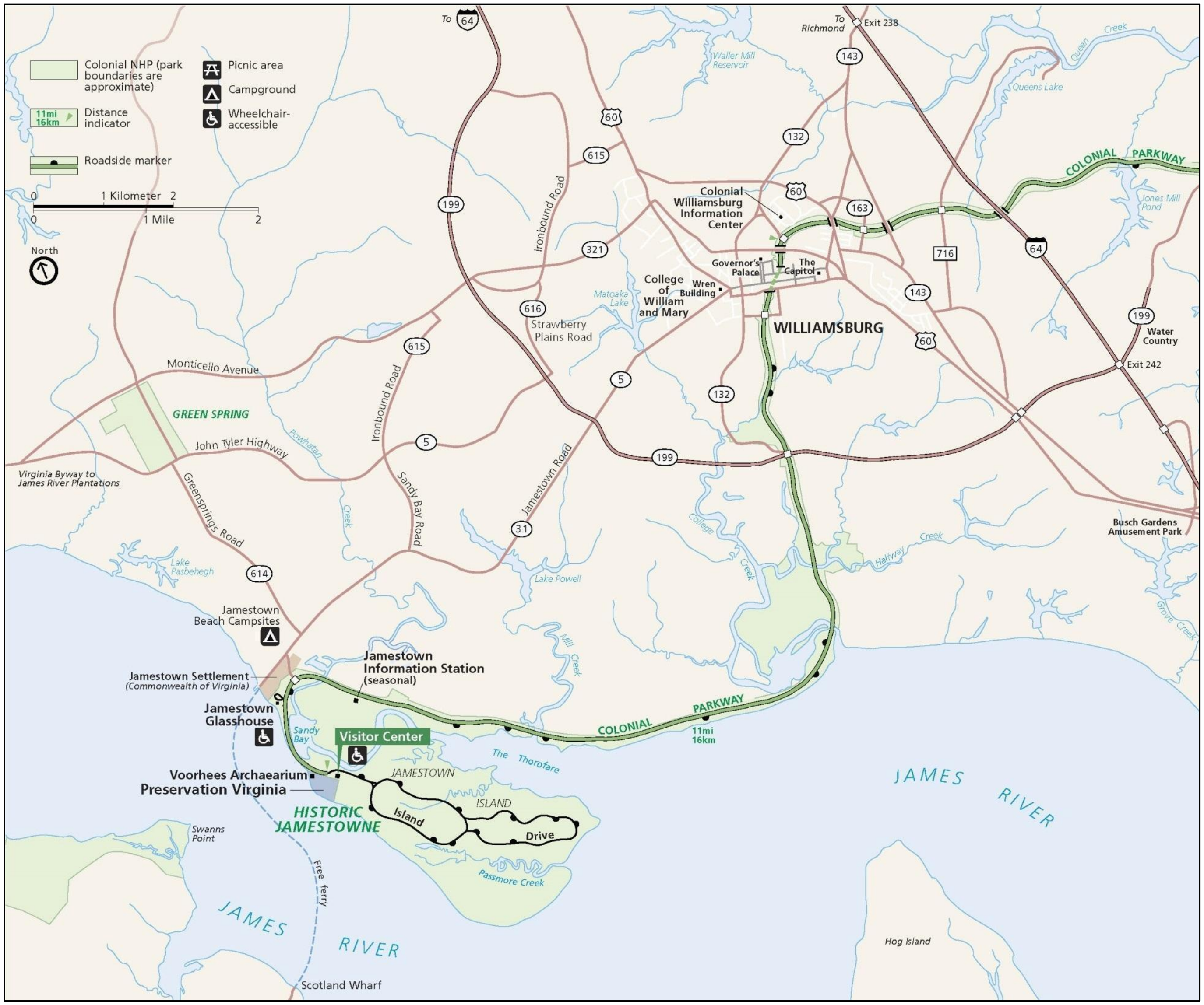

Figure 1a. National Park Service (NPS) map of COLO boundaries and features along the James River. Roads are symbolized based on U.S. standard road use symbolization.

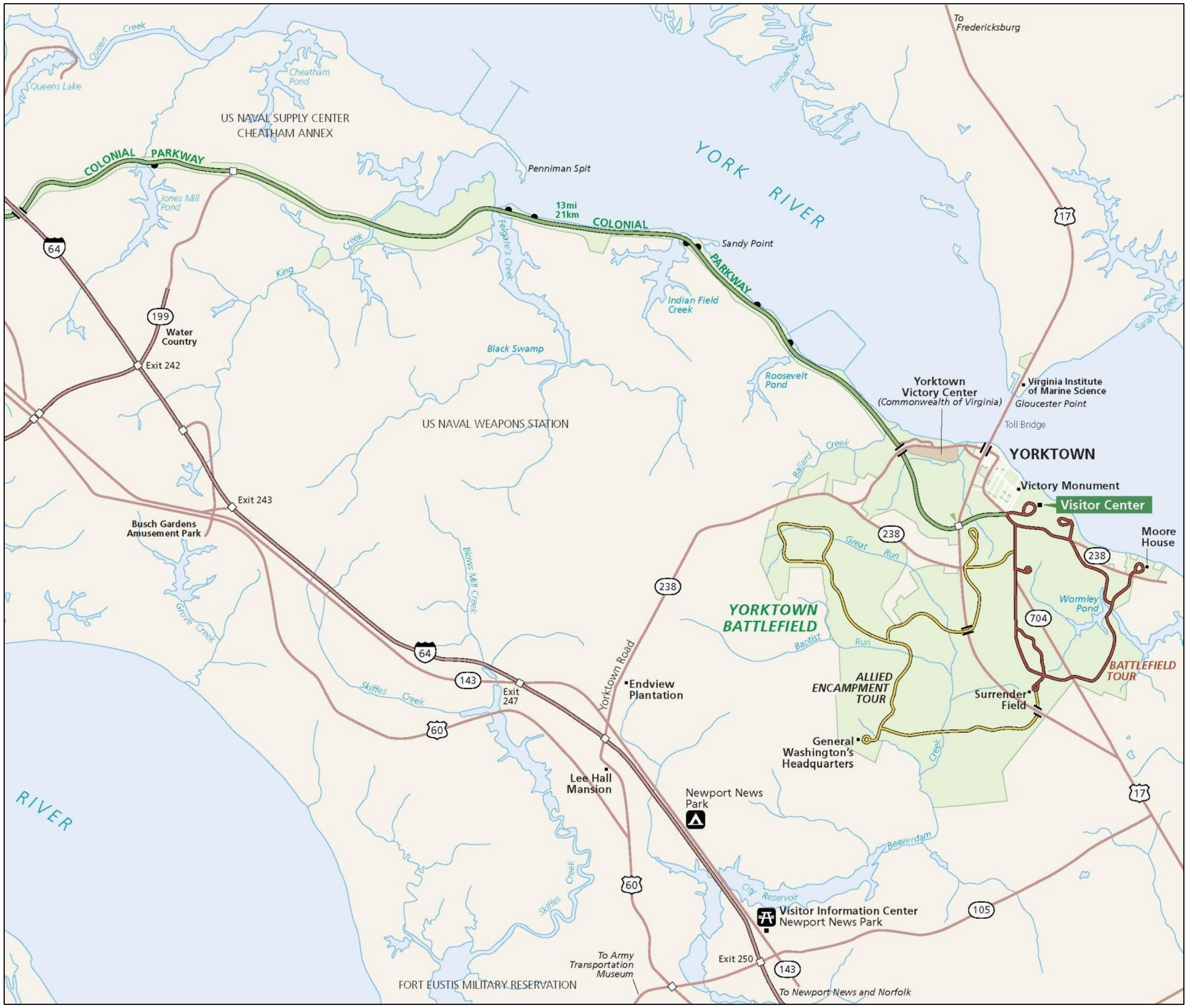

Figure 1b. NPS map of COLO boundaries and features along the York River. Roads are symbolized based on U.S. standard road use symbolization.

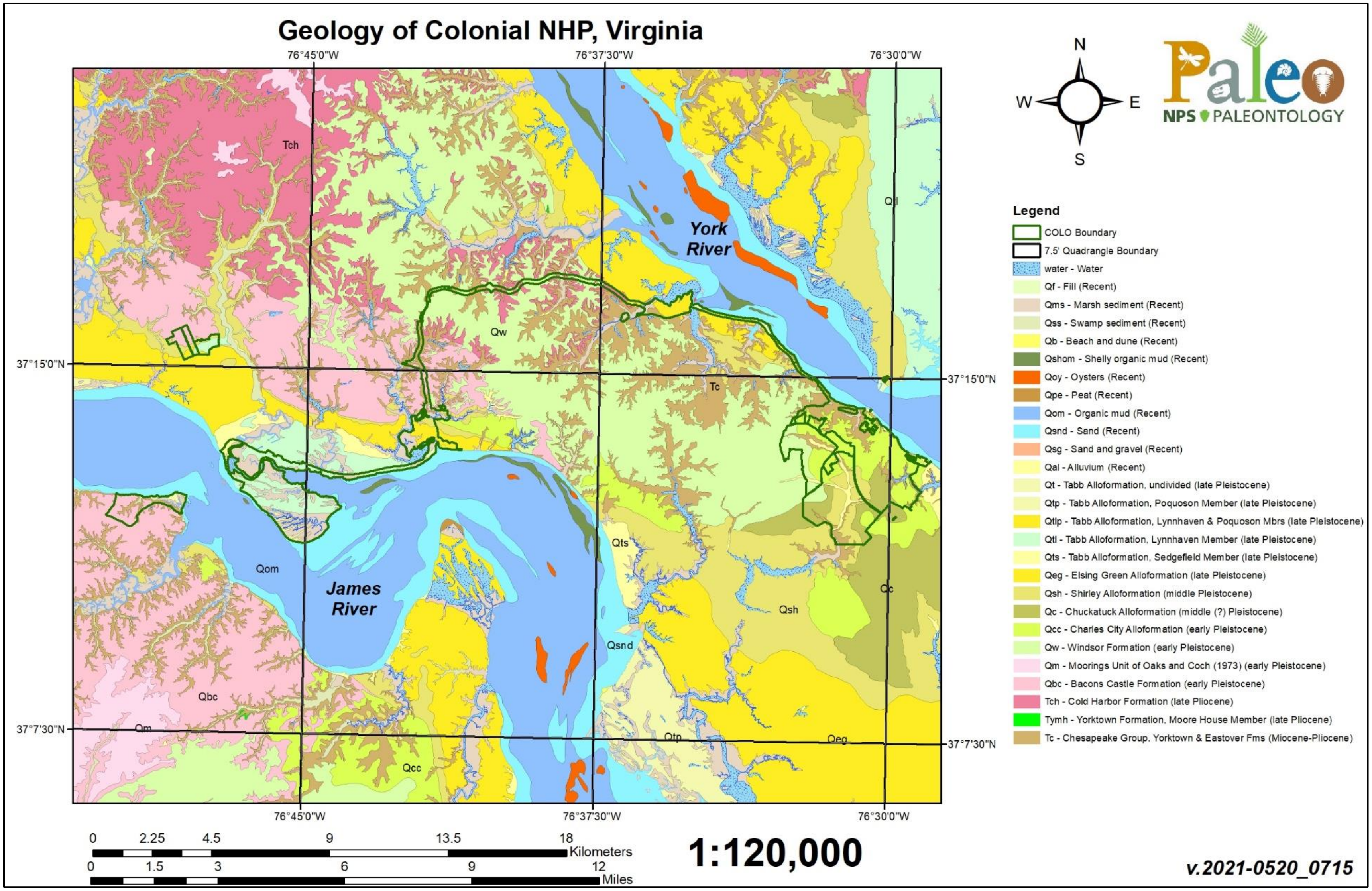

Figure 2. Geological map of COLO derived from Berquist (2015), digitized by the NPS Geologic Resources Inventory (GRI). Digital map data are available at https://irma.nps.gov/DataStore/Reference/Profile/2175563.

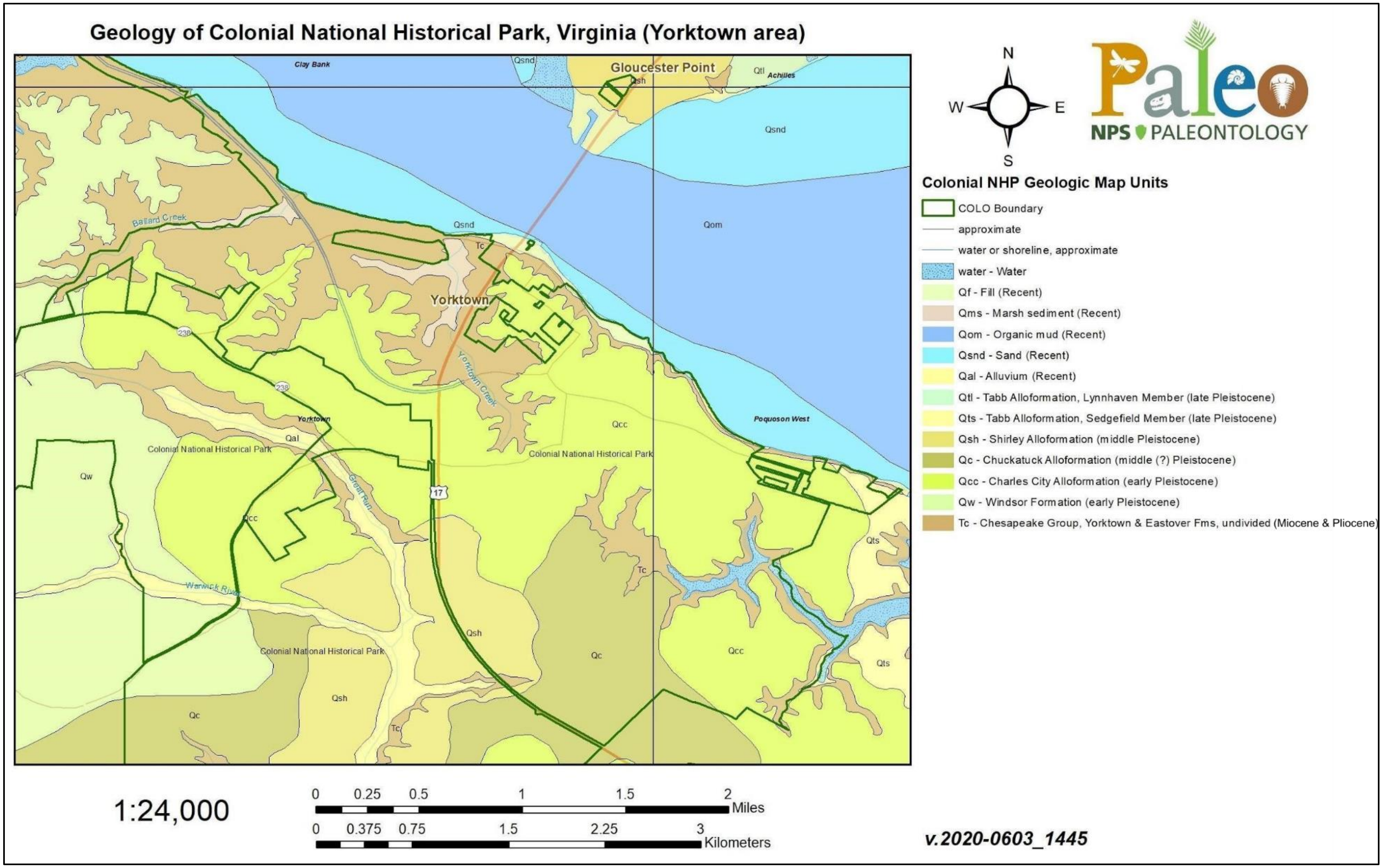

Figure 3. Geological map of the Yorktown area of COLO derived from Berquist (2015), digitized by the NPS GRI. Digital map data are available at https://irma.nps.gov/DataStore/Reference/Profile/2175563.

Purpose and Need

The National Park Service (NPS) is required to manage its lands and resources in accordance with federal laws, regulations, management policies, guidelines, and scientific principles. Those authorities and guidance directly applicable to paleontological resources are cited below. Paleontological resource inventories have been developed by the NPS in order to compile information regarding the scope, significance, distribution, and management issues associated with fossil resources present within parks. This information is intended to increase awareness of park fossils and paleontological issues in order to inform management decisions and actions that comply with these laws, directives, and policies. See Appendix F for additional information on applicable laws and legislation.

Project Objectives

This park-focused paleontological resource inventory project was initiated to provide information to COLO staff for use in formulating management activities and procedures that would enable compliance with related laws, regulations, policy, and management guidelines. Additionally, this project will facilitate future research, proper curation of specimens, and resource management practices associated with the paleontological resources at COLO. Methods and tasks addressed in this inventory report include:

- Locating, identifying, and documenting paleontological resource localities through field reconnaissance and perusal of archives, using photography, GPS data, standardized forms, and cave surveyor reports.
- Relocating and assessing historical localities.
- Assessing collections of COLO fossils maintained within park collections and in outside repositories.
- Documenting current information on faunal assemblages and paleoecological reconstructions.
- A thorough search for relevant publications, unpublished geologic notes, and outside fossil collections from COLO.

Summary of 2021 Paleontological Survey

The 2021 paleontological survey of COLO began in January 2020 with the first meetings between the NPS and William & Mary. This is the first comprehensive, park-specific paleontological resource inventory created for COLO. The beginning of this project involved a literature review of many scientific publications that examine COLO and its surrounding area. By June 2020, field work was underway, under permit COLP-2020-SCI-0003; researchers visited six fossil localities within the park along the York River and collected bulk samples of sediment and fossils at three of them. These bulk samples were sieved to separate sediment and fossil material; the fossils were then sorted by genus and counted (see Appendix G for data). All of these fossils will be given to COLO for their museum collections. The bulk of this inventory was written in the months following field work, and it was sent for peer review in February 2021.

History of Paleontological Work at COLO

The prominent fossil cliffs of COLO, especially those featured along the shores of the York River, played an important role in the early history of paleontology in North America. Key publications outlining the history of geologic and paleontologic work in this region include: Lincoln (1783), Mitchill (1818), Say (1824), Finch (1833), Rogers and Rogers (1837), Clark and Miller (1912), Roberts (1932), Gardner (1943, 1948), Mansfield (1943), Bick and Coch (1969), Johnson (1972), Ward and Blackwelder (1975, 1980), Johnson et al. (1981), Johnson and Berquist (1989), Mixon et al. (1989), Campbell (1993), Ward (1993), Powars and Bruce (1999), and Powars et al. (2016).

Evidence of human settlement in the Virginia Coastal Plain dates back to 16,000 years ago (McAvoy and McAvoy 1997; Feathers et al. 2006). Fossil shark teeth documented with human modifications in Maryland suggest that indigenous peoples have been interacting with fossils in the Chesapeake Bay region for over 2,500 years (Lowery et al. 2011). Written documentation of fossils in the vicinity of COLO dates back to shortly after the founding of the English settlement at Jamestown in 1607. Early English settlers who first arrived in Jamestown used shell beds to make lime. Later communities, such as the Civil War-era Slabtown, may have used marl from the area as building materials. Grace Church in Yorktown was originally made of a material that is similar in composition to local coquina beds, although the structure has been almost completely destroyed and rebuilt with different materials. Part of the original church wall is preserved, however, and it is possible to view the marl foundations as well. Shell beds in the area were also briefly described by several naturalists throughout the 17th and 18th centuries and later published by Ray (1983).

Perhaps the earliest documentation of fossils from within COLO is found in Martin Lister's "*Historiae Conchyliorum*," which was published between 1685 and 1692 (Photo 1). Lister included several illustrations of specimens from the Yorktown Formation in his publication, although they were not recognized at the time as fossils nor were they thought to have originated in Virginia; originally, they were identified as originating from the Virgin Islands. *Chesapecten jeffersonius* is now believed to be the first fossil depicted from North America, with Lister's illustration featuring it having been published in 1687 (Ward and Blackwelder 1975). However, this specimen was not recognized as a fossil until much later, when Thomas Say named the species *Pecten* (now *Chesapecten*) *jeffersonius* and was the first to publish it in a scientific document. Say (1824) also named a number of other taxa from specimens originating in Yorktown, although the origin of these fossils relative to COLO is unknown.

Shell beds in the area yielded some of the first fossil material collected and described by naturalists in the 17th, 18th , and 19th centuries (Lincoln 1783; Maclure 1809; Mitchill 1818; Say 1824; Rogers and Rogers 1837). General Benjamin Lincoln, who served at the siege of Yorktown in 1781, briefly detailed the fossil beds, reporting the presence of cockles, clams, and other shells in several different shell-rich layers in the steep banks (Lincoln 1783). Rogers and Rogers (1837) wrote what is potentially the first geologic description of COLO and the surrounding areas, including information on several fossil localities. Clark and Miller (1912) and Ray (1983) both provide useful summaries of this early work.

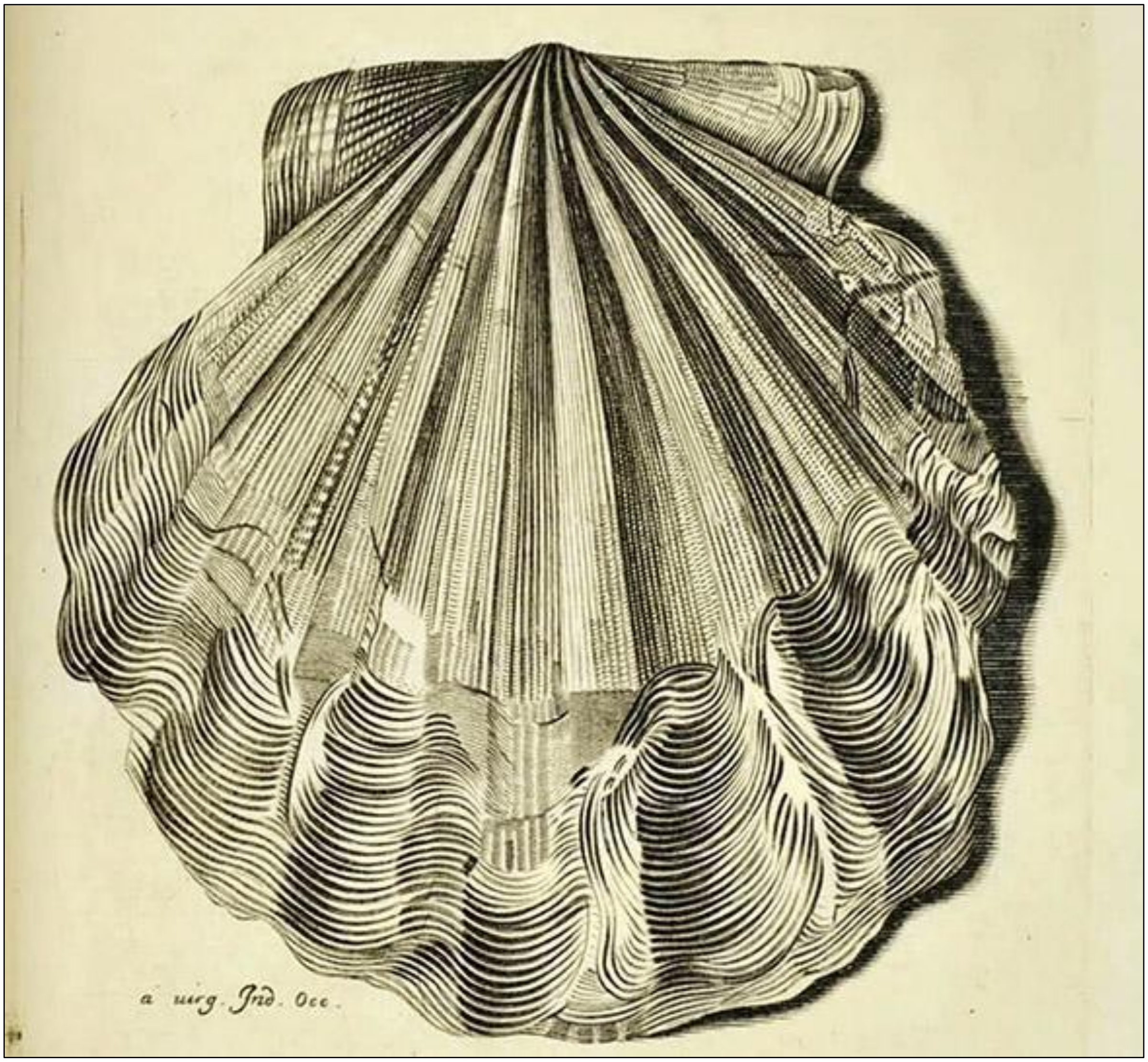

Photo 1. The original drawing from Martin Lister (Lister 1687), representing a specimen of *Chesapecten jeffersonius*, likely collected from lands now within COLO. Photo by L. E. Edwards.

In 1833, geologist John Finch described the geology and paleontology of the Yorktown area. He writes

> "*York River is two miles wide opposite the town...The cliffs are composed of fossil shells. Most of the shells are broken; some are entire, among which is the magnificent Venus deformis. There are also found several species of murex and buccinum; at low water, the shore is covered with fossil turritella...Fossil pectens of a large size, some of them ten inches wide, are found abundantly in the lower part of Virginia. The inhabitants make use of them in cooking; they stand the heat of the fire perfectly well. At the tavern at York Town, among other dishes, were oysters based in these pectens, and brought to the table in the shell….And often in the interior, when seeking in the woods for a spring of pure water, where I might allay my thirst, I have*

> *seen a fossil shell, left on the border of a clear rivulet by some former traveller, who had made use of it as a cup. I also stooped down by the side of the stream, and drank out of the fossil shell, and the water seemed more cool and refreshing out of this goblet of nature's production, than if it had been formed of glass or silver* (Finch 1833)."

During his time in Yorktown, Finch collected a large number of fossil mollusks, which he then distributed to other scientists, including Say, who mistakenly identified them as originating from the St. Marys Formation in Maryland (Kenworthy and Santucci 2003). These specimens, now located in various museum collections (including the Natural History Museum, London) are still listed as Maryland fossils. Along with these errors, the scientists who published on Yorktown Formation mollusks made several mistakes and omissions that are detailed in Campbell (1993) and Kenworthy and Santucci (2003). Research on fossils from the Yorktown area continued at the rate of a few publications each decade, and most of the classic localities have been lost to shoreline protection and stabilization projects.

Ward (1993) reproduced an unpublished document from Gilbert Dennison (G.D.) Harris from 1890 that detailed the Yorktown Formation, including eight different fossil localities, seven of which are likely within or just outside COLO boundaries (Kenworthy and Santucci 2003). Harris collected many specimens of fossil bivalves and gastropods, all of which are now housed at the Smithsonian National Museum of Natural History. Harris's observations and sketches are particularly noteworthy because they detail what a portion of the Yorktown Formation looked like before the installation of riprap in the 1950s, which obscures portions of the outcrops and makes fossil collection difficult (Kenworthy and Santucci 2003).

Early work in the region was expanded on by several subsequent authors (Roberts 1932; Gardner 1943, 1948, Mansfield 1943; Bick and Coch 1969; Johnson 1972; Ward and Blackwelder 1975, 1980; Johnson et al. 1981; Johnson and Berquist 1989; Mixon et al. 1989; Campbell 1993; Ward 1993). Recent work has focused primarily on reconstructing the subsurface geology associated with the Chesapeake Bay Impact Structure (CBIS), through the use of coreholes drilled in the vicinity of COLO (Powars and Bruce 1999; Edwards et al. 2005, 2010; Powars et al. 2016).

The NPS prepared a paleontological resource summary for COLO as part of the Northeast Coastal and Barrier Inventory & Monitoring Network (NCBN) Paleontological Resource Inventory Report (Kenworthy and Santuccii 2003; revised and expanded in Tweet et al. 2014). A brief mention of COLO can also be found within the NPS thematic inventory on paleontological resources associated with NPS caves (Santucci et al. 2001). The NPS Geologic Resources Division coordinated a Geologic Resource Inventory workshop for COLO in August 2005 (Thornberry-Ehrlich 2005). An updated inventory report was published in 2016, with further information about the park's geology and updated plans for management (Thornberry-Ehrlich 2016).

Geology

Geologic History

COLO is located within a physiographic (or geologic) province called the Virginia Coastal Plain, which stretches from the Piedmont to the Atlantic coastline (Figure 4; Powars et al. 2016). This province is characterized by low, rolling hills and terraces (flat plains) that are cut through by large river systems. COLO is located between two of these river systems, the York and James River, on the York–James Peninsula. The Coastal Plain is effectively a large wedge of unconsolidated (not cemented) or semi-consolidated sediment that thickens towards the northeast and is deposited on top of crystalline basement rocks (older igneous and metamorphic rocks). The sediment is composed of small (clay-sized) to larger (gravel-sized) bits of eroded pre-existing rock that were deposited in layers from the Early Cretaceous through to today (see geological timescale provided in Appendix I). These sediments provide a record of fossils and past environments in the region, ranging from onshore to offshore as sea level rose and fell multiple times, and including fluvial (river), deltaic, estuarine, swamp, beach, and shallow shelf (Figure 5; Powars et al. 2016). The geologic record of these sediment layers is complicated by the Chesapeake Bay Impact Structure (CBIS) (Figure 4), which formed during the late Eocene in response to an asteroid or comet impact. This structure, 150–160 km (93–99 mi in diameter) including the outer fracture zone, is completely buried under post-impact sediment. Portions of COLO, in the vicinity of Yorktown, are located within the outer rim of the CBIS. For an in-depth explanation of the geologic history of the Virginia Coastal Plain see Powars et al. (2016).

The subsurface geology of COLO and the surrounding area has been examined primarily through coreholes drilled in the park itself (wells mentioned in Cederstrom 1957; USGS Jamestown core of Powars and Bruce 1999) and throughout the York–James Peninsula (USGS Newport News Park, Langley, and Watkins School cores; Powars and Bruce 1999; Edwards et al. 2005, 2010).

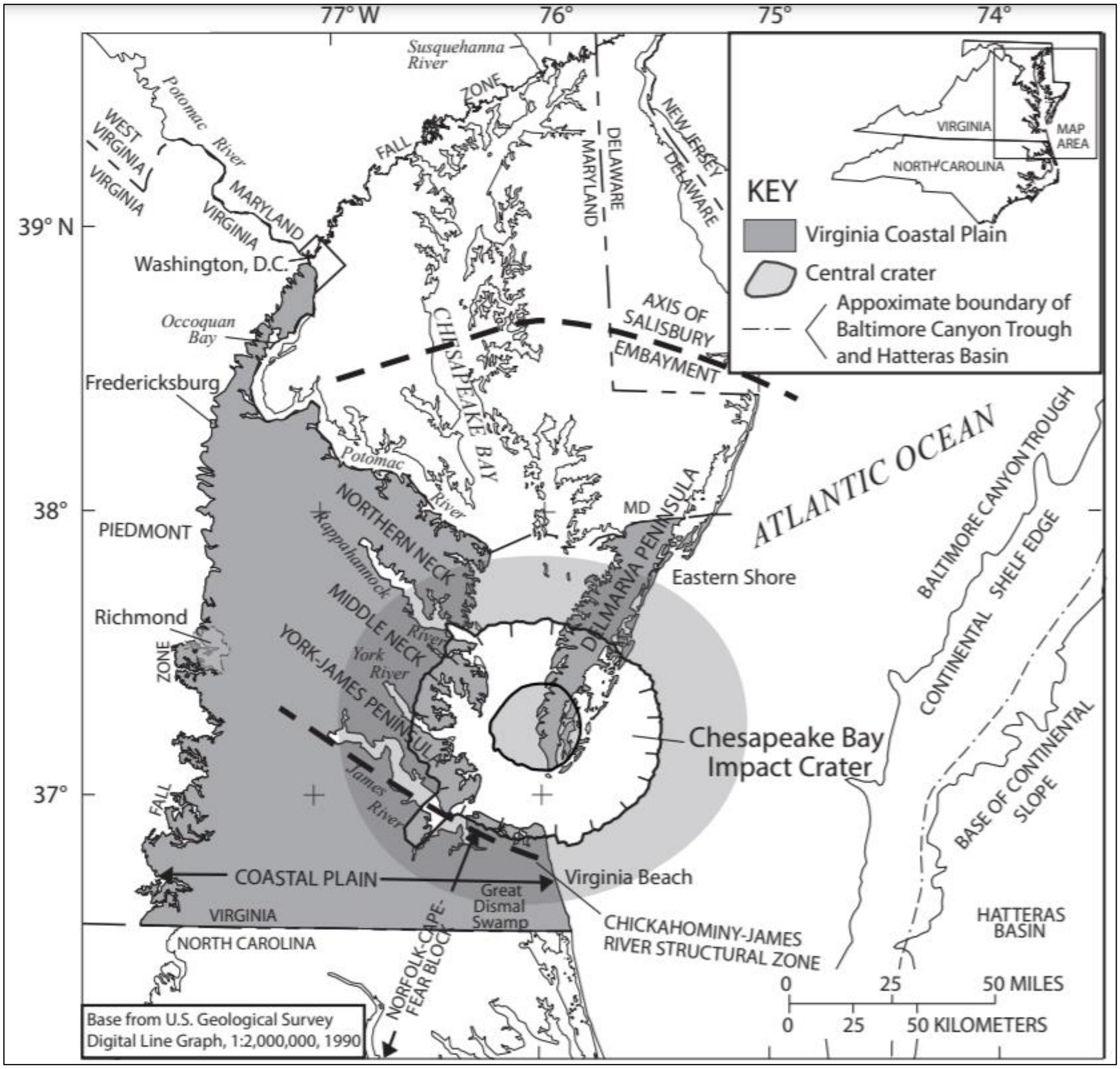

Figure 4. Map highlighting the major features of the Virginia Coastal Plain, including rivers, peninsulas, and the Chesapeake Bay impact structure (Powars et al. 2016).

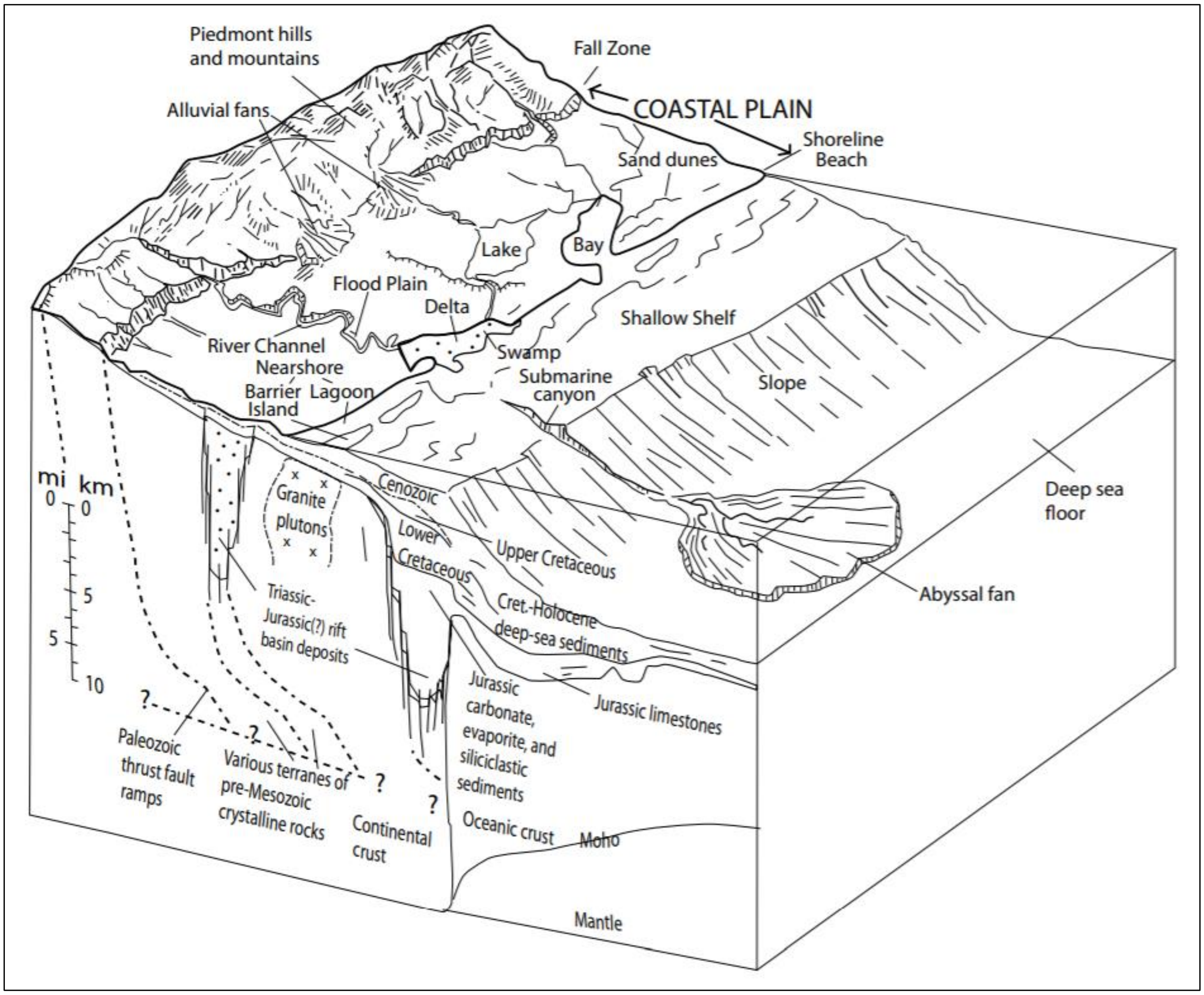

Figure 5. 3D diagram (with extreme vertical exaggeration) highlighting the wedge of sediment that underlies the Virginia Coastal Plain, as well as the depositional environments (shown at the surface) that formed those deposits in fluvial (river), deltaic, estuarine, and marine environments (Powars et al. 2016).

The corehole at Jamestown (37º 13’ 05” N, 76º 46’ 37” W) was drilled in May 1996 at a surface altitude of 0.3 m (1 ft) and yielded 83 m (272 ft) of core material (Powars and Bruce 1999). The base of this core records the Cretaceous Potomac Formation, which is composed of fluvial and deltaic sediments intertonguing with thin glauconitic marine sands (Table 1; Figure 6). The only biostratigraphic material documented from this unit is pollen and spores. This Cretaceous material is overlain by a series of marine sediments and fossils deposited before the Chesapeake Bay Impact occurred during the late Eocene (Powars and Bruce 1999). Pre-impact Tertiary units include the Aquia Formation, the Marlboro Clay, the Nanjemoy Formation, and the Piney Point Formation (Table 1). Syn-impact deposits, which include impact breccia and tsunami material, were not recorded in the Jamestown corehole which is located outside the crater rim (see Figure 3 in Powars and Bruce 1999). Approximately 18 m (60 ft) of syn-impact material is, however, documented in the nearby Newport News Park corehole, which is in close proximity to the outer rim (see Figure 4 in Powars and Bruce 1999) and the Yorktown portion of COLO. The post-impact units recorded in the

Jamestown corehole range from bathyal to nearshore facies (a body of rock that is distinct from the surrounding rock, due to specific aspects of deposition and setting) and include the Old Church Formation, the "Newport News" unit, the Calvert Formation, the St. Marys Formation, and Eastover Formation (Table 1), all of which are unconformably overlain with unnamed Holocene fluvial and deltaic deposits (see Figure 3 in Powars and Bruce 1999).

Table 1. Summary of COLO subsurface stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in Tweet et al. (2014).

Formation	Age	Fossils Within COLO	Depositional Environment
St. Marys Formation	late Miocene	Shelly material, abundant dinocysts (see Appendix 4b in Powars and Bruce 1999), *Turritella*, burrows	Marine, nearshore tidal flat and inner to outer-shelf environments
Calvert Formation	middle Miocene	Shelly material, abundant nannofossils and dinocysts (see Appendix 4a, b in Powars and Bruce 1999)	Marine, nearshore to shallow-shelf but deeper within the CBIS
"Newport News" unit of the Calvert	early Miocene	Abundant shell material, nannofossils and dinocysts (see Appendix 4a, b in Powars and Bruce 1999)	Marine, nearshore to shallow-shelf but deeper within the CBIS
Old Church Formation	early and/or late Oligocene	Shelly material, foraminifera, abundant nannofossils and dinocysts (see Appendix 4a, b in Powars and Bruce 1999), burrows	Marine, middle to outer shallow-shelf to nearshore environments
Chickahominy Formation	late Eocene	Foraminifera (Cederstrom 1957)	Shallow marine
Piney Point Formation	middle Eocene	Abundant shelly material, abundant nannofossils (see Appendix 4a in Powars and Bruce 1999), burrows	Marine, shallow-shelf
Nanjemoy Formation	early Eocene	Shelly material, abundant nannofossils (see Appendix 4a in Powars and Bruce 1999), lignitic material, burrows	Marine, shallow-shelf
Marlboro Clay	early Eocene	Sand-filled burrows	Suboxic, shallow to mid-shelf environment
Aquia Formation	late Paleocene	Semi-indurated shell hash, abundant nannofossils (see Appendix 4a in Powars and Bruce 1999); lignitic material, burrows	Marine, shallow-shelf conditions
Potomac Group	Cretaceous	Lignitic material	Fluvial and deltaic, intertonguing with marine sands

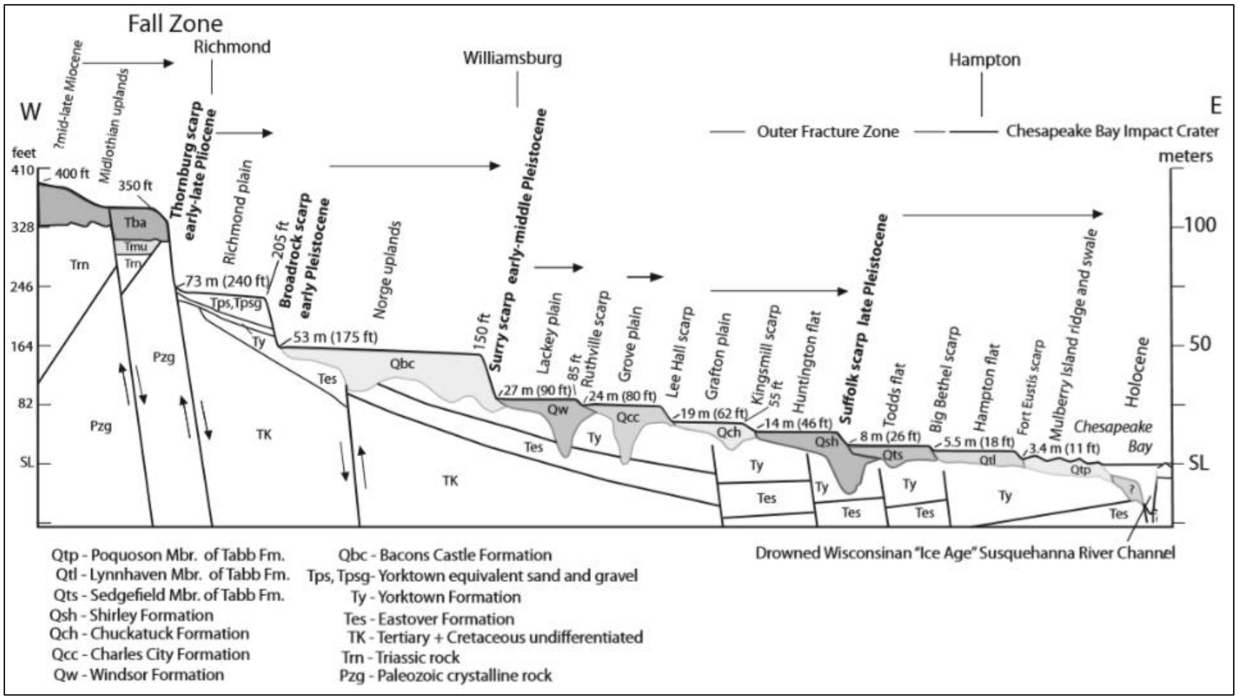

Figure 6. Simplified geologic cross-section of the Virginia Coastal Plain, from the Fall Zone (left) to the Chesapeake Bay (right), including the subsurface and surface stratigraphic units and terraces (modified from Powars et al. 2016). The Elsing Green Formation cuts into both the Shirley and Chuckatuck Formations, but is not included in this figure. The newly documented Cold Harbor Unit is also not shown.

The oldest fossils accessible from surface deposits at COLO pertain to the Eastover Formation, which was deposited during the late Miocene approximately 7.5 to 5.5 million years ago (Ma) (Powars and Bruce 1999; Browning et al. 2009) (Table 2; Figures 6 and 7). This unit and the Yorktown Formation (Pliocene) that overlies it were deposited in a shallow marine shelf to nearshore environment (Ward and Blackwelder 1980). Both of these formations represent transgressive-regressive sequences, with sea level rising and then falling multiple times during deposition. This resulted in the development of intertonguing shallow marine, restricted marine, shell reef, barrier bar, and other paleoenvironments (Ward and Blackwelder 1980; Campbell 1993). The contact between these two units was historically interpreted as conformable (i.e., not missing any time), based on dip measurements (Bick and Coch 1969). Recent interpretations based on fossil data suggest an unconformable contact with at least 1.9 million years of missing time (Edwards et al. 2005, 2009; Powars et al. 2016). The type section of the Moore House Member, the youngest member of the Yorktown Formation, occurs at COLO and the unit itself is named after the Moore House historic site on COLO property (Ward and Blackwelder 1980). The Moore House Member is composed of silt that transitions to bioclastic sand at the top, which is made almost entirely of fragmentary fossil material (Ward and Gilinsky 1993). These two units preserve a great diversity of marine fossils, including an abundance of corals, bryozoans, mollusks, nannofossils, and foraminifera, in addition to sponge borings, brachiopods, sharks, bony fish, whales, and more (for complete lists see Table 2 and "Geologic Formations" below). The majority of fossils described in historic documents and found by COLO visitors are derived from these two formations.

Table 2. Summary of COLO surface stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in Tweet et al. (2014).

Formation	Age	Fossils Within COLO	Depositional Environment
Unnamed Quaternary sediments	late Pleistocene-Holocene	Spores, conifer and angiosperm pollen, pine and angiosperm phytoliths, and foraminifera (about 37 ka to the present); late Pleistocene bivalves and gastropods	Fluvial, estuarine, barrier, near-shore, shallow-marine, colluvial (thin slope soils), eolian (wind blown), and marsh environments
Tabb Formation	late Pleistocene	None to date; some of the fossils in the above section may pertain to the upper Tabb Formation	Fluvial, estuarine, bay, barrier, and nearshore marine settings
Elsing Green Formation	middle–late Pleistocene	None to date; bivalves are possible	Shallow marine
Shirley Formation	middle Pleistocene	None to date; plant fragments and peat are most likely	Marginal marine to fluvial environments, including estuarine, bay, barrier, marsh, and eolian
Chuckatuck Formation	middle Pleistocene	None to date; plant matter (in peat) and burrows are most likely	Nearshore marine, bay, estuarine to marsh, and fluvial
Charles City Formation	early or middle Pleistocene	None to date; *Ophiomorpha* possible	Bay to shallow shelf, becoming fluvial–estuarine
Windsor Formation	early Pleistocene	None to date; fossils are not common in this formation	Shallow marine deposits overlain by restricted-bay or lagoonal deposits
Bacons Castle Formation	early Pleistocene	None to date; invertebrate burrows are most likely	Nearshore to fluvial environments, including tidal flat, tidal channel, braided stream, meandering river, and estuarine
Cold Harbor Unit	late Pliocene	Potentially *Ophiomorpha*, which is common in this unit	Shallow marine and wave-dominated delta
Yorktown Formation	Pliocene	Sponges, corals, bryozoans, brachiopods, bivalves, gastropods, scaphopods, mollusk fragments, annelid worm tubes, barnacles, crabs, ostracodes, unidentified arthropod fragments, echinoids, shark teeth, bony fish, whale bones, unidentified mammal bones, decapod burrows, invertebrate borings on other fossils, foraminifera, and probably the type specimen of the walrus *Prorosmarus alleni*; also reworked Eastover Formation mollusks	Various shallow marine settings, commonly open marine, lagoon or other restricted marine, and barrier

Table 2 (continued). Summary of COLO surface stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in Tweet et al. (2014).

Formation	Age	Fossils Within COLO	Depositional Environment
Eastover Formation	late Miocene	Bivalves, ostracodes, foraminifera, and possibly barnacles; shells also reworked into Yorktown Formation	Marine, shallow-shelf to nearshore

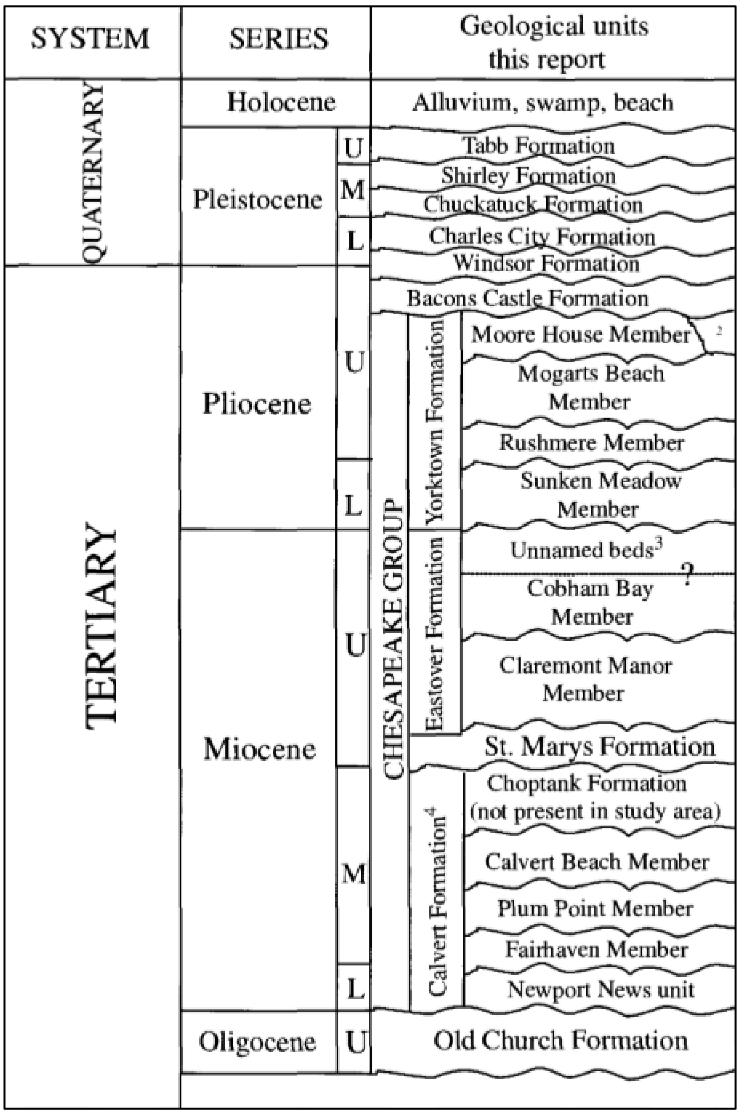

Figure 7. Generalized column of stratigraphic units accessible at the surface in the COLO region (modified from Powars and Bruce 1999). The Elsing Green Formation is not shown, but is placed between the Shirley and Tabb Formations. The newly documented Cold Harbor Unit is also not shown, but is placed between the Yorktown and Bacons Castle Formations.

Geologically younger deposits in COLO, deposited in the late Pliocene, Pleistocene, and Holocene, represent river to estuarine paleoenvironments (Figures 5 and 8). As sea levels fluctuated cyclically, interglacial (warmer) intervals produced higher sea levels and more estuarine conditions. Glacial (cooler) intervals, marked by glaciation far to the north, were associated with decreases in sea level, an increased sediment supply, and more fluvial environments (Newell and Rader 1985; Ramsey 1992). These cycles of warming and cooling have produced terraces (scarps or ancient shorelines) that descend towards the east in a stepwise fashion, running parallel to both rivers and coastlines (Figure 6). The units deposited in the past 3 my, including the Bacons Castle, Windsor, Charles City, Chuckatuck, Shirley, Elsing Green, and Tabb Formations and the Cold Harbor Unit, have yielded few fossils in the vicinity of the park apart from pollen, burrows, and a single mastodon occurrence (Powars and Bruce 1999; Tweet et al. 2014).

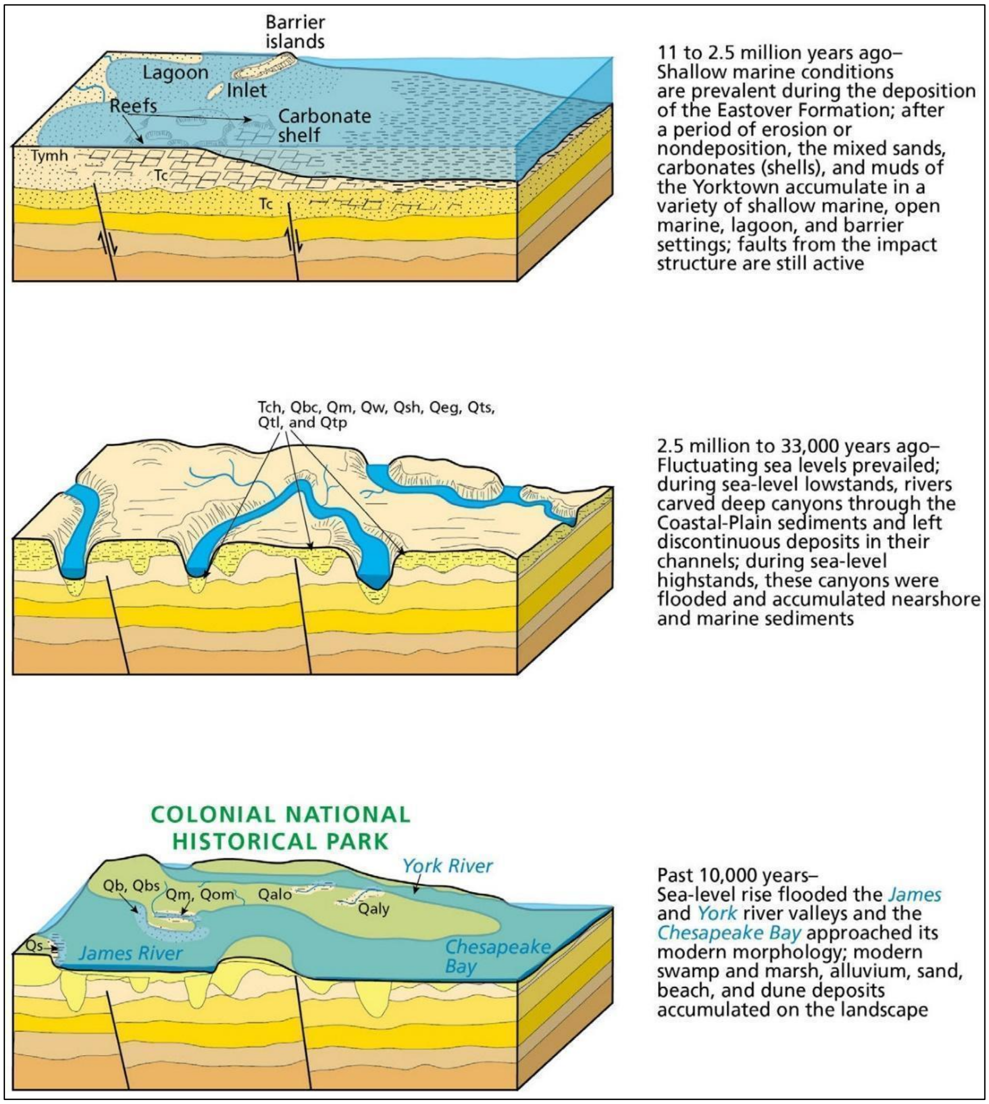

Figure 8. Three diagrams illustrating the physical changes of the COLO area from the Miocene–Pliocene (top) to the Holocene (bottom); modified from Figure 31D–F in Thornberry-Ehrlich (2016). For explanation of map unit abbreviations, see Figure 2 caption.

Nine named subsurface and ten named surface units, as well as various unnamed Quaternary sediments, have been reported from or mapped within COLO (Tables 1 and 2; Figures 2 and 3) (Thornberry-Ehrlich 2016). Although the majority of fossils documented from COLO are derived from the Eastover or Yorktown Formations, all of the units have some potential to yield fossils.

COLO is located within the drainage basins of both the York and James Rivers; it is partially underlain by multiple groundwater aquifers, including the Yorktown–Eastover aquifer, which is one of the most heavily used in the area. The geometry of this aquifer, along with its confining units (layers above and below it), is shaped by erosion and by faulting associated with the Chesapeake Bay impact event (McFarland and Bruce 2006).

Due to the active hydrologic processes in the area, it can be difficult to protect in situ cultural and paleontological resources. Along with the normal tidal variations, storm events are not infrequent, and they can have lasting impacts. In 2003, Hurricane Isabel caused massive levels of erosion that destroyed archaeological sites and breakwaters within COLO (Thornberry-Ehrlich 2005). Additionally, because COLO is in a coastal area, it is vulnerable to potential changes in sea level caused by climate change. Models predict that sea level will continue to rise and that storm events will become more extreme and more frequent, which is particularly hazardous to the resources within COLO (Thornberry-Ehrlich 2016). In order to effectively prepare for future environmental change, it is necessary that COLO managers understand the geologic past as well as present conditions at the park (Thornberry-Ehrlich 2016).

Geologic Formations (Surface Units)

Chesapeake Group: Eastover Formation (late Miocene) (Te)

Description

The Eastover Formation is the oldest unit that is easily accessible within COLO, dating back to 7.5 Ma (Powars and Bruce 1999; Browning et al. 2009; Weems et al. 2017) (Figure 9). It consists of unconsolidated silty sand and clay, with some interspersed thin layers of shelly sand. Historically, this unit was considered to be part of the "St. Marys Formation" or "Virginia St. Marys Formation" (Gardner 1943; Mansfield 1943), but it has been renamed the Eastover Formation (Ward and Blackwelder 1980) and divided into two members: the Claremont Manor Member and the overlying Cobham Bay Member. The Claremont Manor Member consists of fine-grained sand and clay, usually green or gray in color that weathers to tan with the presence of iron. This layer was likely deposited in an open marine environment. The Cobham Bay Member is mainly shelly sand, although whole shells are not commonly found within COLO from this stratum. Deposition in this layer also likely occurred in an open marine environment, although in warmer water than the Claremont Manor Member (Ward and Blackwelder 1980). The Eastover Formation has an unconformable lower contact representing < 0.5 my of missing time between it and the older St. Marys Formation or other, older sediments, depending on location (Edwards et al. 2005, 2009). The Eastover Formation's upper contact with the younger Yorktown Formation is also unconformable (Ward and Blackwelder 1980; Weems et al. 2017) and represents approximately 1.9 my of missing time (Edwards et al. 2005, 2009). Although there are differences in the sediments and fossils found within the Eastover and Yorktown Formations, the contact between these two units can be difficult to distinguish in even moderately weathered outcrops (Johnson et al. 1981). In freshly exposed auger hole or corehole material, however, the two units are easily distinguished. The Eastover is uniformly dark greenish gray, while the Yorktown is either medium greenish gray or medium bluish–greenish gray (Weems et al. 2010).

Figure 9. The Eastover Formation underlies the Yorktown Formation at the Mount Pleasant scenic easement (NPS/MACKENZIE CHRISCOE). Photo taken November 2020.

Fossils found within COLO

The Eastover Formation has yielded a few fossils within COLO. McLean (1966) found a site along the Colonial Parkway south of Williamsburg. This site yielded foraminifera and ostracodes, which are microfossils that can only be viewed with a microscope. A site within COLO on the James River has yielded the genus *Isognomon*, which is a bivalve found only within the Eastover Formation in this area (Hazel 1971). Some Eastover Formation fossils, particularly mollusks, have been reported along the York River (Mansfield 1943; Ward 1993). However, these areas were filled with sediment pumped from other areas in the 1930s and any fossils would be reworked. Although these localities do still contain fossils, they are not found in their original position, and it may be difficult to determine their exact ages (C. R. Berquist, Virginia Department of Mines, Minerals and Energy, pers. comm., 2020).

Fossils found elsewhere

The Eastover Formation crops out from southernmost Maryland to North Carolina (Powars and Bruce 1999), almost as far inland as Richmond in Virginia, indicating a shoreline that would have been much farther west than it is currently. Fossils have been recorded throughout this area (Ward and Blackwelder 1980). The fossil assemblage of the Eastover Formation includes palynomorphs (organic microfossils such as pollen and spores) including moss and fern spores and conifer and angiosperm pollen (Groot 1991), brachiopods (lamp shells), mollusks (e.g., bivalves, gastropods, and scaphopods [tusk shells]) (Ward 1984, 1992; Edwards et al. 2005, 2010), barnacles (Clark and Miller 1912), crabs (Blow and Bailey 1992), ostracodes (McLean 1966; Forester 1980; Edwards et al. 2005), echinoids (sea urchins), sharks and rays (Kimmel and Purdy 1984; Weems et al. 2017), a few types of bony fish (Kimmel and Purdy 1984; Fierstine 1998; Weems et al. 2017), a turtle and an alligator (Weems et al. 2017), birds (Wijnker and Olson 2009; Weems et al. 2017), cetaceans including baleen whales, extinct toothed whales (Whitmore 1984; Weems et al. 2017), river dolphins (Geisler et al. 2012), a horse (Weems et al. 2017), peccaries (Weems et al. 2017), invertebrate burrows (Ward and Blackwelder 1980), foraminifera (single-celled organisms with shells) (McLean 1966), diatoms (phytoplankton with cell walls of silica) (Andrews 1986), calcareous nannofossils (tiny plates from plankton) (Edwards et al. 2005, 2010), and dinoflagellates (single-celled organisms that move using one or more whip-like flagella) (Edwards et al. 2005).

The Claremont Manor Member contains part of this fossil assemblage, but preservation is typically poor and commonly consists of fossil molds and casts. Outcrops along the James River from Claremont to Cobham Wharf contain the most complete specimens, typically mollusks (Ward and Blackwelder 1980). Fossils are more abundant and better preserved in the Cobham Bay Member, which commonly yields bivalves, gastropods, and ostracodes. The Cobham Bay Member also contains pearlaceous bivalves (*Isognomon maxillata*), which makes it easy to differentiate this layer from the overlying Yorktown Formation (Ward and Blackwelder 1980).

A few discoveries have been made near COLO, but just outside NPS jurisdiction. Cobham Wharf, across the river from Jamestown, contained myriad examples of bivalves and gastropods weathering out of the cliff (Ruhle 1962a), before it was destroyed for condominium development. A partial baleen whale skeleton was found at the Cheatham Annex Naval Base off the York River, directly adjacent to COLO property (McClain 2014).

Chesapeake Group: Yorktown Formation (early–late Pliocene) (Ty)

Biostratigraphic data suggest that the Yorktown Formation was deposited from 4.9 to 2.8 Ma (Dowsett and Wiggs 1992; Powars et al. 2016). The Yorktown Formation has gone through several stratigraphic revisions. Mansfield (1943) divided it into two units (Zone 1 and 2), while Johnson (1972, 1976) described four lithic facies. For the purposes of this section, the unit classification by Ward and Blackwelder (1980) is used. In ascending order, the four members are the Sunken Meadow Member, Rushmere Member, Morgarts Beach Member, and Moore House Member. According to Campbell (1993) and Powars et al. (2016), the three youngest units are not distinct or continuous enough to be considered stratigraphic members. Weems et al. (2010) considered the Sunken Meadow Member and Moore House Member to be separate mappable units (their zone 1 and zone 3 of the Yorktown Formation), but they combined the Rushmere Member and Morgarts Beach Member as two facies within a single transgressive-regressive sequence (their zone 2 of the Yorktown Formation). The climatic setting of the Yorktown Formation has been reconstructed as mid-temperate (Ward and Blackwelder 1980; Hazel 1983) to cool temperate (Campbell 1993).

Description

Sunken Meadow Member

The Sunken Meadow Member is early Pliocene in age (maximum of 4.9 Ma) and consists of biofragmental sand interbedded with clayey silty fine-grained sand (Powars et al. 2016). It is unconformably underlain by the Cobham Bay Member of the Eastover Formation in Virginia. Ward and Powars (1991, 2004) interpret the Sunken Meadow Member as the first of three transgressive (high sea level) cycles preserved in the Yorktown Formation. The fossils and sediments within this section were likely deposited on a shallow marine shelf with moderate temperatures (Ward and Blackwelder 1980).

Rushmere Member

The Rushmere Member grades laterally into the Morgarts Beach Member. The Rushmere Member consists of well-sorted, fine quartz sand, to mega-crossbedded biofragmental sand, to locally shelly, poorly sorted, pebbly, coarse-to-fine glauconitic quartz sand (Powars et al. 2016). In some areas, the Rushmere Member has non-conformable contacts with much older sand or rock, but this does not occur within COLO. Ward and Powars (1991, 2004) consider the Rushmere and Morgarts Beach Members together to represent the second of three transgressive cycles in the Yorktown Formation. In many other parts of Virginia, the Rushmere Member directly overlies the Eastover Formation (Ward et al. 1991; Weems et al. 2010).

Morgarts Beach Member

The Morgarts Beach Member consists of gray to blue clay, with some thin beds of silt or very fine sand. The fine-grained sediments of the Morgarts Beach Member were likely deposited in a lagoon behind barriers (e.g., sand bars) that aligned with the edge of the CBIS (Johnson et al. 2001). Both Weems et al. (2010) and Powars et al. (2016) consider the contact between the Morgarts Beach and Moore House Members unconformable based on subsurface data to the southwest of COLO. It is somewhat difficult to find the contact between these members within COLO. A clay horizon exists at or slightly above the contact between the Morgarts Beach Member and the overlying Moore House Member of the Yorktown Formation at some localities, including the Moore House Type Section. This clay layer was originally assigned to the Morgarts Beach Member (Ward and Blackwelder 1980), but current interpretations vary between the Morgarts Beach Member (C. R. Berquist, pers. comm., 2021) and the Moore House Member (L. W. Ward, U.S. Geological Survey Emeritus, pers. comm., 2021). The contact may be visible in Figure 10.

Figure 10. The contact between sand (above, representing the Moore House Member of the Yorktown Formation) and blue clayey silt (near the bottom of the photo, representing either the Morgarts Beach or the Moore House Member of the Yorktown Formation) at a locality in COLO (NPS/MACKENZIE CHRISCOE).

Moore House Member

The Moore House Member of the Yorktown Formation is late Pliocene in age (minimum of 2.8 Ma). The type section of the Moore House Member is located within the Yorktown portion of COLO, near the historic Moore House building from which this member takes its name. Lower Moore House

Member sediments are very shelly, poorly sorted, muddy, calcareous, glauconitic quartz sand. This grades upward into less muddy, fine quartz sand with less glauconite and abundant shell debris (Powars et al. 2016). Cornwallis Cave in Yorktown is composed of sediment from this unit, which takes the form of orange cemented shell hash featuring mega-crossbeds dipping 20–34 degrees to the west (Figure 11; Appendix H). Exposures of the Moore House Member at COLO tend to be strongly cemented, making fossil collection difficult, but also leading to the use of this marl as a local building material. Ward and Powars (1991, 2004) argue that the Moore House Member represents the third of three transgressive cycles within the Yorktown Formation, but other authors have suggested that the Moore House Member might represent a facies of the Rushmere–Morgarts Beach transgression (Campbell 1993; Weems et al. 2010; Powars et al. 2016).

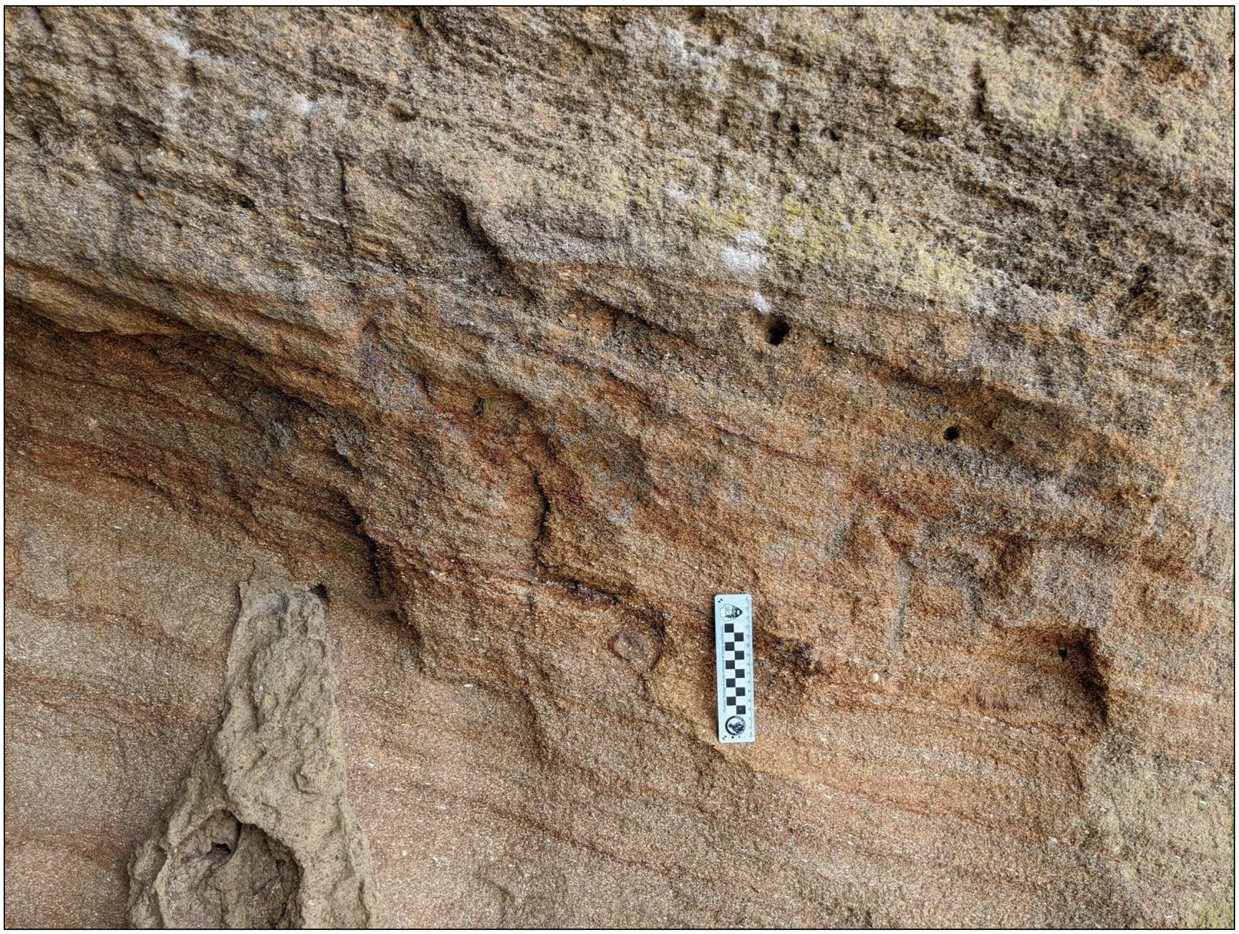

Figure 11. Bedding features at Cornwallis Cave (NPS/MACKENZIE CHRISCOE). All sediment visible in the photo is assigned to the Moore House Member of the Yorktown Formation.

<u>Fossils found within COLO</u>

Within COLO, the Yorktown Formation has produced sponges, corals, bryozoans, brachiopods, bivalves, gastropods, scaphopods, annelid worm tubes, barnacles, crab claws, ostracodes, unidentified arthropod fragments, echinoids, shark teeth, bony fish bones, whale bones, unidentified mammal bones, decapod crustacean burrows, invertebrate borings on other fossils, foraminifera, and probably walrus bones. Examples of nearly all of these fossils were documented in field work conducted over the summer of 2020 across several localities (Appendix G). The most common genera recorded included *Crepidula, Turritella, Mercenaria, Chesapecten,* and *Conradostrea*.

Tweet et al. (2014:90–93) summarized reports from numerous localities from the literature that are plausibly within COLO. That section is largely reproduced below, with edits to remove sensitive locality information:

> *The shells at Bellefield, the coquina [soft rock made from fossil fragments], and the fossils in the bluffs are described as far back as Rogers and Rogers (1837), who also provided perhaps the earliest stratigraphic descriptions of the area. Their descriptions include numerous references to the various fossil bivalve and gastropod species common in the various beds along the York River;*
>
> *Meyer (1888) reported that J. J. Stevenson collected fossils including bivalves, scaphopods, gastropods, barnacles, and ostracodes near Yorktown;*
>
> *G. D. Harris prepared a detailed description of the rocks from Wormley Creek to King Creek from observations made in 1890, but did not publish his material. Ward (1993) reproduced his manuscript with annotations and lists of fossils that Harris collected and are now at the National Museum of Natural History. Harris's manuscript is an essential document for understanding the geology of the York River section of COLO because most of the exposures have been concealed beneath riprap for decades. Harris obtained abundant fossils, including brachiopods, bivalves, scaphopods, gastropods, and barnacles, and also reported a whale vertebra from the Bellefield area. Some of this material was described in Dall's publications (see below);*
>
> *Dall (1892, 1900, 1903) described several species of bivalves and gastropods from sites in and around Yorktown;*
>
> *A species of walrus,* Prorosmarus alleni *(now thought to be the same as* Ontocetus emmonsi*) was based on a partial lower jaw (USNM 9343) found on the beach at Yorktown (Berry and Gregory 1906), very likely within COLO. A walrus ulna has also been found in the Sunken Meadow Member in Williamsburg (Harris and Johnson 1986);*
>
> *Clark and Miller (1912) reported that fossils found at Yorktown include specimens from brachiopods, bivalves, scaphopods, gastropods, barnacles, crabs, walruses, and whales;*
>
> *Banks (1932) in an internal COLO memorandum detailed his collecting activities for a park natural history exhibit, He was able to obtain examples of more than 100 species, and also mentioned that H. C. Frincke had found unspecified mammalian bones in the hydraulic fills along the Colonial Parkway segment between Williamsburg and Yorktown. The Yorktown Formation is the most likely source for these fossils if the fills were local;*
>
> *Roberts (1932) included a great deal of information on fossil collecting;*

Cushman and Cahill (1933) investigated foraminifera from the Yorktown Formation, naming the species Massilina mansfieldi *from a specimen (USNM 371735) found at a locality probably in the vicinity of Moore House;*

Mansfield (1943) described a site above Yorktown, almost certainly in COLO, which yielded bivalves and gastropods. He also reported that various bivalves and gastropods had been found at Yorktown and Felgates Creek, and bivalves (in the Chama *bed) were found east of Williamsburg at a creek crossing of the Colonial Parkway;*

McGavock (1944) named several bivalves from locations either in or near COLO. They include Tellina gardnerae *(ANSP 16012) and* Diplodonta conradi *(ANSP 16014) from above Yorktown,* Diplodonta berryi *(ANSP 16013 per Richards 1968) from below Yorktown, and* Petricola rogeri *(ANSP 16015) from a blue clay lens closer to Moore House;*

Malkin (1953)'s ostracode locality 20 was almost certainly within COLO. Samples VA-2, 3, 10, and 12 came from this locality, and included foraminifera, bivalves, gastropods, barnacles, ostracodes, and shell fragments. Locality 17 was probably nearby but not within COLO. Malkin (1953) named several ostracode species from these localities;

McLean (1956) reported foraminifera from Felgaters [sic] Creek, Moore House Beach, and the bluffs of Yorktown. Bivalves, gastropods, and barnacles were also present at some localities. McLean named several foraminifera species from these localities;

McLean (1957) reported ostracodes from the same areas as the previous publication, naming Murrayina barclayi *(ANSP 22588) from Moore House Beach;*

Hazel (1971)'s ostracode locality 13 (Sample 41, USGS 24717) is within COLO;

Johnson (1972) included several localities relevant to COLO. Site D is probably just within COLO but may be in one of the small non-NPS cutouts near it. Fossils of sponges, corals, bryozoans, bivalves, scaphopods, gastropods, annelids and barnacles have been found here. Shell fragments and decapod burrows have been found at Cornwallis Cave within COLO. The coquina along the York River at Yorktown yields abundant bivalve shells and uncommon corals and bryozoans, with the shells frequently bored by sponges and worms (Johnson 1972). Each of Johnson's facies in the Yorktown area has its own typical fossils. The silty sand facies features diverse fossils, with bryozoans and the gastropods Crepidula *and* Turritella *most abundant. The shelly sand facies, which is present in the Moore House area, has yielded corals, bryozoans, bivalves, scaphopods, gastropods, annelid worm tubes, barnacles, and echinoids. The cross-bedded coquina facies, as seen at Cornwallis Cave, features sands made of bivalve and gastropod shell fragments, and decapod burrows. The sandy silt facies is extensively burrowed, and shells of* Crepidula *and the bivalve* Ostrea [Conradostrea] *are locally common. The coquina facies is dominated by bivalves, often bored by sponges and spirorbid worms. The* Chama *facies is not exposed at the surface;*

Kier (1972), in a discussion of Yorktown Formation echinoids, reported that one (USNM 373038) had been found at Yorktown;

Swain (1974), describing ostracodes from the Yorktown Formation, included the Moore House bluff as a site;

Ward and Blackwelder (1975) reported that Chesapecten jeffersonius *has been found at many places in and around COLO;*

Ward and Blackwelder (1980) reported foraminifera, bryozoans, bivalves, gastropods, and ostracodes at a site in COLO;

Gibson (1983) reported on foraminifera collected from Yorktown;

Wilson (1983) reported that the unusual barnacle Mclellania *had been found at a site in COLO;*

Cronin et al. (1989) reported that foraminifera, bryozoans, bivalves and other mollusks, ostracodes, and shell hash have been found near Moore House;

Dowsett and Wiggs (1992) described foraminifera from Yorktown Formation localities including the Moore House area;

Finally, Santucci et al. (2001), describing National Park Service cave fossils, noted that the coquina of Cornwallis Cave is composed mostly of sand-sized fragments of mollusk shells, "with lesser amounts of arthropod, bryozoan, and echinoid fragments." The cave's coquina erodes readily; perhaps 4.5 metric tons (5 tons) have crumbled from the cave since the 1790s;

Other publications that mention COLO sites include Ruhle (1962a, 1962b) and Frye (1986). Fossils have also been reported from the immediate vicinity. Two notable sites include Zook's Pit and Cobham Wharf. Zook's Pit, included within COLO in the previous NCBN paleontological resources inventory (Kenworthy and Santucci 2003), appears to be in a small non-NPS enclave per Sweet (1974). Fossil collecting was previously allowed at this locality, but is now closed to the public. Brachiopods, bryozoans, bivalves, snails, and other fossils were common (Sweet 1974). At Cobham's Wharf, organic debris, foraminifera, sponge spicules, corals, bryozoans, bivalves, scaphopods, gastropods, barnacles, ostracodes, otoliths (bony fish "ear bones") (Sabol 1960), and gull bones (Olson and Rasmussen 2001) have been found. Cobham Wharf is also described in Cronin et al. (1989).

<u>Fossils found elsewhere</u>
The Yorktown Formation marine fossil assemblage is quite diverse. Marine invertebrates are represented by sponges, hydrozoans (relatives of jellyfish and corals) (Johnson 1972), corals, bryozoans, brachiopods, mollusks (Roberts 1932; Johnson 1972; Edwards et al. 2005), cephalopod statoliths (mineralized deposits that form in some invertebrate ears and are used for equilibrium; Clarke and Fitch 1975), annelid worm tubes, barnacles, ostracodes (Edwards et al. 2005), other

crustaceans, echinoids (Roberts 1932; Johnson 1972), and invertebrate burrows and borings (Johnson 1972). In 2020, near Wormley Creek, fossilized crab claws were found in Moore House sediments as well. Marine vertebrates include cartilaginous fish (Roberts 1932; Johnson 1972), bony fish (Johnson 1972), seals (Vélez-Juarbe and Pyenson 2012), walruses (Berry and Gregory 1906), and cetaceans (Roberts 1932; Johnson 1972). Marine vertebrates are commonly represented by shark teeth (Roberts 1932; Johnson 1972) and vertebrae (Johnson 1972). Marine microfossils includes calcareous nannofossils (Campbell 1993; Edwards et al. 2005), foraminifera, radiolarians (another type of single-celled "shelled" organism), diatoms, dinoflagellates (Edwards et al. 2005), and other microfossils (Roberts 1932). The trace fossils show a variety of interactions, such as snail borings on shells (Hagadorn and Boyajian 1997; Barbour 1998; Kelley et al. 2007), borings on corals from sponges, bivalves, and worms (Corbett 2007), and damage from vertebrate-on-vertebrate predation, including damage on a tuna vertebra from billfish predation (Schneider and Fierstine 2004), and a partially healed whale rib (Kallal et al. 2012).

Documents covering some of these individual groups include: bryozoans (Knowles et al. 2009); brachiopods (Chuang 1964); mollusks (Gardner 1943, 1948; Campbell 1993); barnacles (Ross 1964); crabs (Rathbun 1935; Blow 2003; Blow and Bailey 2003), shrimp (Rathbun 1935); ostracodes (Ulrich and Bassler 1904; Hazel 1971, 1977; Swain 1974; Forester 1980); echinoids (Kier 1972); sharks and rays, mostly from the base of the Sunken Meadow Member (Purdy et al. 2001); bony fish (Fierstine 1999, 2001; Purdy et al. 2001); various whales and dolphins (Baum and Wheeler 1977; Whitmore 1994; Gibson and Geisler 2009); calcareous nannofossils (Akers and Koppel 1974; Blackwelder 1981; Cronin et al. 1984, 1989; Campbell 1997); and foraminifera (Bagg 1898; Cushman and Cahill 1933; McLean 1956).

Cold Harbor Unit (late Pliocene) (Tch)

Description

The Cold Harbor Unit consists of orange to brown clays with some green-gray throughout. Some sand and silt may also be present. This unit is thought to have been deposited in a wave-dominated deltaic setting. This formation was named for the Cold Harbor area near Richmond, Virginia, where Civil War battles took place, and the sediments in the Richmond area actually affected battle strategies in some cases (Cross et al. 2017; C. M. Bailey, William & Mary, pers. comm., 2014). This formation was formerly thought to be part of the Yorktown Formation, as evidenced by some accounts of the Bacons Castle Formation overlying the Yorktown in the absence of "Sedley" material (Coch 1965). The Sedley Formation has since been recognized as a weathering formation at the top of the Yorktown Formation, and in Coch's (1965) report, the Cold Harbor Unit was not differentiated from it. It is possible that the Cold Harbor Unit represents the inshore equivalent of the marine Chowan River Formation in northeastern North Carolina, which would make it early Pleistocene in age rather than late Pliocene.

Fossils found within COLO

The Cold Harbor Unit does not appear to be fossiliferous, and no fossils from this formation have been reported in COLO. Because of the complex history of stratigraphic names in this area, however, it is possible that fossils from what is now the Cold Harbor Unit were previously reported as being from other formations, perhaps the Yorktown or Bacons Castle Formations.

Fossils found elsewhere

Some root casts were found in a core of this section from the Petersburg area (C. M. Bailey, pers. comm., 2014).

Bacons Castle Formation (early Pleistocene) (Qbc)

Description

The age of the Bacons Castle Formation has been difficult to determine, and authors have cited the formation's relative position between the Pliocene-aged Yorktown Formation and the Pleistocene-aged Windsor Formation (Johnson and Berquist 1989). In recent years, palynomorphs have been recovered from the Barhamsville Member of the Bacons Castle Formation (Weems et al. 2017). These palynomorphs, combined with correlation southward based on surface terrace levels, have established an age of approximately 1.8 to 1.6 Ma. The Bacons Castle Formation is distributed from the Coastal Plain in Virginia and North Carolina to the Piedmont of Virginia and beyond. It consists of clayey sand, pebble to cobble-sized gravel, and silty sand that varies in color from gray to yellow-orange and red-brown (Coch 1965). Two facies, which may be members, have been recognized within the Bacons Castle Formation. The older facies, the Barhamsville Member, is composed of clayey silt fining upward into a fine-grained sand with various bedding structures, which seem to indicate deposition along a tidal flat. The younger facies was informally labeled the Varina Grove Member, a massive gravel fining upward into sand, clay, and silt, which was interpreted to represent a fluvial environment. (Johnson and Ramsey 1987; Ramsey 1988). Weems et al. (2010), based on mapping in the Emporia 30' x 60' 1:100,000 Quadrangle, concluded that the Moorings Unit represents barrier island sand perched conformably on the eastern margin of the Barhamsville Member and thus is also part of the Bacons Castle Formation. *Ophiomorpha* burrows are also occasionally found in this section (Mixon et al. 1989; Weems et al. 2017).

Fossils found within COLO

No fossils from the Bacons Castle Formation have been found within COLO, although there is potential for them.

Fossils found elsewhere

The fossils documented closest to COLO are from near Richmond, Virginia, where microfossils, plant spores, and pollen have been found (Groot 1991). Some Pleistocene-aged fossil plant material was also found near Richmond, although there are minimal details about this material and it could overlap with the previously mentioned fossils (Johnson and Berquist 1989; Groot 1991). Burrows may be common or rare, particularly in the Barhamsville Member. *Ophiomorpha nodosa* is the only species mentioned, however (Rader and Evans 1993), and it is uncertain whether these burrows are found throughout the formation or only in concentrated areas. At Stratford Hall in the Northern Neck of Virginia, a "bog iron" unit within the Barhamsville Member has yielded numerous palynomorphs (Weems et al. 2017). These same bog iron beds also contain footprints of 36 different kinds of amphibians, reptiles, birds, and mammals (Weems 2018, 2021).

Windsor Formation (early Pleistocene) (Qw)

<u>Description</u>

The Windsor Formation is thought to have been deposited between 1.5 to 1.2 Ma, based on recent strontium isotope and amino acid racemization dating of fossils (Wehmiller et al. 2010). The Windsor Formation represents a fining-upward sequence that grades from sand and gravel into silt, clay, and sand. Colors of these sediments can be gray or yellow to red-brown (Mixon et al. 1989). Within COLO, the Windsor Formation mainly contains sand, silt, and clay, similar in composition to the Bacons Castle Formation but finer-grained (Bick and Coch 1969). Its contacts with both the Bacons Castle Formation and the overlying sediments are unconformable (Coch 1965). The older facies was likely deposited in a shallow marine environment, whereas the upper facies was likely deposited in a lagoonal environment (Rader and Evans 1993).

<u>Fossils found within COLO</u>

Fossils are rarely found within the Windsor Formation and have not been found within COLO from these sediments.

<u>Fossils found elsewhere</u>

The only fossils that have been reported from this unit include angiosperm fossils from the genus *Pterocarya* (wingnut) (Colquhoun et al. 1991), decapod burrows (likely ghost shrimp) (Johnson 1972; Colquhoun et al. 1991), foraminifera (Bick and Coch 1969), some molds of reworked Yorktown Formation mollusks (Johnson 1972), and reworked Middle Ordovician and Early Devonian fossils (Johnson and Berquist 1989). Burrows and plant fossils have been found in the lower facies of the formation (Colquhoun et al. 1991).

Charles City Formation (early or middle Pleistocene) (Qcc)

<u>Description</u>

The age of this unit is difficult to refine. Sediments in North Carolina that are thought to be equivalent to the Charles City Formation have been dated to 0.65 to 0.6 or 1.2 Ma, based on amino acid racemization and strontium isotope dating of shells (Wehmiller et al. 2010). The Charles City Formation contains a fining upward sequence that grades from gravelly sand to silty or clayey sand. Two facies make up this formation, the lower containing pebbly sand fining upward into coarse sand, and the upper containing mainly silt or clayey silt. The depositional environment for this formation was likely fluvial or estuarine (Johnson and Berquist 1989). The color of these sediments varies from gray and yellow to red-brown (Rader and Evans 1993). Much of the formation has been heavily eroded, with only some preserved outcrops along the James and York Rivers (Johnson and Berquist 1989).

<u>Fossils found within COLO</u>

The Charles City Formation has not produced notable fossils within COLO.

<u>Fossils found elsewhere</u>

With the exception of some burrows in the lower facies of the formation, it is completely lacking in fossil material (Johnson and Berquist 1989). It is unlikely that this formation will produce fossils within COLO in the future.

Chuckatuck Formation (middle Pleistocene) (Qc)

Description

This formation is also difficult to date, but has historically been assigned a middle Pleistocene age due to its placement between the Charles City and Shirley Formations. Wehmiller et al. (2010) document an age of 0.65–0.60 Ma based on amino acid racemization and strontium isotope dating, for stratigraphically equivalent deposits in North Carolina. The contact between the Chuckatuck and Shirley Formations is unconformable, and the lower contact with the Charles City Formation is an erosional disconformity (Johnson and Berquist 1989). The Chuckatuck Formation consists of a fining upward sequence grading from gravelly sand to medium- to fine-grained sand and finally to clayey sand or silt (Johnson and Berquist 1989). The lower part of the formation was most likely deposited in a fluvial or marsh environment, while the overlying sediments were more likely deposited in a bay or lagoon. Throughout the Chuckatuck Formation, there are obvious variations both vertically and laterally within the sediments. In some places, it is possible to find organic-rich silt, with plant matter including trees and shrubs (Johnson and Berquist 1989).

Fossils found within COLO

No fossils from the Chuckatuck Formation have been found within COLO.

Fossils found elsewhere

The formation is only locally fossiliferous. *Ophiomorpha* burrows have been reported in the lower and middle parts, as well as bivalve molds in the upper part of the formation (Powars et al. 2016). Additionally, the peat that is sometimes present contains various fossil plant materials, mainly from trees and shrubs such as hickory, sweet gum, and myrtle (Johnson and Berquist 1989).

Shirley Formation (middle Pleistocene) (Qsh)

Description

Corals from Norris Bridge, Virginia, provided a uranium-series age of 187 ± 20 thousand years ago (ka) that places the Shirley Formation as middle to late Pleistocene in age (Mixon et al. 1982; Szabo 1985). Strontium isotope and amino acid racemization of shells from equivalent deposits in North Carolina yield much older dates of 0.36–0.30 or 0.65–0.60 Ma (Wehmiller et al. 2010). The Shirley Formation was previously included in a unit called the Norfolk Formation and represents the older facies unit within that formation. Peebles et al. (1984) separated the Norfolk Formation into two different units: the Tabb Formation and another, older unit, which was subsequently named the Shirley Formation (Johnson and Berquist 1989). The Shirley Formation is a fining-upward sequence that grades from gravelly sand to gray and red-brown fine- to coarse-grained sand and further to a gray clayey or silty sand. In the COLO area, it was likely deposited under bay or nearshore marine conditions, but it contains several different potential depositional environments throughout its range as sea level changed.

Fossils found within COLO

The Shirley Formation is not known for its fossils, and no paleontological materials have been reported in COLO from this section.

Fossils found elsewhere

Within the upper facies of this formation, it is possible to find some peat along with the organic-rich silt. Tree stumps, leaves, and seeds of cypress, oak, and hickory have been found in these layers (Rader and Evans 1993). Along the James and Rappahannock Rivers, *Crassostrea virginica*, *Mulinia*, *Noetia*, *Mercenaria*, and other mollusks have been reported, along with corals, including *Astrangia* (Mixon et al. 1982; Rader and Evans 1993). Bivalves and burrows have been reported in the sand and silt layers (Peebles et al. 1984). Ostracodes were also described from the Norfolk Formation (Valentine 1971), but it is not clear whether these were derived from the Shirley or Tabb Formation.

Elsing Green Formation (late Pleistocene) (Qeg)

Description

Sediments from this unit were dated based on the concentration of 10Be in quartz sand, which provided an age of approximately 132 ka (Berquist et al. 2014). Amino acid racemization of shell material produced a similar age estimate of 125 ka (Berquist et al. 2014). The Elsing Green Formation contains gray to yellow-gray coarse-grained sand with some pebbles that fines upward into fine and medium-grained sand. This unit was likely deposited in a shallow marine environment, during a cooler climate than today, based on marine shells documented locally (Berquist et al. 2014; Powars et al. 2016). Within COLO, sediments from the Elsing Green Formation are mapped at College Creek near Williamsburg and along the Colonial Parkway by the York River (Thornberry-Ehrlich 2016).

Fossils found within COLO

No fossils have been found in the Elsing Green Formation in COLO.

Fossils found elsewhere

Marine mollusk genera, including *Crassostrea* and *Mercenaria*, have been reported from the Elsing Green Formation (Powars et al. 2016). Additionally, this formation was formerly reported as the Norfolk Formation. While fossils exist within the Norfolk Formation, it is difficult to determine to which of the new units they belong. It is possible that some of the reported Norfolk Formation fossils were found within the Elsing Green Formation, but there is no report of them to date.

Tabb Formation (late Pleistocene) (Qts, Qtl, and Qtp)

Description

Estimates of age for the Tabb Formation have ranged from 90–72 ka (Lamothe and Wehmiller 2010), to 71 ka (Mixon et al. 1982), to 35–23.4 ka (Powars et al. 2016). Previously described as part of the Norfolk Formation, the Tabb Formation has been subdivided into three members which, in ascending order, are the Sedgefield, Lynnhaven, and Poquoson Members (Johnson 1976). Sediments range in color from blue-gray to tan, red-brown, or yellow-brown and the Tabb Formation generally consists of clay, along with sand containing clay, silt, and gravel (Johnson 1976). Each member consists of a fining-upward sequence from gravelly sand to clayey or silty sand, and both the Sedgefield and Lynnhaven Members have local deposits of peat or plant fragments (Mixon et al. 1989). Depositional environments vary, with deposition likely occurring in fluvial, estuarine, bay, barrier, and nearshore marine settings (Johnson and Berquist 1989).

Fossils found within COLO

The Tabb Formation was previously described as part of the surficial deposits at Jamestown Island, but microfossils examined from these deposits were younger than the age of the Tabb sediments themselves (Johnson and Hobbs 2001).

Fossils found elsewhere

In other areas, each of the members contains fossils, especially the Sedgefield Member, which is dominated by *Crassostrea* and *Mercenaria* (Johnson et al. 1981). Peat, stumps (in channel fill; Mixon et al. 1989), wood (Colquhoun et al. 1991), sponges (Johnson et al. 1981), corals (Szabo 1985; Mixon et al. 1989; Scott et al. 2010), bryozoans, other bivalves, gastropods (Johnson et al. 1981), serpulid worm tubes (Peebles et al. 1984), decapods, ostracodes (Johnson et al. 1981), echinoderm fragments (Peebles et al. 1984), burrows (Johnson and Berquist 1989), vertebrae (Scott et al. 2010), and foraminifera (Johnson et al. 1981) have also been found. The Lynnhaven Member is less productive, although plant material (Mixon et al. 1989) as well as burrows have been found (Johnson and Berquist 1989). Peat and wood have also been documented within the Poquoson Member (Scott et al. 2010). The Womack Borrow Pit in Virginia Beach has yielded numerous vertebrate remains from the Kempsville Formation (which is Tabb Formation equivalent) including sharks, rays, bony fish, coastal birds, and marine mammals (Ray et al. 1968). Recently, fossil alligator and land mammal footprints have been reported from the Tabb Formation at Stratford Hall in the Virginia Northern Neck (Weems et al. 2021).

Unnamed Quaternary sediments (late Pleistocene–Holocene) (various)

Description

There are many types of Quaternary sediments overlying the Tabb Formation in the COLO area. These sediments range from marsh and swamp sediments to alluvium, beach and dune sand, and organic mud. Most of the Holocene deposits are from tidal marshes (Bick and Coch 1969).

Fossils found within COLO

Within COLO, these sediments are fossiliferous. On Jamestown Island, microfossils as well as conifer and angiosperm pollen were reported from vibracores in the area. These fossils are particularly useful in climate reconstructions (Sager et al. 1994). Johnson and Hobbs (2001) described more fossils from the same locality; these included phytoliths (bits of silica secreted in the tissues of some plants), pollen, foraminifera, and spores. The fossil record dates back to 37 ka and is nearly complete over that time span (Johnson and Hobbs 2001). Along the York River, G.D. Harris, published in Ward (1993), reported dark "soil" deposits containing bivalves and gastropods, which Ward places as late Pleistocene in age. In the late Pleistocene–Holocene deposits of COLO, reworked shell fragments have been reported (Bick and Coch 1969). Additionally, plant fragments (Roberts 1932) and peat, which can contain a variety of plant material, are present (Johnson 1972; Johnson and Berquist 1989). Typical plants represented include cypress, black gum, sweet gum, other hygrophilous trees (trees that prefer damp conditions), arum, and cordgrass (Johnson and Berquist 1989).

Fossils found elsewhere

In deposits similar to those found within COLO, such as the Great Dismal Swamp, palynomorphs, plant macrofossils, and other fossils are represented and may be present in COLO as well. Organisms represented include diatoms, mosses, clubmosses, ferns, conifers, angiosperms, fungi, and sponges (Cocke et al. 1934). Holocene sediments from the Chesapeake Bay contain foraminifera, dinoflagellates, angiosperm and conifer pollen, and bivalve shells (Willard et al. 2003). Some vertebrate fossil sites within Virginia were described by Hay (1923) and Eshelman and Grady (1986). One site, located adjacent to COLO within what is now the Cheatham Annex Naval Base, has yielded fossil remains from a proboscidean (Madison 1811, 1812).

In July 1811, the discovery of an "elephant" (later described variously as a mammoth or mastodon) was reported along the south bank of the York River, 10 km (6 mi) south (Anonymous 1811) or east (Madison 1812) of Williamsburg and 137 m (150 yards) from the mansion of Gawin Corbin, Esq. (Madison 1812). Although this site was previously thought to potentially occur within COLO (Tweet et al. 2014; Mead et al. 2020), recent research has revealed that it was most likely excavated from what is now part of the Cheatham Annex Naval Base, near but not within COLO just north of Colonial Parkway. Multiple Gawin Corbins inhabited this area of Virginia, but the most likely candidate is Gawin Lane Corbin (1778–1821), whose property was referred to as "Kings Creek Plantation", now within the Cheatham Annex Naval Base. This land was colonized by Europeans and referred to as "Utimaria" by Captain John Utie in 1630. It passed to the Tayloe (or Taylor) family, then to Nathaniel Bacon (cousin to Nathaniel Bacon of Bacon's Rebellion), then to the Burwell family, during which time it was renamed "Kings Creek" (Anonymous 1913). In 1790, the property was sold to John Tayloe Corbin (Tyler 1894). John Tayloe Corbin was the father of Gawin Lane Corbin (Anonymous 1922). Later this area became known as Penniman and was eventually acquired by the U.S. Navy. Given that the east side of Kings (or King's, or King) Creek near the York River, now within COLO, was occupied by Ringfield and Bellefield (or Bellfield, or Belfield) plantations during this interval, any specimen found near the home of Gawin Corbin on the York River shore was found on the other side of King's Creek, in what is now part of the Cheatham Annex.

Madison (1812) noted that the bones were discovered upon or within marsh mud amongst the roots of cypress trees. They included a pelvis, femur, two vertebrae, two ribs, two tusks, and seven molars, four of which were still attached to the jaw (Madison 1811, 1812). The largest of the molars weighed as much as 3.29 kg (7.25 lbs.) (Madison 1812). While Mitchill (1818) identified the material as mammoth, Godman (1826) considered them mastodon (*Mammut*). Clark and Miller (1912) determined the stratigraphic unit as the Pleistocene Talbot Formation (now obsolete). The excavation and storage of the specimen at William & Mary was subsequently documented in a letter by William Nelson to St. George Tucker (Madison 1811). The President of the College, Dr. Lyon G. Tyler, informed Hay (1923) that the fossils were destroyed in a fire in 1859.

Several other sites within 50 km (approximately 31 mi) of COLO have produced vertebrate fossils, but usually with only one or two specimens or taxa attached to them. These include City Point, 46 km (29 mi) west-northwest of Jamestown (mastodon) and a more diverse fossil collection found at Eclipse, about 38 km (24 mi) south of Yorktown (loons, gannets, and auks). Fossils of giant beavers, walruses, and gray whales have been found on coastal barrier islands in Accomack County to the northeast, and boats frequently recover Pleistocene mammal bones from the drowned coastal plains offshore of Virginia, including specimens of mammoths, mastodons, musk oxen, and bison (Eshelman and Grady 1986).

Taxonomy

See Appendix A for full lists of taxa. Locality data for fossil sites can be found in Appendix G.

Fossil Plants

Plant fossils within COLO are rare and primarily found in the form of microfossils such as pollen, particularly in the Jamestown area. Groot (1991) reported palynomorphs (organic microfossils, including pollen and spores), including moss and fern spores, conifer and angiosperm pollen, and some reworked older material within the Eastover Formation. Similar fossils have been reported from the Yorktown Formation, in addition to clubmoss spores (Groot 1991; Sirkin and Owens 1998). Resin and wood from trees such as pines, cypresses, junipers, and locust trees have also been found within the Yorktown Formation (Hueber 1983). More recent Quaternary deposits near Jamestown contain pollen as well as phytoliths (bits of silica secreted in the tissues of some plants) that represent grass families, oak, and pine (Johnson and Hobbs 2001). Spruce pollen can be found in the Bacons Castle Formation, which is helpful in determining climate at the time of its deposition, but it has not been found within COLO (Groot 1991). Most of Groot's sites are not within COLO; this list of flora is meant to indicate what might be found within COLO with future studies. More unidentified macrofossil plant material has been found within the stratigraphic formations that make up the park, but is generally lacking within NPS boundaries in this area.

Fossil Invertebrates

Fossil assemblages documented in COLO are dominated by marine invertebrates from the Yorktown Formation, in particular the highly fossiliferous Moore House Member. Older publications refer to "shell beds" without specific descriptions of the taxa or locality, but they likely contained mainly bivalves and gastropods, which make up most of the bulk samples collected during 2020 field work.

Phylum Mollusca: Class Bivalvia (clams, oysters, etc.)

Bivalves are two-shelled mollusks that typically have a plane of symmetry running between their shells (i.e., the shells are mirror images). These organisms make up the majority of fossils in COLO and have been reported and described in several publications, including Gardner (1943), Ward and Blackwelder (1980), and Campbell (1993). *Chesapecten madisonius*, a large scallop which is the descendent species of the Virginia state fossil (*Chesapecten jeffersonius*), is one of the most abundant species in the Moore House Member of the Yorktown Formation (see Appendix B for photos). These scallops are dark gray to brown in color and have a greater number of ribs than *C. jeffersonius*.

Bivalves such as *Mercenaria*, *Glycymeris*, *Dosinia*, *Astarte*, and *Plicatula* are also common in COLO. *Mercenaria* and *Dosinia* are both large clams (5–25 cm or 2–5 in long). *Dosinia* has a rounder shell outline and a thinner shell than *Mercenaria* (Figure 12). *Glycymeris* is medium in size (1.3–8 cm or 0.5–3 in long) with growth lines as well as obvious ribs that radiate across the shell. The hinge of *Glycymeris* is taxodont, resembling vertical striations, which makes this genus easy to identify (Figure 13). *Astarte* is smaller (<2.5 cm or 1 in long) triangular shells, with pronounced concentric rings and a very angular hinge line. Several different species of *Astarte* occur in the Moore House Member (Figure 13). *Plicatula*, also called "cat's paws", look similar to oysters, particularly *Conradostrea sculpturata*, but their hinge areas are different. Where *Conradostrea* has a resilifer (flat hinge area), *Plicatula* has hinge teeth and sockets that articulate (fit together) between the two valves. *Plicatula* is also much smaller (<2.5 cm or 1 in long) and has a distinct shape, much like the paw of a cat, which is where it receives its nickname (Figure 14).

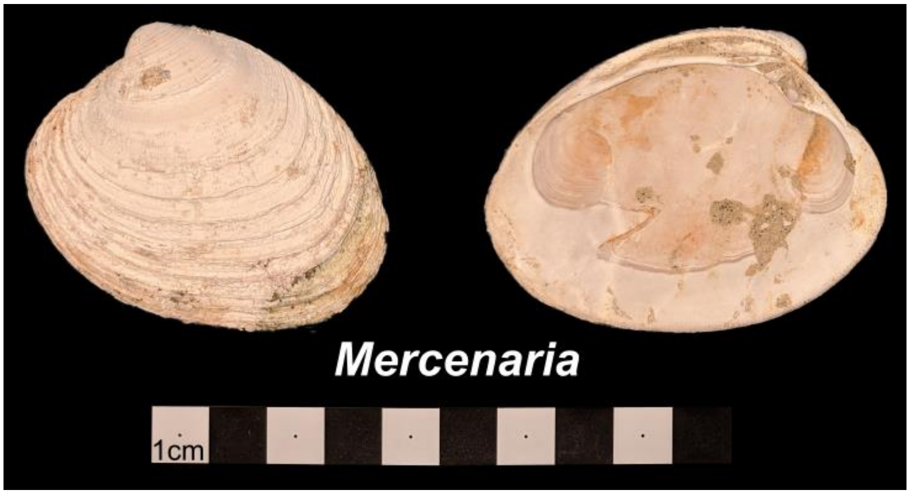

Figure 12. The genus *Mercenaria* is one of the larger fossil clams that occurs in COLO (NPS/MACKENZIE CHRISCOE).

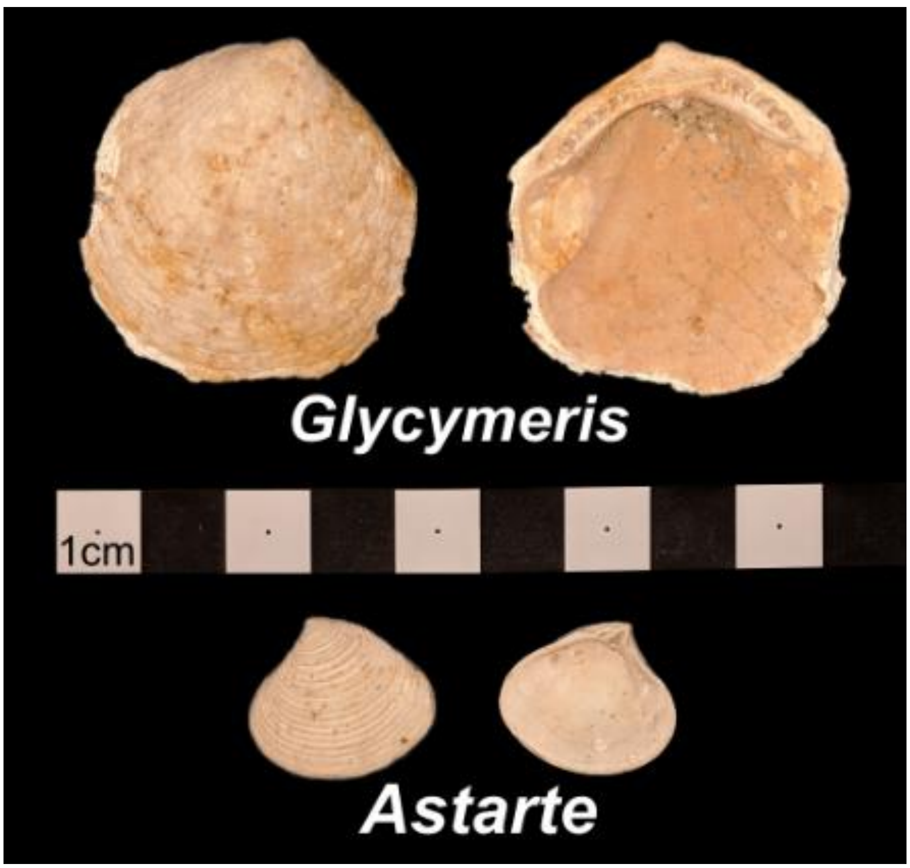

Figure 13. Two fossil clam genera that are commonly found in COLO, *Glycymeris* (top) and *Astarte* (bottom) (NPS/MACKENZIE CHRISCOE).

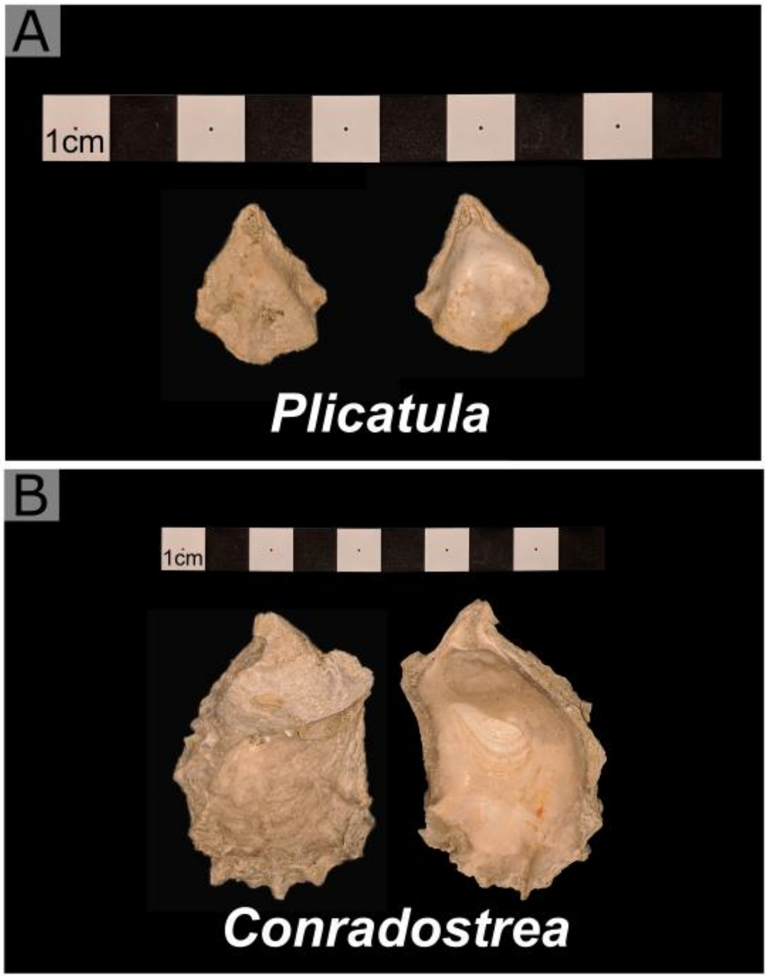

Figure 14. A comparison of bivalve genera (NPS/MACKENZIE CHRISCOE). **(A)** *Plicatula* and **(B)** *Conradostrea sculpturata* both occur in the Moore House Member of the Yorktown Formation.

Oysters, namely the genus *Conradostrea*, are also common throughout the Yorktown Formation. *Conradostrea sculpturata* is perhaps the most common species encountered within COLO, and it has a distinct hinge shape as described above (Figure 14). Other bivalves are also found in smaller numbers, including *Abra aequalis*, *Yoldia laevis*, *Chlamys decemnaria*, *Anadara*, *Cerastoderma* (rare), *Ctena*, *Macoma*, *Nucula*, *Thracia*, *Cyclocardia*, and *Parvilucina*.

Phylum Mollusca: Class Gastropoda (snails)

Gastropods are the second most common type of fossil found within COLO, particularly within the Moore House Member; see Gardner (1948) and Campbell (1993) for descriptions. *Crepidula fornicata*, *Crepidula plana*, and *Bostrycapulus aculeatus* are especially prominent, with some stratigraphic layers being composed almost entirely of these species. In some outcrops of the Moore House Member, *Crepidula fornicata* dominates nearly every layer. These species are commonly referred to as “slipper shells” because of the shape and distinctive ledge that extends across part of the inside of the shell (Figure 15). *Crepidula fornicata* is almost egg-shaped and is generally smooth on the outside; these may be found in life position (meaning they were preserved immediately after death and remain in their original position) as large mating clumps stacked on top of each other (Figure 16). *Crepidula plana* is almost completely flat and oval-shaped, whereas *Bostrycapulus aculeatus* is similar in shape to *Crepidula fornicata*, but usually smaller and with more texture on the outside; depending on the extent of weathering, this texture may be present as small bumps or pronounced spines (Figure 15). These gastropods can be mistaken for bivalve shells, especially when not examined closely.

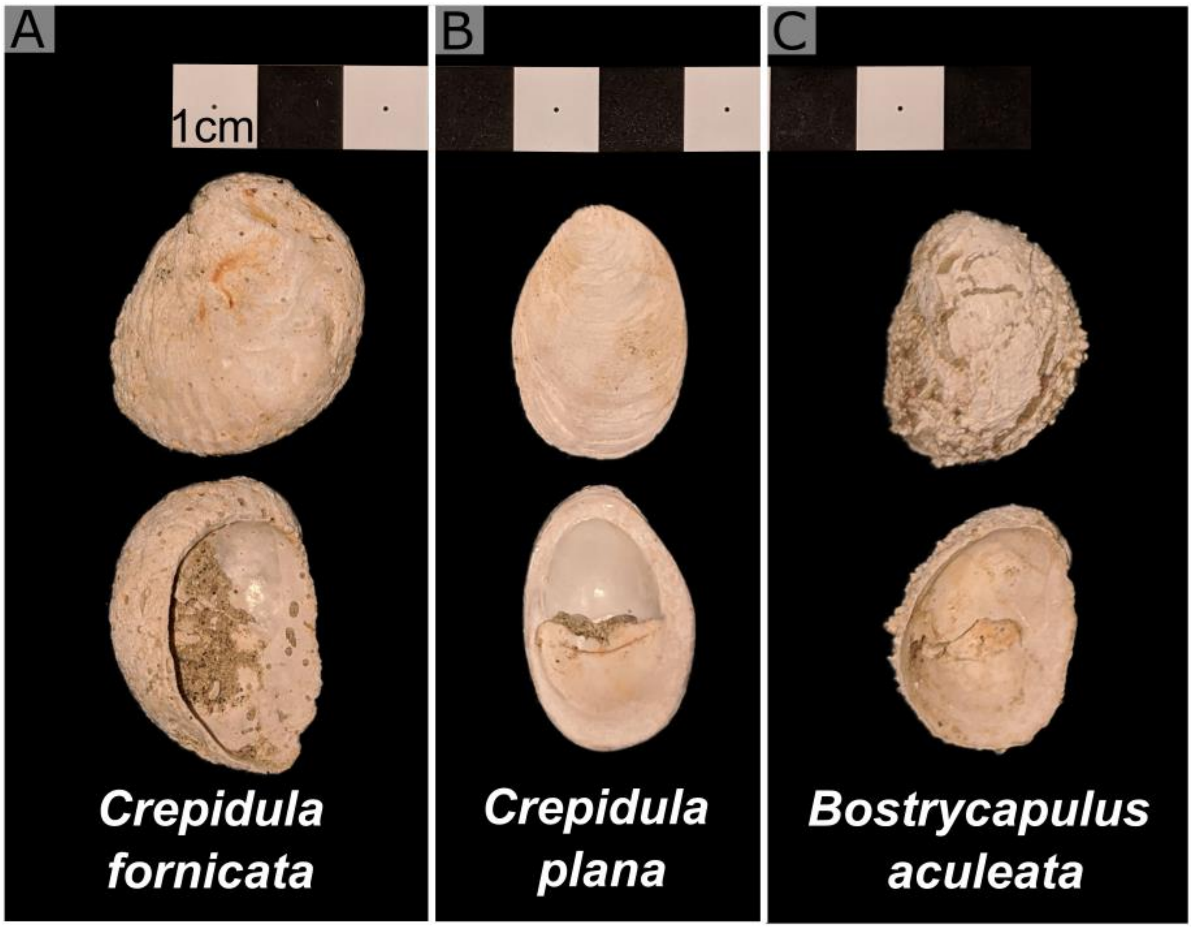

Figure 15. Fossil gastropod species from the genera *Crepidula* and *Bostrycapulus* (NPS/MACKENZIE CHRISCOE). **A.** *C. fornicata*. **B.** *C. plana*. **C.** *B. aculeatus*.

Figure 16. Clayey silt representing either the Morgarts Beach Member or the Moore House Member of the Yorktown Formation (NPS/MACKENZIE CHRISCOE). Gastropods (*Crepidula*) are visible to the left of the scale bar, some in life position in a stack. Smaller, high-spired *Turritella* are also visible.

Turritella, *Urosalpinx, Sinum* (rare), *Mitrella*, *Marginella*, *Epitonium*, *Crucibulum*, *Diodora*, *Ecphora*, *Fasciolaria*, *Tritia*, *Terebra*, and *Ptychosalpinx* are also present in smaller numbers. These represent more snails, whelks, and limpets. *Turritella* is by far the most common of these genera. *Turritella* shells are considered "high-spired", and they are elongate shells that spiral along one axis, with a small opening at the base (Figure 17). *Epitonium* and *Terebra* are similarly shaped, with subtle differences in the shape of the aperture (shell opening) (Figure 17).

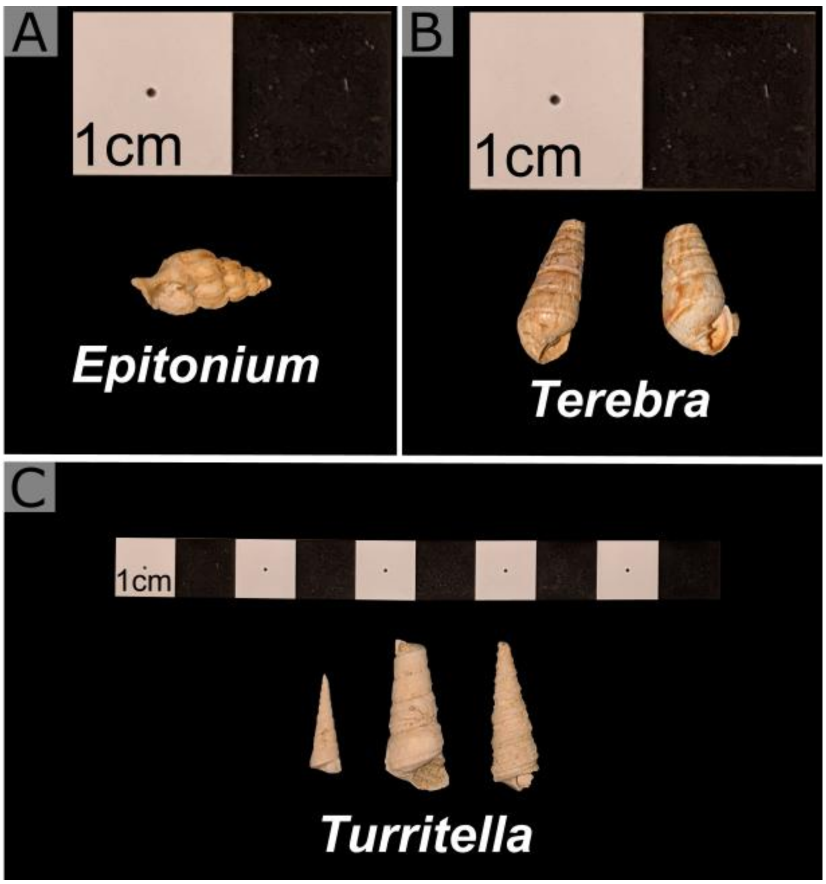

Figure 17. Three additional gastropod genera that occur at COLO sites (NPS/MACKENZIE CHRISCOE). **A.** *Epitonium*. **B.** *Terebra*. **C.** *Turritella*.

Other Mollusks and Other Invertebrates

Corals, bryozoans, scaphopods, and barnacles were all found in 2020 samples from COLO. Bryozoans and barnacles are by far the most abundant of these groups and can be found at nearly every locality in COLO.

Bryozoans (Phylum Bryozoa) occur as two colonial forms: they may either be encrusted on other organisms (epibionts), or they may exist as solitary branching shapes. Bryozoans are tiny filter-feeding organisms that form colonies together. Their colonies have a unique texture characterized by abundant sub-millimeter-sized holes, which is where the organisms would have lived (Figure 18). Knowles et al. (2009) identified multiple species of bryozoans collected from COLO, all of which were found encrusting other fossils.

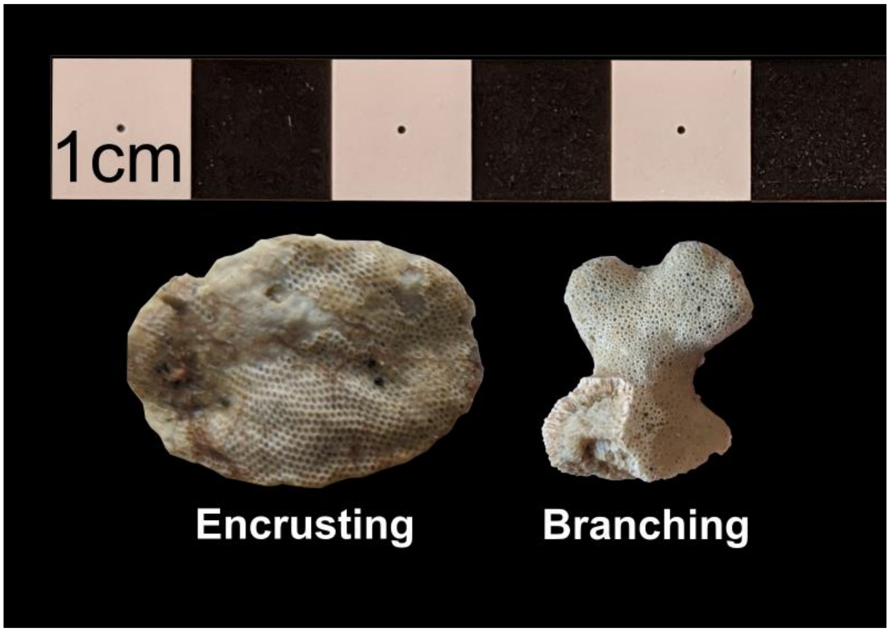

Figure 18. Examples of the different types of bryozoans sampled from COLO (NPS/MACKENZIE CHRISCOE).

Stony corals (Phylum Cnidaria, Class Anthozoa), likely from the genus *Astrangia*, are relatively rare, and tend to appear in bunches cemented to other shells (Figure 19). They may be difficult to identify; on their own, they tend to break down into smaller pieces that are easily overlooked.

Scaphopods (Phylum Mollusca, Class Scaphopoda) are represented by the genus *Dentalium*, which is a tusk-like shell with ridges running along its length (Figure 19).

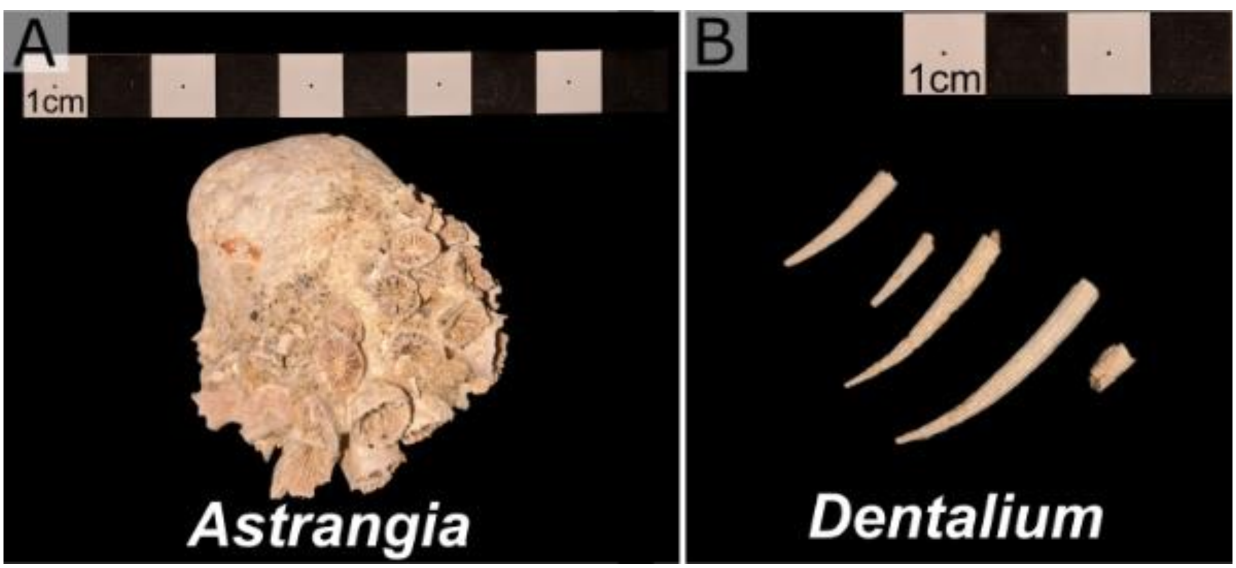

Figure 19. A. Fossil coral genus *Astrangia* encrusting a *Crepidula* shell. **B.** Scaphopod genus *Dentalium* (NPS/MACKENZIE CHRISCOE).

Tubes from annelids (segmented worms; Phylum Annelida) were reported by Johnson (1972).

Arthropods (Phylum Arthropoda) are well-represented by crustaceans (Subphylum Crustacea). Barnacles (Infraclass Cirripedia) are represented by the species *Chesaconcavus proteus*. They are similar to the modern barnacles that occur in the York River, but the fossil examples are much larger with thicker shells. Additionally, during 2020 sampling, three examples of crab claws (Class Malacostraca) were found (Figure 20). No examples of crab claws have been documented at other COLO localities; however, it is likely that similar fossils could occur elsewhere in the park. The most diverse crustaceans found at COLO are ostracodes (Class Ostracoda). These tiny animals, also known as seed shrimp, reach no more than 30 mm (1.2 in) in size. Specimens have been reported by McLean (1957) from two sites within COLO. *Clithrocytheridea virginiensis* was recorded from both of these sites, and McLean's specimens match descriptions of the same species found in the Yorktown Formation by Malkin (1953). McLean (1966) also recorded ostracodes from well borings; his "Locality H" is described as being along Colonial Parkway in Halfway Creek near Williamsburg, which would make this a COLO locality. *Clithrocytheridea diagonalis* was reported from this site, and this species would indicate the boring material comes from the "St. Marys" (Eastover) Formation rather than the Yorktown Formation (McLean 1966). Hazel (1971) and Swain (1974) also reported ostracode specimens from COLO.

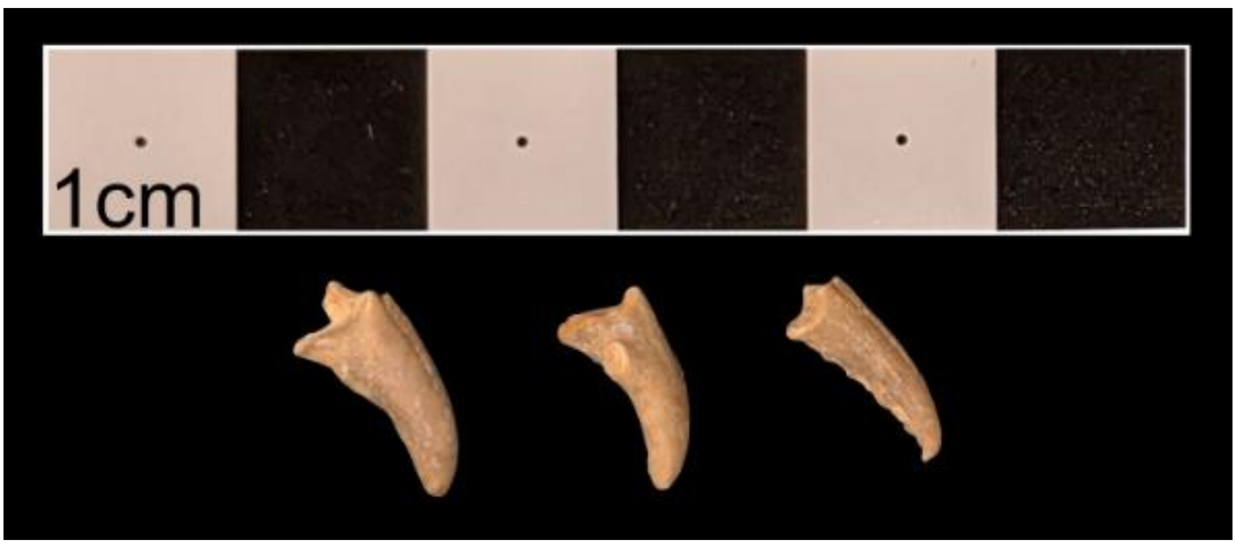

Figure 20. Three crab claws found in COLO samples (NPS/MACKENZIE CHRISCOE).

Echinoids (sea urchins; Phylum Echinodermata, Class Echinoidea) from near COLO were described by both Johnson (1972) and Kier (1972), although none of those described appear to come from within the park.

Fossil Vertebrates

Vertebrate fossils within COLO are relatively rare, often difficult to identify, and generally found as isolated material (i.e., float; singular specimens that are not in cliffs) on river beaches.

Class Chondrichthyes

Chondrichthyes is the taxonomic class containing cartilaginous fishes such as sharks, skates, and rays. The most common fossils from this group are shark teeth, which are abundant along streams in the areas surrounding COLO. Teeth are found within COLO boundaries, but they are rarely found in their original stratigraphic position. This means it is impossible to determine their exact stratigraphic position.

Class Mammalia

The only evidence of mammals from within COLO are bone fragments, most likely of whale or seal bones. These fragments are frequently unidentifiable due to the amount of weathering they have experienced. They look similar to wood but are much harder and have a vesicular texture that is diagnostic for fossilized bone (Figure 21). Mammalian bones are commonly found as float at some sites, although some bone fragments have been found in place at a site just outside of COLO boundaries. More complete fragments were also found here, including a whale vertebra. Proboscidean bones have been documented from a site near, but not within, what is now COLO property (see comments under "Unnamed Quaternary sediments" above) (Madison 1811, 1812).

Figure 21. An example of whale bone collected by rangers from within COLO (NPS).

Ichnofossils

Ichnofossils, or trace fossils, are fossils that represent the movement or life habit of an organism, but do not preserve the organism itself. Ichnofossils are common within COLO, including at Cornwallis Cave (Figure 22), which contains invertebrate burrows that appear as thin, near-vertical lines within the cliff. During 2020 sampling, a locality with multiple types of burrows preserved was found along the York River (Figure 23). These burrows likely represent the movement of marine worms and shrimp. Additionally, boreholes from predatory sponges (*Cliona*) and drillholes from gastropods can be found in various shells, although the body fossils associated with these holes are likely also found in COLO.

Figure 22. A close-up of a fossilized burrow found on the cliff face at Cornwallis Cave in the shell hash facies of the Moore House Member (NPS/MACKENZIE CHRISCOE). The burrow is likely from *Callianassa* (L. W. Ward, pers. comm., 2021), which in ichnofossil taxonomy would correspond to the name *Ophiomorpha*.

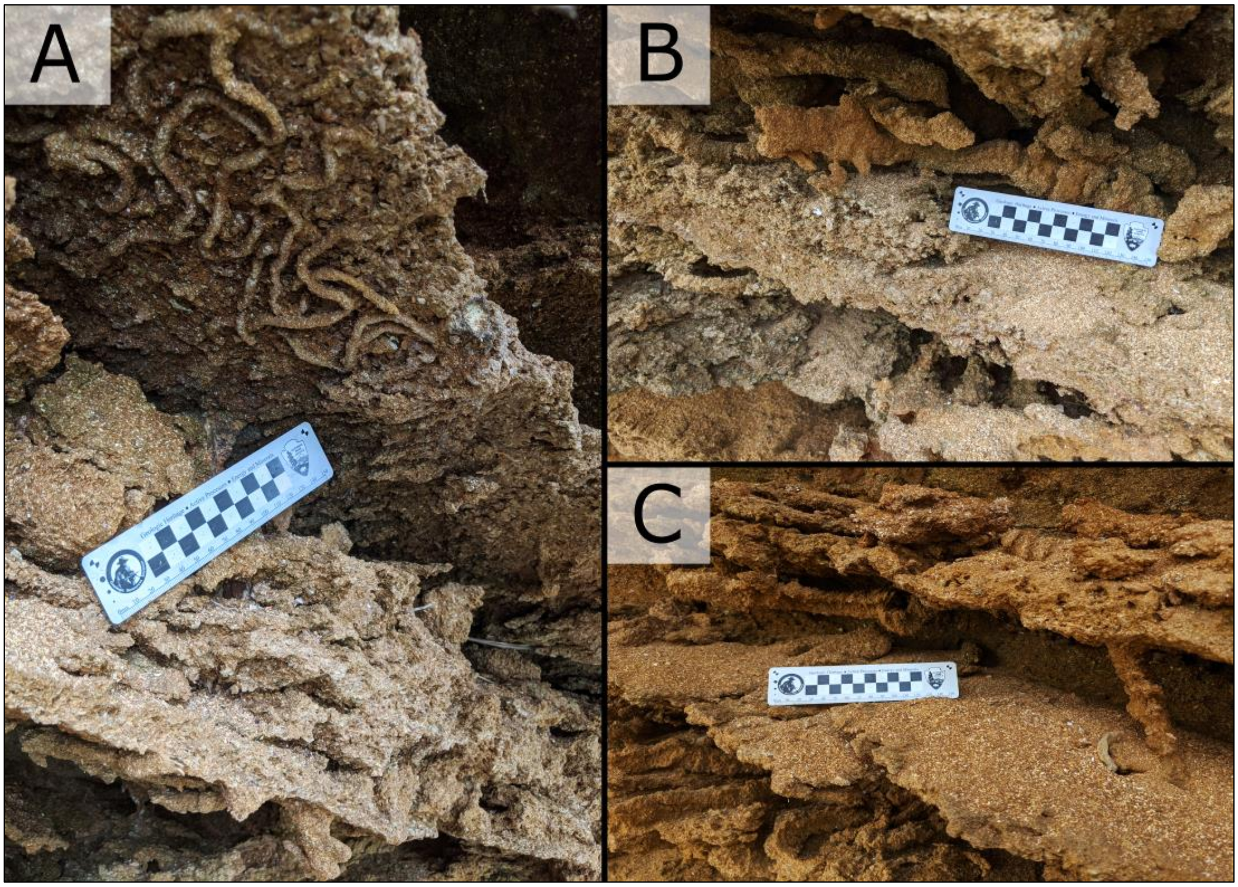

Figure 23. Burrows at a Moore House Member locality in COLO (NPS/MACKENZIE CHRISCOE). "**A**" is likely from a marine worm, whereas "**B**" and "**C**" represent the movement of a larger organism, perhaps a shrimp, likely *Callianassa* (L. W. Ward, pers. comm., 2021).

Fossil Protists

Protists are tiny fossils that usually cannot be seen without the aid of a microscope; therefore, none of these are included in 2020 sampling. However, several researchers have reported foraminifera from within COLO. McLean (1956) collected several species of foraminifera from COLO, including *Textularia aculeata*, a common species for the area. Many other species can be found throughout the Yorktown area, likely within COLO (McLean 1956). Dowsett and Wiggs (1992) also collected foraminifera from McLean's locality, including abundant quantities of *Neogloboquadrina* species and *Globigerinoides ruber*. Several species of calcareous nannofossils and dinocysts were found in USGS Jamestown borehole 55 as reported in Powars and Bruce (1999). These specimens date back to the Miocene and Eocene and are generally much older than the macroscopic fossils found within COLO.

Cultural Resource Connections

There are many ways for paleontological resources to have connections to cultural resources. Examples of paleontological resources in cultural contexts include, but are not limited to: fossils used by people for various purposes, such as petrified wood used for tools, spear points, and other artifacts, or fossil shells taken as charms or simply because they looked interesting. Associations of prehistoric humans with paleontological resources, such as kill sites of mammoths, prehistoric bison, and other extinct animals; incorporation of fossils into cultural records, such as fossils in American Indian lore, "tall tales" of mountain men, and emigrant journals; and fossils in building stones of prehistoric or historic structures. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

With its long-term history of human habitation dating back more than 16,000 years (McAvoy and McAvoy 1997; Feathers et al. 2006), the area surrounding COLO has frequently been the subject of archeological study (National Park Service 2018). There are many examples of fossils being used in cultural contexts outside the park, but examples from within COLO are scarce or their exact localities are difficult to trace (Tweet et al. 2014). Most of the archeological work within the park has focused on surveying and identifying sites, rather than excavation of artifacts. It is likely that artifacts composed of fossil materials are present in the park but have not been identified as such. To identify cultural artifacts in this area that are composed from fossil materials, it would be useful to focus on shells, shark teeth, and bones, all of which can be readily distinguished from modern shells and bones. Fossil shells from bivalves and gastropods are the most common paleontological resources within COLO, and they may well have been used in the creation of jewelry or tools. Finch (1833) recorded the use of large "fossil pectens" as cooking utensils, plates, and cups, the last of which would be left by travelers along clear streams for drinking purposes. One locality within COLO is adjacent to what was once a historic town for formerly enslaved people and their descendants until the 1930s, when the land was appropriated to establish the park (Mahoney 2013). This site features a 3.5 m (11 ft) high cliff of partially cemented sediment that was likely the site of quarrying. Shell hash of the same composition may have been used in the construction of many buildings in Yorktown, including Grace Episcopal Church (Figure 24) (Roberts 1932; Johnson et al. 1981). At this church (which has been rebuilt), it is possible to view the original foundation and part of the original wall, both of which were composed of coquina quarried from the area. Shell marl was historically used for other purposes, including the original construction of the Colonial National Historical Parkway (National Register of Historic Places 2001).

Figure 24. The preserved wall at Grace Episcopal Church. Original shell hash is visible in the center section (NPS/MACKENZIE CHRISCOE).

Fossil Localities

Localities within COLO

There are few well-exposed fossil localities that are still accessible within COLO. Many historical fossil sites have been destroyed or covered by human activities, including the addition of rip-rap and the grading and grassing of outcrops. Those localities that remain are at risk for further degradation by development, natural weathering processes, and/or invasive plant species covering the fossiliferous outcrops. COLO preserves some of the few natural cliffs in the area, such as the Moore House Type Section. Seven sites within COLO and one in a scenic easement were described during the field work for this inventory; details can be found in the sensitive version of this report. Bulk samples were collected from three of these localities. Taxonomic abundances and stratigraphic figures and diagrams for these localities are included in Appendix G.

Museum Collections and Paleontological Archives

Museum Collections and Curation

Park Collections

The museum collections at COLO are extensive and distributed across the Yorktown and Jamestown properties. These collections do contain specimens described as “fossil”, although some of it is likely derived from locations outside the park. As of January 2021, the catalog for the Yorktown collection contained 117 catalog numbers referring to objects labeled as “shell”, “stone”, “teeth”, “bone”, and “marl”. Most of the material is fragmented modern oyster shells. Some of the bone is derived from modern mammals, including pig, sheep, and cow, rather than fossils. As of January 2021, the catalog for the Jamestown collection included 165 catalog numbers with similar material to that described from the Yorktown collection. However, a few entries from Jamestown include large pieces of fossiliferous sandstone or limestone. These stones were likely used as ballast in ships arriving from England and could have originated from a number of localities in England, as well as the Caribbean. There are also multiple entries listed as “tile (flooring)” that include pieces of limestone that were used in the floors of historic structures. The origin of this material is also unknown. One piece is described as containing “mostly brachiopods”, which would be unusual in this area because brachiopods are most abundant in Paleozoic rocks. The closest brachiopod-rich Paleozoic units occur in the Valley and Ridge of Virginia (near Staunton, Virginia, 250 km or 160 miles northwest of Yorktown). Due to COVID-19 restrictions, it was not possible for current researchers to visit the collections and verify uncertain entries.

COLO also had a collection of fossils in the 1930s. In 1932, Gerard Banks, a ranger at COLO, collected specimens of approximately 109 species of bivalves, gastropods, and a few other groups. Recent shells were also included in this collection. These fossils were displayed at the Somerwell house, and according to Banks (1932), Joseph Roberts of the University of Virginia and Julia Gardner of the National Museum of Natural History both helped identify the material. Roberts reported that a museum was displaying fossils from Yorktown (Roberts 1942), but this collection was not mentioned in a later publication (Phillips and Brennan 1983). There was once a collection at Jamestown that included animal skeletons, but it was removed in the 1980s, and any fossils that may have been displayed with this collection were likely removed as well. The current whereabouts of the Banks fossil collection is unknown (Tweet et al. 2014).

Collections in Other Repositories

Because Yorktown has been a popular area for fossil shell collection since the beginnings of paleontology in North America, many repositories have at least a few fossils with locality information indicating they came from the Yorktown area, although frequently there is not enough locality information to establish whether or not a given fossil came from within what is now COLO. In addition, there must be a significant number of personal collections with fossils obtained from lands within COLO, either before or after the park was established. For these reasons, a complete accounting of fossils from COLO is not feasible. The primary external collections are discussed below, along with some smaller collections identified from the literature or collections databases.

Fossil specimens definitely collected from within COLO can be found at the following museums (see Appendix E for contact information):

- Academy of Natural Sciences of Drexel University (ANSP; formerly the Academy of Natural Sciences of Philadelphia) in Philadelphia, Pennsylvania (McGavock 1944; Moore 1962; Richards 1968)
- Cincinnati Museum Center (CMC) in Cincinnati, Ohio (including material transferred from the University of Minnesota, some originally acquired in exchange from Johns Hopkins University; J. Tweet, pers. obs. of the Minnesota material, 2017)
- Columbia University in New York, New York (Malkin 1953)
- Laboratoire de Geologie (Institut Catholique de Paris) in Paris, France (McLean 1957)
- Louisiana State University/Louisiana Museum of Natural History (LSU/LMNH) in Baton Rouge, Louisiana (Malkin 1953)
- National Museum of Natural History (USNM) in Washington, D.C., including U.S. Geological Survey material (Dall 1892, 1900, 1903; Schuchert 1905; Cushman and Cahill 1933; Malkin 1953; Swain 1974; Wilson 1983; Dowsett and Wiggs 1992; Ward 1993 [Harris's 1890 collections])
- Natural History Museum of Los Angeles County (LACM), Los Angeles, California (invertebrate localities LACMIP 2847 and 3028)
- Paleontological Research Institution (PRI) in Ithaca, New York (McLean 1956, 1957, 1966)
- Peabody Museum of Natural History, Yale University (YPM), New Haven, Connecticut (specimens including YPM IP 25568 and 32453 from Bellefield)
- Virginia Division of Geology and Mineral Resources in Charlottesville, Virginia (Tweet et al. 2014)

Based on searches of digital collections, specimens listed as collected in the "Yorktown" area, which may potentially be within COLO, can be found at the following museums: the American Museum of Natural History (AMNH) in New York City, New York; the Cleveland Museum of Natural History (CMNH) in Cleveland, Ohio; the Florida Museum of Natural History (FLMNH) in Gainesville, Florida; the Museum of Comparative Zoology at Harvard (MCZ) in Cambridge, Massachusetts (including material formerly held by the Boston Society of Natural History and Massachusetts Institute of Technology); the Natural History Museum (NHM or BMNH in older references) in London, United Kingdom; the University of California Museum of Paleontology (UCMP) in Berkeley, California; and the University of Kansas (KU) in Lawrence, Kansas.

An example of the issues inherent in confirming repositories of fossils from COLO lands is the case of George Barclay. The following is taken with minor edits from Tweet et al. (2014): An article in the Daily Press (Anonymous 1938) discussed the local collecting activities of Barclay, who collected various fossils for museums from the shores of the James and York Rivers during the mid-1930s. Barclay obtained fossils from the Eastover Formation (identified as "the St. Mary's formation" in the article) from Claremont to Scotland Wharf on the James River and the Yorktown Formation from

Queen Creek to "Wimberley's Creek" (probably a typo for Wormley Creek) on the York River. He sent specimens to a number of institutions, including the AMNH; the NHM; the University of Cincinnati; the Field Museum of Natural History in Chicago, Illinois; Fresno State College (now California State University, Fresno) in Coalinga, California; the National Museum of Mexico City (it is unclear which museum is intended); the North Carolina State Museum (the North Carolina Museum of Natural Sciences in Raleigh?); the South Dakota School of Mines and Technology in Rapid City; William & Mary in Williamsburg; the Virginia State Museum (the Virginia Museum of Natural History in Martinsville?); the Virginia Polytechnic Institute (Virginia Tech in Blacksburg); and the "Vocational and Technical high school at Grand Rapids, Michigan". The article reported that Barclay had extensive notes about his collections, but in the absence of such information, it cannot be determined if any specimens were from COLO, and where such specimens were sent. Therefore, those institutions which have not been previously mentioned are not included.

Type Specimens

At least 25 species have been named and described from specimens collected within the property that now belongs to COLO. A complete list of these species can be found in Appendix C. Many others (at least 96) are labeled with vague localities, such as "Williamsburg" and "Yorktown", which may plausibly come from within COLO. A list of these species can be found in Appendix D.

Archives

NPS Paleontology Archives

All data, references, images, maps and other information used in the development of this report are maintained in the NPS Paleontology Archives and Library. These records consist of both park-specific and servicewide information pertaining to paleontological resources documented throughout the NPS. If any resources are needed by NPS staff at COLO, or additional questions arise regarding paleontological resources, contact the NPS Senior Paleontologist & Paleontology Program Coordinator Vincent Santucci, vincent_santucci@nps.gov. Park staff are also encouraged to communicate new discoveries to the NPS Paleontology Program, not only when support is desired, but in general, so that this information can be incorporated into the archives. A description of the Archives and Library can be found in Santucci et al. (2018).

E&R Files

E&R files (from "Examination and Report on Referred Fossils") are unpublished internal USGS documents. For more than a century, USGS paleontologists identified and prepared informal reports on fossils sent to the survey by other geologists, for example to establish the relative age of a formation or to help correlate beds. The system was eventually formalized as a two-part process including a form sent by the transmitting geologist and a reply by the USGS geologist. Sometimes the fossil identifications were incorporated into publications, but in many cases this information is unpublished. These E&R files include documentation of numerous fossil localities within current NPS areas, usually predating the establishment of the NPS unit in question and frequently unpublished or previously unrecognized. Extensive access to the original files was granted to the NPS by the USGS beginning in 2014 (Santucci et al. 2014).

Photographic Archives

COLO's photographic archives contain three images of the interior of Cornwallis Cave from 1957 (Photos 2–4). Although they are not included in the archives, there are several historic photos of Cornwallis Cave, including postcards and stereoscopic photographs from the late 1800s (Appendix H). These stereoviews may have been created in celebration of the centennial of the Yorktown Surrender in 1881 (K. W. Ramsey, Delaware Geological Survey, pers. comm., 2021).

Photo 2. Interior view of Cornwallis Cave, 1957 (NPS/COLO).

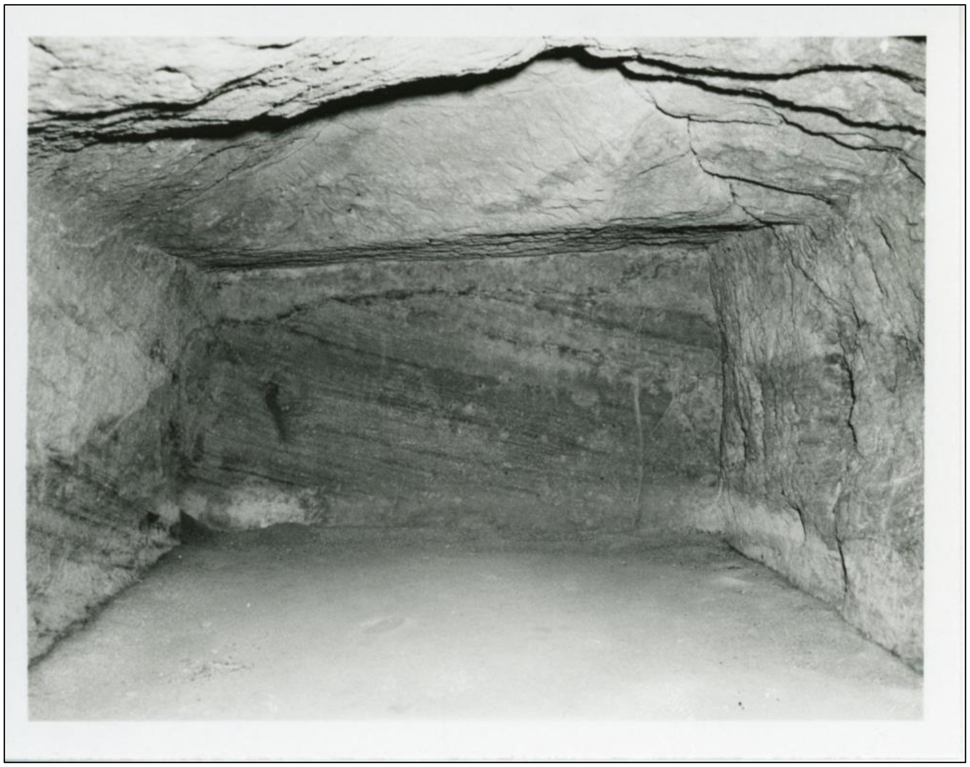

Photo 3. Interior view of Cornwallis Cave, 1957 (NPS/COLO).

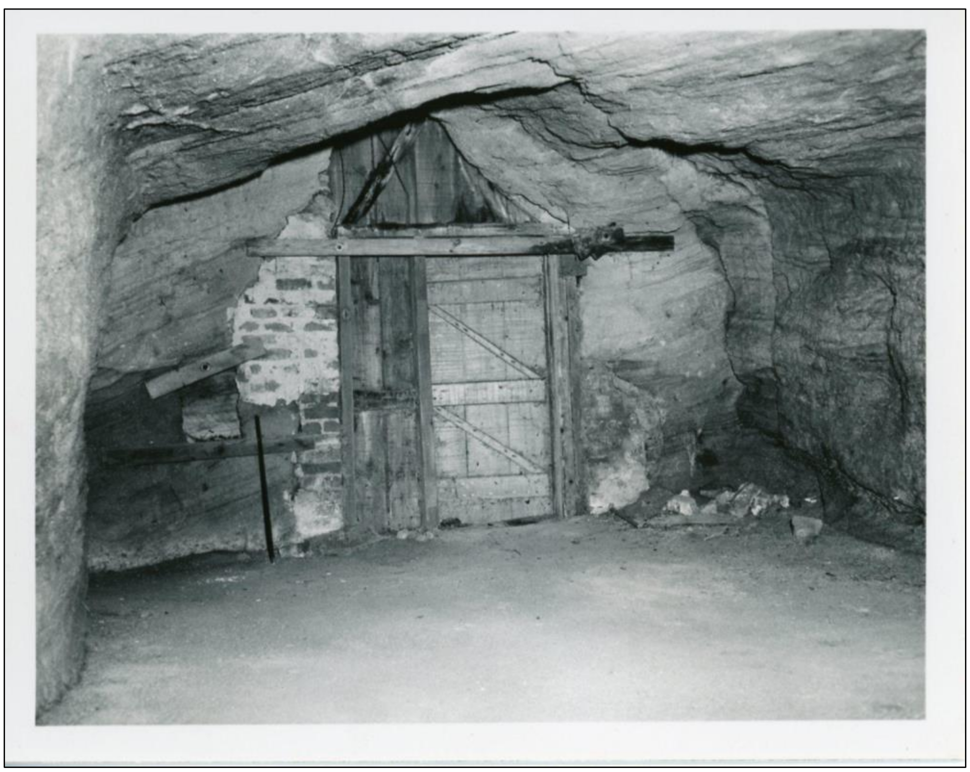

Photo 4. Interior view of Cornwallis Cave, 1957 (NPS/COLO).

Park Paleontological Research

Current and Recent Research

Beginning with 1991, 12 permits have been issued for projects with a significant paleontological or geological component within COLO. In descending chronological order, the permitted projects include the following ("principal investigator" is the person listed as such in the Research Permitting and Reporting System [https://irma.nps.gov/RPRS/]; projects may have many more investigators and associated institutions):

COLO1991ABDQ, principal investigator Carl Hobbs III of William & Mary, project "*Geological Studies of Jamestown Island*", issued for 1991; this project was continued in succeeding years under permit COLO1992ADXT (1992) and COLO1997JOHN (1997).

COLO1991ABDE, principal investigator Gerald Johnson of William & Mary, project "*Stratigraphy and Paleontology of Passamore and Kingsmill Creeks, Jamestown Island*", issued for 1991; this project was continued in succeeding years under permit COLO1992ADXF (1992).

COLO1992ADYE, principal investigator Gerald Johnson of William & Mary, project "*Geological Development of Jamestown Island*", issued for 1992; this project was continued in succeeding years under permit COLO1994AJHS (1994), COLO1996ARRN (1996), and COLO1999JOHNSON (1999).

COLO1999hydrogeo, principal investigator Michael Hughes of the U.S. Geological Survey, project "*Geohydrology of Yorktown and Environs*", issued for 2000–2002.

COLO-2007-SCI-0003, principal investigator Rick Berquist of the Virginia Division of Mineral Resources, project "*Geological Mapping of Jamestown Island and Surry Quadrangle north of the James River*", issued for 2007–2009.

COLP-2020-SCI-0003, principal investigator Rowan Lockwood of William & Mary, project "*Effects of the mid Pliocene Warm Period on fossil mollusks from the mid-Atlantic Coastal Plain (USA)*", issued for 2020–2023. This report was supported by this permit.

During summer 2020, the authors completed a survey of COLO and currently accessible fossil sites to develop this inventory and enhance overall understanding of the paleontological resources of COLO, under permit COLP-2020-SCI-0003. Researchers visited the James and York River shorelines within COLO property by boat, scouting out exposures that were accessible and not destroyed by rip-rapping or shoreline alteration. They collected extensively at six different sites and described the sedimentology, stratigraphy, and paleontology of these outcrops in detail. They collected eight bulk samples (approximately 9 kg or 20 lbs. each) of sediment and fossils for later interpretation and identification. Sorted and identified material (see Appendix G), in addition to bulk sediment samples, have been accessioned in COLO collections to greatly expand their breadth and depth. The sorted and identified material may be used as interpretive material in the future, while bulk sediment samples provide a historic archive of outcrops that may be destroyed or covered in the future. Recommendations and any other information acquired from this study has been incorporated throughout this inventory.

In summer 2021, COLO will host multiple Scientists-in-Parks (SIP) interns, one of whom will work with the park to develop more effective communication and interpretation of its fossil resources. The project will build on the information and specimens collected for this inventory.

Paleontological Research Permits

See the National Park Service Natural Resource Management Reference Manual DO-77 section on Paleontological Resource Management, subsection on Scientific Research and Collection (https://irma.nps.gov/DataStore/Reference/Profile/572379). NPS Management Policies 2006, section 4.8.2.1 on Paleontological Resources, states that

> *The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit.*

Any collection of paleontological resources from an NPS area must be made under an approved research and collecting permit. The NPS maintains an online Research Permit and Reporting System (RPRS) database for researchers to submit applications for research in NPS areas. Applications are reviewed at the park level and either approved or rejected. Current and past paleontological research and collecting permits and the associated Investigator's Annual Reports (IARs) are available on the RPRS website (https://irma.nps.gov/RPRS/). Additional information on NPS law and policy can be found in Appendix F.

Interpretation

COLO personnel are encouraged to interpret the park's rich paleontological resources and provide additional opportunities or programs for visitors to learn about fossils on National Fossil Day. The National Park Service coordinates the National Fossil Day partnership (second Wednesday in October) (https://www.nps.gov/subjects/fossilday/index.htm) and hosts fossil-focused events across the country, in conjunction with Earth Science Week. The NPS Geologic Resources Division can assist parks with planning for National Fossil Day activities and provide Junior Paleontologist Program supplies including activity booklets, badges, posters and other fossil-related educational resources (https://www.nps.gov/subjects/fossils/junior-paleontologist.htm).

Current Long Range Interpretive Plan

As of 2020, there is no finalized long range interpretive plan for COLO. A plan is currently in progress, but it does not address the park's fossil resources specifically. Currently, COLO does post on social media, with a couple of posts focusing specifically on fossils, and there are plans to try to make the park's social media presence more robust. There is interest in creating more interpretive media and building an interpretive collection for the park in the future. Additionally, there is some training with law enforcement regarding illegal fossil collecting, but fossils are not addressed in seasonal training, which could be beneficial in the future (see section titled "Paleontological Resource Management Recommendations" below).

Recommended Interpretive Themes

I. General Paleontological Information

All of the following interpretation topics include a section instructing visitors how to be paleontologically aware while in the park. The ranger will provide the visitor with advice on why fossils are important, how paleontologists look for fossils, what to do if fossils are found, and reminders to be aware that fossils exist and should be respected within park boundaries.

- Fossils are non-renewable resources that possess scientific and educational information and provide insight into what Earth looked like thousands and even millions of years ago.
- When paleontologists survey for paleontological resources, one of the most important tools is a geologic map. Paleontological resources are more common in certain geologic units, so knowing where those units are exposed is important for a successful search. Other tools that a paleontologist takes into the field include a field notebook for recording data and observations, small picks and brushes, consolidants to stabilize fossils, GPS, camera, hand lens, topographic maps, and appropriate First Aid and safety equipment. It might be helpful to provide examples of these items for visitors when giving an interpretive talk.
- If fossils are found in the park by a visitor, the visitor should photograph them and notify a ranger of where the resources were found. Most importantly, they should leave the fossils where they found them. It is extremely important for scientific and resource management purposes for locational information to be preserved. Visitors should be informed that park fossils are protected by law.

II. Fossils of COLO

- A program could be developed to educate the public on what types of fossils are present in COLO and what they tell scientists about Earth's dynamic history. The goal of this program is to increase visitors' understanding of local geology and paleontology. Therefore, information regarding fossils from the vicinity of COLO can be included.

III. Caves and Fossil Resources

- Resources for this Interpretation theme are listed in the references section.

IV. Further Interpretation Themes

National Fossil Day is celebrated annually on Wednesday of the second full week in October, which is National Earth Science Week. For more information on this event visit: https://www.nps.gov/subjects/fossilday/index.htm. Conducting one or more paleontology-focused activities on this day would be a perfect opportunity to not only increase public awareness about paleontological resources in COLO, but also connect with other parks and museums who are also participating in this national event. The NPS Geologic Resources Division can assist with planning for National Fossil Day activities and provide supplies for the Junior Paleontologist Program including activity booklets, badges, posters and other fossil-related educational resources (https://www.nps.gov/subjects/fossils/junior-paleontologist.htm).

Paleontological Resource Management and Protection

National Park Service Law and Policy

Paleontological resources are non-renewable remains of past life preserved in a geologic context. At present, there are 423 official units of the National Park System, plus national rivers, national trails, and affiliated units that are not included in the official tally. Of these, 283 are known to have some form of paleontological resources, and paleontological resources are mentioned in the enabling legislation of 18 units. Fossils possess scientific and educational value and are of great interest to the public; therefore, it is exceedingly important that appropriate management attention be placed on protecting, monitoring, collecting, and curating these paleontological specimens on federal lands. In 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law as part of the Omnibus Public Land Management Act of 2009. The new paleontology-focused legislation includes provisions related to inventory, monitoring, public education, research and collecting permits, curation, and criminal/civil prosecution associated with fossils from designated DOI lands. More information on laws, policies, and authorities governing NPS management of paleontological resources is detailed in Appendix F. Paleontological resource protection training is available for NPS staff through the NPS Geologic Resources Division (GRD). GRD is also available to provide support in investigations of paleontological resource theft or vandalism.

As of the date of this publication, an interagency coordination team that includes representatives from the Bureau of Land Management (BLM), Bureau of Reclamation (BOR), National Park Service (NPS) and U.S. Fish & Wildlife Service (FWS) is in the process of developing Department of Interior (DOI) final regulations for PRPA. Draft DOI regulations were published in the Federal Register in December 2016 and were available for 60 days to allow for public comment. The interagency team has reviewed public comments provided for the draft regulation and has drafted the final regulation. The final regulation has completed surnaming by the DOI Solicitor's Office and each of the four bureau directors. The final regulation has been forwarded for final review by DOI Assistant Secretaries. For more information regarding this act, visit https://www.nps.gov/subjects/fossils/fossil-protection.htm.

2006 National Park Service Management Policies (section 4.8.2.1) state:

> *… Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).*
>
> *Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of*

a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.

The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

Fossils have scientific, aesthetic, cultural, educational, and tourism value, and impacts to any of these values impairs their usefulness. Effective paleontological resource management protects fossil resources by implementing strategies that mitigate, reduce, or eliminate loss of fossilized materials and their relevant data. Because fossils are representatives of adaptation, evolution, and diversity of life through deep time, they have intrinsic scientific values beyond just the physical objects themselves. Their geological and geospatial contexts provide additional critical data concerning paleoenvironmental, paleogeographic, paleoecological, and a number of other conditions that together allow for a more complete interpretation of the physical and biological history of the Earth. Therefore, paleontological resource management must act to protect not only the fossils themselves, but to collect and maintain other contextual data as well.

In general, losses of paleontological resources result from naturally occurring physical processes, by direct or indirect human activities, or by a combination of both. These processes or activities influence the stability and condition of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). The greatest loss of associated contextual data occurs when fossils are removed from their original geological context without appropriate documentation. Thus, when a fossil weathers and erodes from its surrounding sediments and geologic context, it begins to lose significant ancillary data until, at some point, it becomes more a scientific curiosity than a useful piece of scientific data. A piece of loose fossil "float" can still be of scientific value. However, when a fossil has been completely removed from its original context, such as an unlabeled personal souvenir or a specimen with no provenance information in a collection, it is of very limited scientific utility. As recently as 2020, park visitors illegally collected fragmented cetacean bones from COLO property, although limited information about their recovery location was documented, and it would be impossible to tell which stratigraphic layer contained these fossils when they were found (D. Geyer, COLO, pers. comm., 2020). Similarly, inadvertent exhumation of fossils during roadway construction or a building excavation may result in the loss or impairment of the scientific and educational values associated with those fossils. It is not necessary to list here all of the natural and anthropogenic factors that can lead to the loss of paleontological resources; rather it is sufficient to acknowledge that anything that disturbs native sediment or original bedrock has potential to result in the loss of the paleontological resources that occur there, or the loss of associated paleontological resource data.

Cave localities are in a distinct class for management due to the close connection with archeological resources and unique issues affecting cave resources. See Santucci et al. (2001) for additional discussion of paleontological resources in cave settings.

Management strategies to address any of these conditions and factors could also incorporate the assistance of qualified specialists to collect and document resources rather than relying solely on staff to accomplish such a large task at COLO. Active recruitment of paleontological research scientists should also be used as a management strategy.

Baseline Paleontology Resource Inventories

A baseline inventory of paleontological resources is critical for implementing effective management strategies, as it provides information for decision-making. This inventory report has compiled information on previous paleontological research done in and near COLO, taxonomic groups that have been reported within COLO boundaries, and localities that were previously reported. This report can serve as a baseline source of information for future research, inventory reports, monitoring, and paleontological decisions. An updated Northeast Coast and Barrier Network (NCBN) Paleontological Resource Inventory and Monitoring summary report was completed by Tweet et al. (2014) and the references cited within were important baseline paleontological resource data sources for this COLO-specific report.

Paleontological Resource Monitoring

Paleontological resource monitoring is a significant part of paleontological resource management, and one which usually requires little to implement beyond time and equipment already on hand, such as cameras and GPS units. Monitoring enables the evaluation of the condition and stability of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). A monitoring program revolves around periodic site visits to assess conditions compared to a baseline for that site, with the periodicity depending on factors such as site productivity, accessibility, and significance of management issues. For example, a highly productive site which is strongly affected by erosion or unauthorized collection, and which can be easily visited by park staff, would be scheduled for more frequent visits than a less productive or less threatened site. Within COLO there are sites that have been mentioned in the fossil collecting literature (e.g., Burns 1991) or in online fossil collecting communities, and are therefore of greater priority for monitoring.

A monitoring program is generally implemented after an inventory has been prepared for a park and sites of concern have been identified, with additional sites added as necessary. Because each park is different, with different geology and paleontology among other factors, ideally each park which has in situ fossils or significant accumulations of reworked fossils would have its own monitoring protocol to define its monitoring program. Data accumulated via monitoring are used to inform further management decisions, such as the following questions: Is the site suitable for interpretation and education? Does the site require stabilization from the elements? Is collection warranted? Is there a need for some form of law enforcement presence?

Collection is recommended to be reserved for fossils possessing exceptional value (e.g., rare or high scientific significance) or at immediate risk of major degradation or destruction by human activity and natural processes. Therefore, paleontological resource monitoring is a more feasible potential management tool. The first step in establishing a monitoring program is identification of localities to be monitored, as discussed previously. Locality condition forms are then used to evaluate factors that could cause loss of paleontological resources, with various conditions at each locality rated as good, fair, or poor. Risks and conditions are categorized as Disturbance, Fragility, Abundance, and Site Access. "Disturbance" evaluates conditions that promote accelerated erosion or mass wasting resulting from human activities. "Fragility" evaluates natural conditions that may influence the degree to which fossil transportation is occurring. Sites with elevated fragility exhibit inherently soft, rapidly eroding sediment or mass wasting on steep hillsides. A bedrock outcrop that is strongly lithified has low fragility. "Abundance" judges both the natural condition and number of specimens preserved in the deposits as well as the risk of being easily recognized as a fossil-rich area which could lead to the possibility of unpermitted collecting. "Site Access" assesses the risk of a locality being visited by large numbers of visitors or the potential for easy removal of large quantities of fossils or fossil-bearing sediments. A locality with high access would be in close proximity to public use areas or other access (along trails, at roadcuts, at beach or river access points, and so on).

Each of the factors noted above may be mitigated by management actions. Localities exhibiting a significant degree of disturbance may require either active intervention to slow accelerated erosion, periodic collection and documentation of fossil materials, or both. Localities developed on sediments of high fragility naturally erode at a relatively rapid rate and would require frequent visits to document and/or collect exposed fossils in order to prevent or reduce losses. Localities with abundant or rare fossils, or high rates of erosion, may be considered for periodic monitoring in order to assess the stability and condition of the locality and resources, in regard to both natural processes and human-related activities. Localities that are easily accessible by road or trail would benefit from the same management strategies as those with abundant fossils and by occasional visits by park staff, documentation of in situ specimens, and/or frequent law enforcement patrols. Further information on paleontological resource monitoring can be found in Santucci and Koch (2003) and Santucci et al. (2009).

Foundation Documents and Resource Stewardship Strategies

Foundation documents and Resource Stewardship Strategies are two types of park planning documents that may contain and reference paleontological resource information. A foundation document is intended to provide basic guidance about a park for planning and management. It briefly describes a given park and its purpose, significance, fundamental resources and values, other important resources and values, and interpretive themes. Mandates and commitments are also identified, and the state of planning is assessed. Foundation documents may include paleontological information, and are also useful as a preliminary assessment of what park staff know about their paleontological resources, the importance they place on these resources, and the present state of these non-renewable resources. A foundation document for COLO has been published (National Park Service 2018).

A Resource Stewardship Strategy (RSS) is a strategic plan intended to help park managers achieve and maintain desired resource conditions over time. It offers specific information on the current state of resources and planning, management priorities, and management goals over various time frames. An RSS for COLO has not yet been published.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the age and lowercase letters indicating the formation's name. The American Geosciences Institute website (https://www.americangeosciences.org/environment/publications/mapping) provides more information about geologic maps and their uses. The NPS Geologic Resources Inventory (GRI) has been digitizing existing maps of NPS units and making them available to parks for resource management.

Geologic maps are one of the foundational elements of a paleontological resource management program. Knowing which sedimentary rocks and deposits underlie a park and where they are exposed are essential for understanding the distribution of known or potential paleontological resources. The ideal scale for resource management in the 48 contiguous states is 1:24,000 (maps for areas in Alaska tend to be coarser). Whenever possible, page-sized geologic maps derived from GRI files are included in paleontological resource inventory reports for reference, but park staff are encouraged to download GRI source files from IRMA. The source files can be explored in much greater detail and incorporated into the park GIS database. Links to the maps digitized by the GRI for COLO can be found in IRMA at https://irma.nps.gov/DataStore/Reference/Profile/2175563. In addition to a digital GIS geologic map, the GRI program also produces a park-specific report discussing the geologic setting, distinctive geologic features and processes within the park, highlighting geologic issues facing resource managers, and describing the geologic history leading to the present-day landscape of the park. A GRI report for COLO has been published (Thornberry-Ehrlich 2016) and is available at https://irma.nps.gov/DataStore/Reference/Profile/2230203.

Paleontological Resource Potential Maps

A paleontological resource potential map is included in this report (Figure 25). The map shows the distribution of geologic units within a park (in this case COLO) that are known to have yielded fossils within the park (green on Figure 25), have not yielded fossils within the park but are fossiliferous elsewhere (yellow), or have not yielded fossils (red). This map gives a quick indication of areas where fossils may be discovered, which in turn can provide suggestions for areas to survey or monitor, or areas where the discovery of fossils may be of concern during work that disturbs the ground (road work, building construction, etc.).

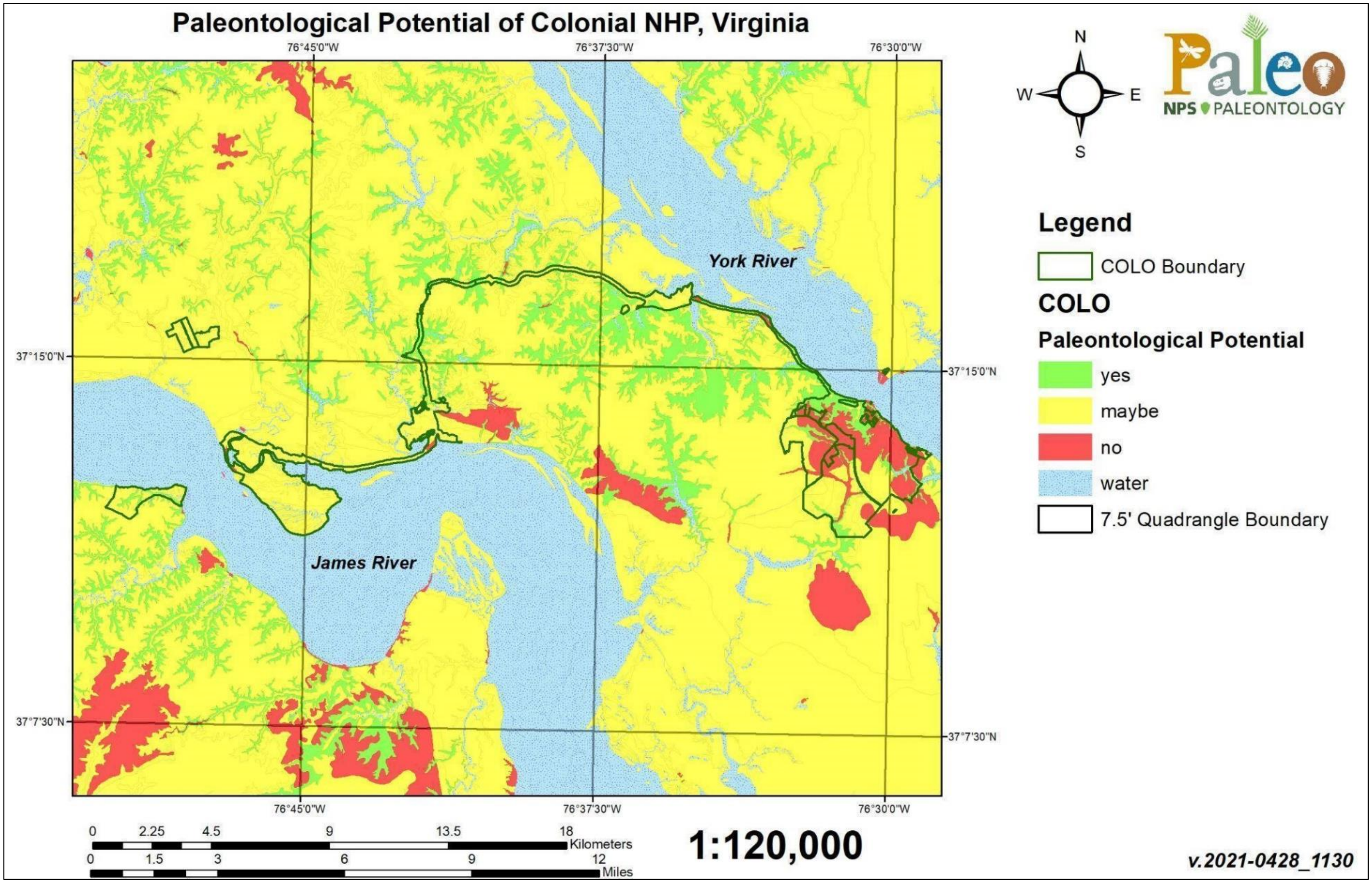

Figure 25. Map indicating paleontological potential of geologic map units, derived from Berquist (2015), digitized by the NPS GRI. Green areas indicate where fossils are definitely found, yellow indicates the potential for fossils, and red indicates where fossils are least likely to be found.

Paleontological Resource Management Recommendations

The paleontological resource inventory at COLO has documented the park's rich paleontological resources. This report captures the scope, significance, and distribution of fossils at COLO as well as provides recommendations to support the management and protection of the park's non-renewable paleontological resources.

- COLO staff should be encouraged to observe exposed rocks and sedimentary deposits for fossil material while conducting their usual duties. To promote this, staff should receive guidance regarding how to recognize common local fossils. When opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, staff should take advantage of them, if funding and time permit.
- COLO staff should photo-document and monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding rock) should be documented, but left in place unless they are subject to imminent degradation or theft. A Geologic Resource Monitoring Manual published by the Geological Society of America and NPS Geologic Resources Division (GRD) includes a chapter on paleontological resource monitoring (Santucci et al. 2009). Santucci and Koch (2003) also present information on paleontological resource monitoring.
- Fossil theft is one of the greatest threats to the preservation of paleontological resources and any methods to minimize these activities should be utilized by staff. Any occurrence of paleontological resource theft or vandalism should be investigated by a law enforcement ranger. Law enforcement officials as well as seasonal employees should be educated on what common fossil material looks like (see for example the plates in Appendix B) and where it is commonly found. When possible, incidents should be fully documented and the information submitted for inclusion in the annual law enforcement statistics. Online fossil collecting forums should be checked occasionally for discussions of collecting in COLO.
- Future archeological digs should target cultural items and note whether fossil material was found. Special attention should be given to bone or shell material, which could be either modern or fossil; these should be differentiated.
- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist or a cultural resource specialist. Any fossil which has a cultural context may be culturally sensitive as well (e.g., subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.
- A future survey of COLO's museum archives and collections for fossil material would be useful. Some fossil specimens may have been overlooked or not labeled as "fossil" in the archives. This survey could not be conducted in 2020 due to the volume of the museum collections and COVID-19 restrictions preventing in-person site visitation.

- The park may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Scientists in Parks Program is an established program for recruitment of geology and paleontology interns.
- Cornwallis Cave is an important site both historically and geologically, and measures should be taken to protect it. The English ivy (an invasive species) should be trimmed from the face of the outcrop periodically, and the inside of the cave should be monitored for differences in humidity, which could accelerate the weathering inside (C. M. Bailey, pers. comm., 2020). Historic photos of the cave's interior and exterior, such as included here in Photos 2–4 and Appendix H, can be used to assess changes over time.
- Where possible, it is recommended that the installation of riprap be avoided, as it restricts access to outcrops, starves the river bottom and beach habitats of sand, and may destroy fossil resources in the process.
- Contact the NPS Paleontology Program for technical assistance with paleontological resource management issues.

If fossil specimens are found by COLO staff, it is recommended they follow the steps outlined below to ensure proper paleontological resource management.

- Photo-document the specimen without moving it from its location (unless it is loose and in immediate danger of being lost or destroyed). Include a common item, such as a coin, pen, or pencil, for scale if a ruler or scale bar is not available.
- If a GPS unit is available, record the location of the specimen. If GPS is not available, record the general location within COLO and height within the outcrop, if applicable. If possible, revisit the site when a GPS unit is available. Most smartphones also have the ability to record coordinates; if no GPS unit is available, attempt to record the coordinates with a phone.
- Write down associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location in COLO, sketch of the fossil, position within the outcrop or if it is loose on the ground, any associated fossils, and any other additional information.
- Do not remove the fossil unless it is loose in an area of heavy traffic, such as a public trail, and is at risk of being taken or destroyed. If the fossil is removed, be sure to wrap it in soft material, such as tissue paper, and place it in a labeled plastic bag with associated notes.

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Appendix A: Paleontological Taxa

The following table (Appendix A-Table 1) documents the fossil species found at COLO in stratigraphic context as reported in the literature. The rows are organized systematically, placing taxa of the same broad groups together, with bolded summary rows as necessary. The columns are organized by formation, which are presented in ascending order (oldest to youngest) left to right. The columns also include the taxonomic group (first column) and references (last column; included in "Literature Cited" above). For the stratigraphic columns, the Eastover Formation, Yorktown Formation (undivided), and the four members of the Yorktown Formation have been included. For space, the member names are shortened to "YSM Mbr." (Sunken Meadow Member), "YR Mbr." (Rushmere Member), "YMB Mbr." (Morgarts Beach Member), and "YMH Mbr." (Moore House Member).

If a taxon has been reported from a certain geologic unit within COLO, the cell is marked "Y". It is possible that some "Y" records are erroneous, due to the complex distribution of NPS and private land in parts of Yorktown, but it is very likely that any such taxa erroneously marked as present can be found in COLO. A null record is marked "–". A record only reported from generalized "Yorktown" is marked "?". Taxa marked with an asterisk (*) are those that may have been mistakenly identified by the author, because they are not otherwise found in the reported stratigraphic interval. The exact stratigraphic position of a few records is uncertain, and they are marked with "U". Finally, "AT" designates foraminifera reported in Anderegg (1930; taxa from this thesis reprinted in McLean 1956). They have been designated separately because the reference has not been seen firsthand and the taxa reported by Anderegg have little taxonomic overlap with foraminifera reported by others, indicating there may be some differences in how species were identified.

With taxonomic descriptions going back to the 1820s, inevitably many species have complex histories of generic assignments, species and genus synonymization, and so on. Listing every record exactly as presented by each author would produce many redundancies due to different authors' taxonomic interpretations, as well as usage changes over time. We have preferred to use recent synonymies and species assignments (although two recent summaries, Ward [1992] and Campbell [1993], have some significant differences), and attempted to catch every possible redundancy, but some have probably been missed. Taxonomic notes are included following the table to allow the reader to trace the various usages and "translate" between publications. However, it is beyond the scope of this document to produce definitive genus- and species-level assignments; rather, we hope that consistent usage, documentation of sources, and taxonomic notes will allow future readers to know what taxa are being identified regardless of changes that may occur in the future.

References used to create the table were restricted to essentially 1890 and after. Before this there is too little locality information to reliably place specimens as anything but general Yorktown, and taxonomy is increasingly archaic going back in time, making it more difficult to correlate taxonomic reports to the names used here. Dall and Harris (1892) was omitted because many of the taxa were presented as genera only, making it more difficult to determine how their observations relate to later classifications.

Appendix A-Table 1. Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Invertebrates	**Invertebrates overall**	**Y**	**Y**	**Y**	**Y**	**–**	**Y**	**–**
Scleractinia	*Astrangia lineata*	–	Y	–	–	–	–	Roberts 1932; Johnson 1972
	Septastrea marylandica	–	?	–	–	–	–	Roberts 1932
Bryozoa	*Acanthodesia savartii*	–	Y	–	–	–	Y	Knowles et al. 2009
	Hippaliosina rostrigera	–	Y	–	–	–	Y	Knowles et al. 2009
	Hippoporina sp.	–	Y	–	–	–	Y	Knowles et al. 2009
	Microporella sp.	–	Y	–	–	–	Y	Knowles et al. 2009
	Puellina capronensis	–	Y	–	–	–	Y	Knowles et al. 2009
	Reptadeonella collinsae	–	Y	–	–	–	Y	Knowles et al. 2009
	Tretocycloecia sp.	–	Y	–	–	–	–	Burns 1991
	Cheilostomata indet.	–	Y	–	–	–	–	Johnson 1972
	Bryozoa indet.	–	Y	–	–	–	Y	Ward and Blackwelder 1980; Santucci et al. 2001
Brachiopoda	*Discinisca lugubris*	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
Mollusca	**Mollusca overall**	**Y**	**Y**	**Y**	**Y**	**–**	**Y**	**–**
	Mollusca indet.	–	Y	–	–	–	Y	Malkin 1953; Ward and Blackwelder 1980; Santucci et al. 2001

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia	**Bivalvia overall**	**Y**	**Y**	**Y**	**Y**	**–**	**Y**	**–**
	Abra subreflexa	–	Y	–	–	–	–	Clark and Miller 1912; Mansfield 1943
	Aligena striata	–	Y	–	–	–	Y	Ward 1993
	Anadara lienosa	–	U	–	U	–	–	Clark and Miller 1912; Ward 1993
	Anadara staminea	–	?	–	–	–	–	Clark and Miller 1912
	Anadara sp.	–	Y	–	–	–	–	Burns 1991
	Anomia aculeata	–	?	–	–	–	–	Clark and Miller 1912
	Anomia simplex	–	?	–	–	–	–	Clark and Miller 1912
	*Arca idonea**	–	Y	–	–	–	–	Clark and Miller 1912
	*Argopecten gibbus**	–	Y	–	–	–	–	McLean 1956
	Astarte castrana?	–	Y	–	–	–	–	McLean 1956
	Astarte coheni	–	Y	–	–	–	Y	Ward 1993
	Astarte concentrica	–	Y	–	U	–	Y	Mansfield 1943; McLean 1956; Ward 1993
	Astarte concentrica bella	–	?	–	–	–	–	Clark and Miller 1912
	Astarte limulata	–	?	–	–	–	–	Clark and Miller 1912
	Astarte mundorffi	–	U	–	–	–	–	McLean 1957

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	*Astarte perplana*	–	U	–	–	–	–	McLean 1956
	Astarte rappahannockensis	U	–	–	–	–	–	Ward 1993
	Astarte spp.	–	Y	–	–	–	–	McLean 1956
	Astarte symmetrica	–	Y	–	–	–	–	Mansfield 1943
	Astarte undulata	–	Y	–	U	–	–	Mansfield 1943; McLean 1957; Ward 1993
	Astarte undulata vaginulata	–	Y	–	–	–	–	Mansfield 1943
	Bornia triangula (and/or *B. rota*)	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993
	Brachidontes sp.	–	Y	–	–	–	–	Mansfield 1943
	Carditamera arata	–	Y	–	U	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993
	Carolinapecten eboreus	–	Y	–	–	–	–	Clark and Miller 1912; Johnson 1972
	Carolinapecten eboreus yorkensis	–	Y	–	–	–	Y	Mansfield 1943; Ward 1993
	Cerastoderma sp.	–	Y	–	–	–	–	Johnson 1972

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	*Chama congregata*	–	Y	–	U	–	Y	Clark and Miller 1912; McLean 1956; Ward 1993
	Chesapecten jeffersonius	–	Y	U	–	–	–	Clark and Miller 1912; Mansfield 1943; McLean 1956; Ward and Blackwelder 1975; Ward 1993
	Chesapecten madisonius	–	Y	–	U	–	Y	Clark and Miller 1912; Mansfield 1943; McLean 1956, 1957; Ward and Blackwelder 1975; Ward 1993
	Chesapecten septenarius	–	?	–	–	–	–	Ward and Blackwelder 1975
	Chione grus	–	Y	–	–	–	–	Mansfield 1943
	Chione latilirata	–	?	–	–	–	–	Clark and Miller 1912
	Chlamys decemnaria	–	Y	–	–	–	–	Clark and Miller 1912; Mansfield 1943
	Cochlodesma antiqua	–	Y	–	–	–	–	Mansfield 1943
	Conradostrea sculpturata	–	Y	–	U	–	Y	Clark and Miller 1912; McLean 1956, 1957; Ward 1993
	Cooperella parilis	–	Y	–	–	–	–	Dall 1900; Clark and Miller 1912; Mansfield 1943

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	*Corbula cuneata*	–	Y	–	–	–	–	McLean 1956
	Corbula inaequalis	–	Y	–	–	–	Y	Clark and Miller 1912; McLean 1956; Ward 1993
	Corbula retusa	–	Y	–	–	–	–	Mansfield 1943; McLean 1956
	Costaglycymeris subovata	–	Y	U	–	–	Y	Clark and Miller 1912; Mansfield 1943; McLean 1956; Ward 1993
	Crassatellites undulatus	–	Y	–	–	–	–	Clark and Miller 1912; McLean 1957
	Crassatellites sp.	–	Y	–	–	–	–	McLean 1956
	Crassinella lunulata	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993
	Crassinella lunulata harrisi	–	Y	–	–	–	–	Mansfield 1943
	Crassostrea cf. *C. virginica*	–	?	–	–	–	–	Clark and Miller 1912
	Ctena speciosa	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993
	*Cubitostrea sellaeformis**	–	Y	–	–	–	–	McLean 1956
	Cumingia subtellinoides	–	?	–	–	–	–	Clark and Miller 1912

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	*Cumingia tellinoides*	–	Y	–	–	–	Y	Ward 1993
	Cyclocardia granulata	–	Y	U	U	–	Y	Clark and Miller 1912; Mansfield 1943; McLean 1956, 1957; Johnson 1972; Ward 1993
	Cyrtopleura arcuata	–	Y	–	–	–	Y	Ward 1993
	Dallarca carolinensis	U	–	–	–	–	–	Ward 1993
	Dinocardium robustum	–	?	–	–	–	–	Clark and Miller 1912
	Diplodonta acclinis	–	Y	–	–	–	Y	Clark and Miller 1912; McLean 1956; Ward 1993
	Diplodonta conradi	–	?	–	–	–	–	McGavock 1944
	Diplodonta nucleiformis	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Diplodonta punctulata	–	?	–	–	–	–	McGavock 1944
	Divaricella quadrisulcata	–	?	–	–	–	–	Clark and Miller 1912
	Donax emmonsi	–	Y	–	–	–	–	Mansfield 1943
	Dosinia acetabulum	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; McLean 1956; Ward 1993
	Ensis ensiformis	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	*Ensis* sp.	–	?	–	–	–	–	Clark and Miller 1912
	Ensitellops compressa	–	?	–	–	–	–	Clark and Miller 1912
	Erycinella ovalis	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993
	Gemma magna	–	?	–	–	–	–	Dall 1903
	Gemma magna virginiana	–	Y	–	–	–	Y	Mansfield 1943; Ward 1993
	Glossus fraternus	–	Y	–	–	–	–	Clark and Miller 1912
	Glycymeris	–	Y	–	–	–	–	McLean 1957
	Glycymeris americana	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993
	Glycymeris parilis	–	Y	–	–	–	–	McLean 1956
	Glycymeris pectinata	–	?	–	–	–	–	Clark and Miller 1912
	Gouldia metastriatum	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Hiatella arctica	–	Y	–	–	–	Y	Ward 1993
	Isognomon sp.	Y	–	–	–	–	–	Hazel 1971, Ward 1993
	Leptomactra delumbis	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	*Lucinisca cribrarius*	–	Y	–	–	–	–	Clark and Miller 1912; Mansfield 1943
	Macoma cookie	–	Y	–	–	–	–	Mansfield 1943
	Macoma virginiana	–	Y	–	–	–	–	Clark and Miller 1912; Mansfield 1943
	Macrocallista albaria	–	?	–	–	–	–	Clark and Miller 1912
	Macrocallista emmonsi	–	Y	–	–	–	–	Mansfield 1943
	Macrocallista greeni	–	Y	–	–	–	Y	Ward 1993
	Margaritaria abrupta	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Marvacrassatella undulata	–	Y	U	U	–	Y	Ward 1993
	*Melina maxillata**	–	Y	–	–	–	–	Clark and Miller 1912
	Mercenaria corrugata	–	Y	–	–	–	–	Clark and Miller 1912; Mansfield 1943
	Mercenaria inflata	–	Y	–	–	–	–	Dall 1903; Clark and Miller 1912; Mansfield 1943
	Mercenaria mercenaria	–	Y	–	–	–	–	Mansfield 1943
	Mercenaria sp.	–	Y	–	–	–	Y	Ward 1993
	Mercenaria sp. (young)	–	Y	–	–	–	Y	Ward 1993

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	*Mercenaria tridacnoides*	–	Y	–	U	–	–	Clark and Miller 1912; Mansfield 1943; McLean 1956, 1957; Johnson 1972; Wilson 1983; Ward 1993
	"*Modiolus ducatelli*"[1]	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Moerella declivis	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Montacuta sagrinata	–	?	–	–	–	–	Clark and Miller 1912
	Mulinia congesta	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; McLean 1957; Ward 1993
	Musculus virginica	–	?	–	–	–	–	Clark and Miller 1912
	Mya arenaria	–	Y	–	–	–	–	Clark and Miller 1912; Mansfield 1943; McLean 1956
	"*Mytilus hamatus*"[2]	–	?	–	–	–	–	Clark and Miller 1912
	Noetia incile	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; McLean 1956, 1957; Johnson 1972; Ward 1993

[1] Yorktown Formation records are a mix of indeterminate fragments and *Modiolus inflatus* per Campbell (1993)

[2] Indeterminate material per Campbell (1993)

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	*Nucula diaphana*	–	Y	–	–	–	–	McLean 1956
	Nucula proxima	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; McLean 1956; Ward 1993
	Nuculana acuta	–	Y	–	–	–	Y	Clark and Miller 1912; McLean 1956; Ward 1993
	Ostrea compressirostra	–	Y	U	–	–	Y	Clark and Miller 1912; McLean 1956; Johnson 1972; Ward 1993
	Pandora arenosa	–	Y	–	–	–	Y	Mansfield 1943; Ward 1993
	Pandora crassidens	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993
	Pandora tuomeyi	–	Y	–	–	–	–	Mansfield 1943
	Panopea goldfusii	–	?	–	–	–	–	Clark and Miller 1912
	Panopea reflexa	–	Y	U	U	–	–	Clark and Miller 1912; Ward 1993
	Panopea sp.	–	Y	–	–	–	Y	Ward 1993
	Parvilucina crenulata	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Parvilucina postalveata	–	Y	–	–	–	–	Mansfield 1943

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	*Pecten* sp.	–	Y	–	–	–	–	Malkin 1953
	Pecten spp.	–	Y	–	–	–	–	McLean 1956
	Petricola pholadiformis	–	Y	–	–	–	–	Mansfield 1943; McGavock 1944
	Pitar sayana	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; McLean 1956; Ward 1993
	Placopecten clintonius	–	Y	–	–	–	–	Clark and Miller 1912; Mansfield 1943
	Planicardium acutilaqueatum	–	Y	U	U	–	Y	Mansfield 1943; Ward 1993
	Planicardium taeniopleura	–	?	–	–	–	–	Dall 1900
	Planicardium virginianum	–	Y	–	–	–	–	Mansfield 1943
	Pleiorytis centenaria	–	Y	U	U	–	Y	Dall 1900; Clark and Miller 1912; Mansfield 1943; Ward 1993
	Pleuromeris tridentata	–	Y	–	–	–	–	Mansfield 1943
	Plicatula gibbosa	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; McLean 1956, 1957; Johnson 1972; Ward 1993

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	*Pseudochama corticosa*	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993
	Pteria colymbus	–	Y	–	–	–	Y	Ward 1993
	Pteromeris abbreviata	–	Y	–	–	–	–	Mansfield 1943
	Pteromeris perplana	–	Y	–	–	–	–	Mansfield 1943
	Pycnodonte percrassa	–	Y	–	–	–	–	McLean 1956
	Raeta alta	–	?	–	–	–	–	Clark and Miller 1912
	Raeta sp.	–	?	–	–	–	–	Clark and Miller 1912
	Rangia clathrodonta	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993
	Rupellaria pectarosa	–	Y	–	–	–	–	Mansfield 1943
	Semele nuculoides	–	Y	–	–	–	–	Clark and Miller 1912; Mansfield 1943
	Semele subovata	–	Y	–	–	–	Y	Mansfield 1943; Johnson 1972; Ward 1993
	Semele subovata alta	–	Y	–	–	–	–	Mansfield 1943
	Sphenia dubia	–	Y	–	–	–	Y	Ward 1993
	Spisula modicella	–	Y	–	–	–	Y	Mansfield 1943; Ward 1993

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	"Spisula" sp.	–	Y	–	–	–	Y	Ward 1993
	Sportella yorkensis	–	?	–	–	–	–	Dall 1900; Clark and Miller 1912
	Stewartia anodonta	U	Y	–	U	–	Y	Clark and Miller 1912; McLean 1956; Ward 1993
	Striarca centenaria	–	Y	–	–	–	–	Clark and Miller 1912; McLean 1956; Johnson 1972
	Tagelus plebeius	–	Y	–	–	–	–	Clark and Miller 1912; Mansfield 1943
	Tellina dupliniana	–	Y	–	–	–	Y	Mansfield 1943; Ward 1993
	Tellina egena	–	?	–	–	–	–	McGavock 1944
	Tellina sp.	–	Y	–	–	–	Y	Ward 1993
	Tellina sp. indet.	–	Y	–	–	–	Y	Ward 1993
	Teredina fistula	–	Y	–	–	–	Y	Clark and Miller 1912; McLean 1956; Ward 1993
	Thracia magna	–	?	–	–	–	–	Clark and Miller 1912
	Thracia transversa	–	?	–	–	–	–	Clark and Miller 1912
	Thracia transversa (possibly)	–	Y	–	–	–	–	Mansfield 1943

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Bivalvia (continued)	*Transennella carolinensis*	–	Y	–	–	–	Y	Ward 1993
	Venericardia sp.	–	Y	–	–	–	–	Burns 1991
	Venus sp.	–	Y	–	–	–	–	Clark and Miller 1912; Malkin 1953
	Yoldia laevis	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993
	Yoldia laevis(?)	–	?	–	–	–	–	Clark and Miller 1912
	Lucinae indet.	–	?	–	–	–	–	Clark and Miller 1912
	Tellinae indet.	–	?	–	–	–	–	Clark and Miller 1912
	Indet. boring clam	–	Y	–	–	–	–	Johnson 1972
	Indet. oysters	–	Y	–	–	–	Y	Ward and Blackwelder 1980
	Indet. pectens	–	Y	–	–	–	Y	Ward and Blackwelder 1980
Mollusca: Gastropoda	**Gastropoda overall**	**–**	**Y**	**Y**	**Y**	**–**	**Y**	**–**
	Acteocina candei	–	Y	–	–	–	Y	Ward 1993
	Acteon novellus	–	Y	–	–	–	Y	Ward 1993
	Adeorbis sp.	–	Y	–	–	–	Y	Ward 1993

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Gastropoda (continued)	*Anachis parvula*	–	Y	–	–	–	Y	Dall 1892; Clark and Miller 1912; Ward 1993
	Anachis sp.	–	Y	–	–	–	Y	Ward 1993
	Anachis sp., near *A. camax*	–	Y	–	–	–	Y	Ward 1993
	Aurinia obtusa	–	Y	–	–	–	Y	Gardner 1948; Ward 1993
	Aurinia sp.	–	U	–	–	–	–	Ward 1993
	Boreotrophon tetricus	–	Y	–	U	–	Y	Ward 1993
	Bostrycapulus aculeatus costata	–	Y	–	–	–	Y	Clark and Miller 1912; McLean 1956, 1957; Johnson 1972; Ward 1993
	Busycon maximus	–	Y	U	U	–	Y	Clark and Miller 1912; McLean 1957; Ward 1993
	Busycon perversum	–	?	–	–	–	–	Clark and Miller 1912
	Busycon sp. indet.	–	Y	–	–	–	Y	Ward 1993
	Busycotypus incile	–	Y	U	U	–	Y	Clark and Miller 1912; Gardner 1948; McLean 1956; Ward 1993
	Caecum stevensoni	–	?	–	–	–	–	Gardner 1948
	Caecum virginianum	–	?	–	–	–	–	Clark and Miller 1912

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Gastropoda (continued)	*Calliostoma basicum*	–	Y	–	–	–	–	Clark and Miller 1912; McLean 1956
	*Calliostoma distans**	–	?	–	–	–	–	Clark and Miller 1912
	Calliostoma harrisii	–	Y	–	–	–	–	Dall 1892; Clark and Miller 1912; Gardner 1948
	Calliostoma lapidosum	–	?	–	–	–	–	Gardner 1948
	Calliostoma mitchelli	–	?	–	–	–	–	Clark and Miller 1912
	Calliostoma philanthropus	–	Y	–	–	–	Y	Clark and Miller 1912; McLean 1956; Ward 1993
	Calliostoma ruffini	–	?	–	–	–	–	Clark and Miller 1912
	Calliostoma virginicum	–	?	–	–	–	–	Clark and Miller 1912
	Calliostoma virginicum gizehi	–	?	–	–	–	–	Gardner 1948
	Calliostoma sp.	–	Y	–	–	–	Y	Ward 1993
	Cerithiopsis bicolor persubulata	–	?	–	–	–	–	Gardner 1948
	Cochliolepis concava	–	?	–	–	–	–	Gardner 1948
	Compsodrillia eburnea	–	Y	–	–	–	Y	Gardner 1948; Ward 1993
	Conus marylandicus	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Gastropoda (continued)	*Crepidula fornicata*	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; McLean 1956, 1957; Johnson 1972; Ward 1993
	Crepidula plana	–	Y	–	–	–	Y	Clark and Miller 1912; McLean 1957; Johnson 1972; Ward 1993
	Crepidula sp.	–	Y	–	–	–	Y	Clark and Miller 1912; Malkin 1953; Ward and Blackwelder 1980
	Crucibulum constrictum	–	Y	–	–	–	Y	McLean 1956, 1957; Ward 1993
	Crucibulum scutellatum	–	Y	–	–	–	–	Clark and Miller 1912
	Cyclostremiscus obliquestriatus	–	Y	–	–	–	Y	Ward 1993
	Cyclostremiscus pseudaeorbis	–	Y	–	–	–	–	Dall 1892; Clark and Miller 1912
	Cylichna sp.	–	Y	–	–	–	Y	Ward 1993
	Cymatosyrinx lunata	–	Y	–	–	–	Y	Ward 1993
	Delphinula sp.	–	?	–	–	–	–	Clark and Miller 1912
	Diodora oblonga	–	?	–	–	–	–	Gardner 1948

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Gastropoda (continued)	*Diodora redimicula*	–	Y	–	U	–	Y	Clark and Miller 1912; McLean 1956; Johnson 1972; Ward 1993
	*Drillia limatula**	–	?	–	–	–	–	Clark and Miller 1912
	"Drillia" sp.	–	Y	–	–	–	Y	Ward 1993
	Ecphora gardnerae	–	Y	–	–	–	–	Burns 1991
	Ecphora quadricostata	–	Y	U	U	–	Y	Clark and Miller 1912; Ward 1993
	Epitonium pratti	–	?	–	–	–	–	Gardner 1948
	Epitonium sp.	–	Y	–	–	–	Y	Ward 1993
	Eulima ephamilla	–	Y	–	–	–	Y	Ward 1993
	Eulima sp.	–	Y	–	–	–	Y	Ward 1993
	Eulima sp.?	–	Y	–	–	–	Y	Ward 1993
	*Eupleura caudata**	–	?	–	–	–	–	Clark and Miller 1912
	Euspira sayana	–	Y	–	–	–	Y	Clark and Miller 1912; Mansfield 1943; Ward 1993
	Euspira sayana (thin var.)	–	Y	–	–	–	Y	Ward 1993
	Fissurella spp.	–	Y	–	–	–	–	McLean 1956
	Fissuridea alticosta	–	Y	–	–	–	–	Clark and Miller 1912

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Gastropoda (continued)	*Fissuridea marylandica*	–	?	–	–	–	–	Clark and Miller 1912
	Fossarus lyra	–	Y	–	–	–	Y	Ward 1993
	Fusinus burnsii	–	?	–	–	–	–	Gardner 1948
	Fusinus exilis	–	Y	–	–	–	Y	Ward 1993
	"Granulina ovuliformis"	–	Y	–	–	–	Y	Ward 1993
	Hesperisternia filicata	–	Y	–	U	–	Y	Ward 1993
	Ilyanassa granifera	–	Y	–	–	–	Y	Clark and Miller 1912; Gardner 1948; Ward 1993
	Ilyanassa harpuloides	–	?	–	–	–	–	Clark and Miller 1912; Gardner 1948
	*Ilyanassa obsoleta**	–	Y	–	–	–	–	Clark and Miller 1912
	Ilyanassa porcina	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Ilyanassa scalaspira	–	?	–	–	–	–	Gardner 1948
	Ilyanassa sexdentata	–	Y	–	–	–	–	Dall 1892; Clark and Miller 1912; Gardner 1948
	Lirosoma sulcosa	–	Y	–	–	–	Y	Ward 1993
	Lirosoma sp.	–	Y	–	–	–	Y	Ward 1993
	Littorina irrorata	–	?	–	–	–	–	Gardner 1948

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Gastropoda (continued)	*Lunatia interna*	–	Y	–	–	–	Y	Ward 1993
	Marginella bella	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Marginella sp.	–	Y	–	–	–	Y	Ward 1993
	Melanella laevigata	–	?	–	–	–	–	Gardner 1948
	Mitrella communis	–	Y	–	–	–	Y	Ward 1993
	Mitrella sp.	–	Y	–	–	–	Y	Johnson 1972; Ward 1993
	Nassarius quadrulatus	–	?	–	–	–	–	Gardner 1948
	Nassarius sp.	–	Y	–	–	–	Y	Ward 1993
	Neverita duplicata	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Oliva canaliculata	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Olivella mutica	–	?	–	–	–	–	Clark and Miller 1912
	Olivella sp.	–	Y	–	–	–	Y	Ward 1993
	Petaloconchus sculpturatus	–	?	–	–	–	–	Clark and Miller 1912
	Pisania nux	–	?	–	–	–	–	Gardner 1948
	Prunum limatulum	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Gastropoda (continued)	*Pseudotorinia nupera*	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Pterorytis umbrifer	–	?	–	–	–	–	Clark and Miller 1912
	Ptychosalpinx altilis	–	?	–	–	–	–	Clark and Miller 1912; Gardner 1948
	Ptychosalpinx laqueata	–	Y	–	–	–	Y	Clark and Miller 1912; Gardner 1948; Ward 1993
	Ptychosalpinx tuomeyi	–	Y	–	–	–	–	Gardner 1948; Ward 1993
	Scalaspira strumosa	–	?	–	–	–	–	Clark and Miller 1912
	Scaphella sp.	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Seila adamsi	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Serpulorbis granifera	–	Y	U	U	–	Y	Clark and Miller 1912; Gardner 1948; Johnson 1972; Ward 1993
	Sinum chesapeakensis	–	Y	–	–	–	Y	Gardner 1948; Ward 1993
	*Siphonalia devexa**	–	Y	–	–	–	–	McLean 1956
	Strombiformis sp.	–	Y	–	–	–	Y	Ward 1993
	Strombiformis? sp.	–	Y	–	–	–	Y	Ward 1993

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Gastropoda (continued)	*Terebra emmonsii emmonsii*	–	?	–	–	–	–	Gardner 1948
	Terebra emmonsii grayi	–	?	–	–	–	–	Gardner 1948
	Terebra sp.	–	Y	–	–	–	Y	Ward 1993
	Trigonostoma sp. (young)	–	Y	–	–	–	Y	Ward 1993
	Triphora sp.	–	Y	–	–	–	Y	Ward 1993
	Turritella alticostata	–	Y	–	U	–	Y	Clark and Miller 1912; Mansfield 1943; McLean 1956, 1957; Johnson 1972; Ward 1993
	Turritella plebia	–	Y	–	–	–	–	Burns 1991
	Turritella sp. grading into *T. alticostata*	–	Y	–	U	–	Y	Ward 1993
	Turritella sp.	–	U	–	–	–	–	Ward 1993
	Turritella virginica	–	Y	–	–	–	–	Clark and Miller 1912; McLean 1956
	Urosalpinx barbitoides	–	?	–	–	–	–	Gardner 1948
	Urosalpinx lepidota	–	?	–	–	–	–	Gardner 1948
	Urosalpinx trossula	–	Y	–	–	–	Y	Clark and Miller 1912; Gardner 1948; Ward 1993
	Urosalpinx sp.	–	U	–	–	–	–	Ward 1993

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Mollusca: Gastropoda (continued)	*Vitrinella*? sp.	–	Y	–	–	–	Y	Ward 1993
	Three unidentified taxa	–	Y	–	–	–	Y	Ward 1993
Mollusca: Scaphopoda	*Cadulus thallus*	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Dentalium attenuatum	–	Y	–	–	–	Y	Clark and Miller 1912; Ward 1993
	Dentalium carolinense	–	Y	–	–	–	–	Johnson 1972
Annelida	*Spirorbis* sp.	–	Y	–	–	–	–	Johnson 1972
Arthropoda	**Arthropoda overall**	**Y**	**Y**	**–**	**–**	**Y**	**Y**	**–**
	Arthropoda indet.	–	Y	–	–	–	–	Santucci et al. 2001
	Cancroidea indet.	–	?	–	–	–	–	Clark and Miller 1912
Arthropoda: Cirripedia	*Balanus* sp.	U	Y	–	–	–	Y	Malkin 1953; Ward 1993
	Chesaconcavus proteus	–	**Y**	–	–	–	–	Clark and Miller 1912; McLean 1956; Johnson 1972
Arthropoda: Ostracoda	**Ostracoda overall**	**–**	**Y**	**–**	**–**	**Y**	**Y**	**–**
	Actinocythereis dawsoni	–	Y	–	–	–	–	Hazel 1971
	Actinocythereis exanthemata exanthemata	–	Y	–	–	–	–	Swain 1974

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Arthropoda: Ostracoda (continued)	*Actinocythereis exanthemata gomillionensis*	–	Y	–	–	–	–	Malkin 1953; McLean 1957
	Actinocythereis [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Anomocytheridea floridana	–	Y	–	–	–	–	Malkin 1953
	Aurila [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Bairdia spp.	–	Y	–	–	–	–	Malkin 1953
	Bairdoppilata triangulata	–	Y	–	–	–	–	Swain 1974
	Bensonocythere whitei	–	Y	–	–	–	–	Malkin 1953
	Bensonocythere sp. B, D	–	Y	–	–	–	–	Hazel 1971
	Bensonocythere [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Campylocythere laeva	–	Y	–	–	–	–	Malkin 1953
	Campylocythere laeva laeva	–	Y	–	–	–	–	Swain 1974
	Campylocythere laevissima	–	Y	–	–	–	–	Malkin 1953; McLean 1957
	Campylocythere laevissima laevissima	–	Y	–	–	–	–	Swain 1974

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Arthropoda: Ostracoda (continued)	*Campylocythere laevissima punctata*	–	Y	–	–	–	–	Swain 1974
	Campylocythere [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Cletocythereis mundorffi	–	Y	–	–	–	–	Swain 1974
	Climacoidea [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Costa barclayi	–	Y	–	–	–	–	McLean 1957
	Cushmanidea ulrichi	–	Y	–	–	–	–	Malkin 1953; McLean 1957; Swain 1974
	Cytheridea diagonalis	Y	–	–	–	–	–	McLean 1966
	Cytheridea virginiensis	–	Y	–	–	–	–	Malkin 1953; McLean 1957
	Cytheromorpha warneri	–	Y	–	–	–	–	Malkin 1953; Hazel 1971
	Cytheromorpha cf. *C. warneri*	–	Y	–	–	–	–	McLean 1957
	Cytheropteron subreticulatum	–	Y	–	–	–	–	Swain 1974
	Cytheropteron talquinensis	–	Y	–	–	–	–	Hazel 1971
	Cytheropteron [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Arthropoda: Ostracoda (continued)	*Cytheropteron*? *yorktownensis*	–	Y	–	–	–	–	Malkin 1953; Swain 1974
	Cytherura elongata	–	Y	–	–	–	–	Malkin 1953; Swain 1974
	Cytherura forulata	–	Y	–	–	–	–	Malkin 1953; Swain 1974
	Cytherura howei	–	Y	–	–	–	–	Swain 1974
	Cytherura wardensis	–	Y	–	–	–	–	Malkin 1953
	Cytherura [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Echinocythereis planibasalis	–	Y	–	–	–	–	Hazel 1971
	Echinocythereis? *clarkana*	–	Y	–	–	–	–	Swain 1974
	Eucythere declivis	–	Y	–	–	–	–	Hazel 1971
	Eucythere [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Jonesia? sp.	–	Y	–	–	–	–	Swain 1974
	Loxoconcha purisubrhomboidea	–	Y	–	–	–	–	Malkin 1953; McLean 1957
	Loxoconcha reticularis	–	Y	–	–	–	–	Malkin 1953; Swain 1974
	Loxoconcha wilberti	–	Y	–	–	–	–	Swain 1974
	Loxoconcha [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Malzella conradi	–	Y	–	–	–	–	Malkin 1953; McLean 1957; Swain 1974

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Arthropoda: Ostracoda (continued)	*Malzella* [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Microcytherura curta	–	Y	–	–	–	–	Malkin 1953
	Microcytherura similis	–	Y	–	–	–	–	Malkin 1953
	Muellerina micula	–	Y	–	–	–	–	Malkin 1953; McLean 1957; Swain 1974
	Muellerina sp. A	–	Y	–	–	–	–	Hazel 1971
	Muellerina [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Neocytherideis sp.	–	Y	–	–	–	–	Swain 1974
	Orionina vaughani	–	Y	–	–	–	–	McLean 1957; Swain 1974
	Orionina [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Paracypris choctawatcheensis	–	Y	–	–	–	–	McLean 1957
	Paracytheridea altila	–	Y	–	–	–	–	Malkin 1953; McLean 1957
	Paracytheridea mucra	–	Y	–	–	–	–	Malkin 1953
	Paracytheridea [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Paradoxostoma robustum	–	Y	–	–	–	–	Swain 1974
	Paradoxostoma [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Arthropoda: Ostracoda (continued)	*Paranesidea* [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Peratocytheridea [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Pontocythere (*Hulingsina*) *agricola*	–	Y	–	–	–	–	Malkin 1953
	Pontocythere (*Hulingsina*) *rugipustulosa*	–	Y	–	–	–	–	Malkin 1953; McLean 1957; Hazel 1971
	Pontocythere (*Hulingsina*) spp.	–	Y	–	–	–	–	Malkin 1953; McLean 1957; Hazel 1971
	Pontocythere (*Hulingsina*) [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Propontocypris [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Pseudocytheretta burnsi	–	Y	–	–	–	–	Malkin 1953; McLean 1957
	Pseudocytheretta [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Pterygocythereis inexpectata	–	Y	–	–	–	–	McLean 1957; Hazel 1971
	Puriana rugipunctata	–	Y	–	–	–	–	Malkin 1953; Hazel 1971
	Puriana [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Sahnicythere [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Arthropoda: Ostracoda (continued)	*Tetracytherura* [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Thaerocythere schmidtae	–	Y	–	–	–	–	Malkin 1953; McLean 1957; Swain 1974
	Thaerocythere sp.	–	Y	–	–	–	–	Swain 1974
	Thaerocythere [genus only]	–	Y	–	–	Y	Y	Cronin et al. 1989
	Ostracoda indet.	–	Y	–	–	–	Y	Malkin 1953; Ward and Blackwelder 1980
Echinodermata: Echinoidea	*Psammechinus philanthropus*	–	?	–	–	–	–	Kier 1972
	Echinoidea indet.	–	Y	–	–	–	–	Santucci et al. 2001
Other invertebrates	*Mclellania aenigma*	–	Y	–	–	–	–	Wilson 1983
	Indet. shell fragments	–	Y	–	–	–	–	Malkin 1953
Vertebrata	**Vertebrata overall**	**–**	**Y**	**–**	**–**	**–**	**–**	**–**
Chondrichthyes	*Carcharias egertoni*	–	Y	–	–	–	–	Burns 1991
	Carcharias sp.	–	Y	–	–	–	–	Burns 1991
	Carcharodon hastalis	–	Y	–	–	–	–	Burns 1991
	Galeocerdo aduncus	–	Y	–	–	–	–	Burns 1991
	Hemipristis serra	–	Y	–	–	–	–	Burns 1991

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Chondrichthyes (continued)	*Notidanus primigenius*	–	Y	–	–	–	–	Burns 1991
	Oxyrhina desori	–	Y	–	–	–	–	Burns 1991
Osteichthyes	*Diodon* sp.	–	Y	–	–	–	–	Burns 1991
Mammalia	*Ontocetus emmonsi*	–	?	–	–	–	–	Berry and Gregory 1906; Clark and Miller 1912
	Orycterocetus crocodilinus	–	Y	–	–	–	–	Burns 1991
	Rhegnopsis palaeatlanticus	–	?	–	–	–	–	Clark and Miller 1912
Ichnofossils	*Cliona* sp. borings	–	Y	–	–	–	–	Johnson 1972
	Ophiomorpha isp.	–	Y	–	–	–	–	J. Tweet, pers. obs., 2019
Others: Foraminifera	**Foraminifera overall**	**Y**	**Y**	**–**	**–**	**Y**	**Y**	**–**
	Angulogerina sp.	–	Y	–	–	–	–	McLean 1956
	Anomalina punctata	–	AT	–	–	–	–	Anderegg in McLean 1956
	Bolivina lafayettei	–	Y	–	–	–	–	McLean 1956
	Bolivina marginata	–	AT	–	–	–	–	Anderegg in McLean 1956
	Bolivina marginata multicostata	–	Y	–	–	–	–	Gibson 1983
	Bolivina paula	–	Y	–	–	–	–	Cushman and Cahill 1933
	Bolivina spissa	–	AT	–	–	–	–	Anderegg in McLean 1956

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Others: Foraminifera (continued)	*Bolivina striatula*	–	Y	–	–	–	–	McLean 1956
	Buccella andersoni	Y	Y	–	–	–	–	McLean 1956, 1957, 1966
	Buccella hannai	–	Y	–	–	–	–	McLean 1956
	Buccella parkerae	–	Y	–	–	–	–	McLean 1956
	Bulimina gracilis	–	Y	–	–	–	–	McLean 1956
	Buliminella curta	–	Y	–	–	–	–	Malkin 1953
	Buliminella elegantissima	–	Y	–	–	–	–	Cushman and Cahill 1933; Anderegg in McLean 1956
	Buliminella cf. *B. elegantissima*	–	Y	–	–	–	–	McLean 1956
	Cancris sagra	–	Y	–	–	–	–	Malkin 1953; McLean 1956
	Cassidulinoides bradyi	–	Y	–	–	–	–	Cushman and Cahill 1933
	Cibicidella variabilis	Y	Y	–	–	–	–	McLean 1956, 1966
	Cibicides americanus	–	Y	–	–	–	–	Cushman and Cahill 1933; Malkin 1953
	Cibicides concentricus	–	Y	–	–	–	–	Malkin 1953
	Cibicides floridanus	–	Y	–	–	–	–	Cushman and Cahill 1933
	Cibicides lobulatus	–	Y	–	–	–	–	Malkin 1953

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Others: Foraminifera (continued)	*Cibicides* cf. *C. lobatulus*	–	Y	–	–	–	–	McLean 1956
	Cibicides sublobus	–	Y	–	–	–	–	McLean 1956
	Cibicides tenuimargo	–	AT	–	–	–	–	Anderegg in McLean 1956
	Cibicides tumidula	–	AT	–	–	–	–	Anderegg in McLean 1956
	Dentalina kaicherae	–	Y	–	–	–	–	McLean 1956
	Dentoglobigerina altispira	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Discorbis aff. *D. assulata*	–	Y	–	–	–	–	Malkin 1953
	Discorbis candeiana	–	Y	–	–	–	–	Malkin 1953
	Discorbis consobrina	–	Y	–	–	–	–	Cushman and Cahill 1933
	Discorbis floridana	Y	Y	–	–	–	–	Cushman and Cahill 1933; McLean 1956, 1957, 1966
	Discorbis globularis	–	AT	–	–	–	–	Anderegg in McLean 1956
	Discorbis isabelleana	–	AT	–	–	–	–	Anderegg in McLean 1956
	Discorbis orbicularis	–	AT	–	–	–	–	Anderegg in McLean 1956
	Discorbis rehderi	–	Y	–	–	–	–	McLean 1956
	Discorbis rosacea	–	AT	–	–	–	–	Anderegg in McLean 1956
	Discorbis turrita	–	Y	–	–	–	–	McLean 1956
	Discorbis vilardeboana	–	AT	–	–	–	–	Anderegg in McLean 1956

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Others: Foraminifera (continued)	*Discorbis* sp., n. sp.	–	AT	–	–	–	–	Anderegg in McLean 1956
	Elphidium incertum	–	Y	–	–	–	–	Cushman and Cahill 1933; McLean 1956
	Elphidium cf. *E. incertum*	–	Y	–	–	–	–	Malkin 1953
	Elphidium johnstonae	Y	Y	–	–	–	–	McLean 1956, 1957, 1966
	Elphidium kaicherae	–	Y	–	–	–	–	McLean 1956, 1957
	Elphidium sp. (papillose)	–	Y	–	–	–	–	Malkin 1953
	Epistomina bradyi	–	AT	–	–	–	–	Anderegg in McLean 1956
	Epistomina partschiana	–	AT	–	–	–	–	Anderegg in McLean 1956
	Eponides broeckhiana	–	AT	–	–	–	–	Anderegg in McLean 1956
	Eponides mansfieldi	–	Y	–	–	–	–	Malkin 1953
	Eponides aff. *E. mansfieldi*	–	Y	–	–	–	–	Malkin 1953
	Eponides repandus	–	AT	–	–	–	–	Anderegg in McLean 1956
	Eponides repandus (?)	–	Y	–	–	–	–	Malkin 1953
	Gaudryina rugosa	–	AT	–	–	–	–	Anderegg in McLean 1956
	Globigerina apertura	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Globigerina bulloides	–	Y	–	–	Y	Y	Anderegg in McLean 1956; Cronin et al. 1989; Dowsett and Wiggs 1992

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Others: Foraminifera (continued)	*Globigerina falconensis*	–	Y	–	–	Y	Y	Cronin et al. 1989; Dowsett and Wiggs 1992
	Globigerina sp. form A, B, C, D, E	–	Y	–	–	–	–	McLean 1956, 1957
	Globigerina woodi	–	Y	–	–	Y	Y	Cronin et al. 1989
	Globigerinella aequilateralis	–	Y	–	–	Y	Y	Cronin et al. 1989; Dowsett and Wiggs 1992
	Globigerinita glutinata	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Globigerinoides obliquus	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Globigerinoides ruber	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Globigerinoides sacculifer	–	Y	–	–	Y	Y	Cronin et al. 1989; Dowsett and Wiggs 1992
	Globigerinoides sacculifer sensu lato	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Globigerinoides sp. form G	–	Y	–	–	–	–	McLean 1956
	Globorotalia crassaformis	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Globorotalia hirsuta hirsuta	–	Y	–	–	–	Y	Gibson 1983
	Globorotalia menardii (?)	–	AT	–	–	–	–	Anderegg in McLean 1956
	Globorotalia menardii / G. *tumida* group	–	Y	–	–	–	Y	Dowsett and Wiggs 1992

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Others: Foraminifera (continued)	*Globorotalia puncticulata*	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Globorotalia scitula	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Globorotalia tumida	–	AT	–	–	–	–	Anderegg in McLean 1956
	Globorotalia sp.	–	Y	–	–	–	–	McLean 1956
	Globotruncana concamerata	–	AT	–	–	–	–	Anderegg in McLean 1956
	Guttulina pseudocostatula	–	Y	–	–	–	–	McLean 1956
	Hanzawaia concentrica	–	Y	–	–	–	–	McLean 1956, 1957
	Lagena pseudosulcata	–	Y	–	–	–	–	McLean 1956, 1957
	Lagena substriata	–	Y	–	–	–	–	McLean 1956
	Loxostoma wilsoni	–	Y	–	–	–	–	McLean 1956
	Massilina mansfieldi	–	Y	–	–	–	–	Cushman and Cahill 1933; McLean 1956, 1957
	Neogloboquadrina acostaensis	–	Y	–	–	Y	Y	Cronin et al. 1989; Dowsett and Wiggs 1992
	Neogloboquadrina atlantica	–	Y	–	–	Y	Y	Cronin et al. 1989; Dowsett and Wiggs 1992
	Neogloboquadrina humerosa	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Nonion bouena	–	AT	–	–	–	–	Anderegg in McLean 1956

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Others: Foraminifera (continued)	*Nonion depressula*	–	AT	–	–	–	–	Anderegg in McLean 1956
	Nonion extensa	–	AT	–	–	–	–	Anderegg in McLean 1956
	Nonion granosum	–	Y	–	–	–	–	Malkin 1953
	Nonion cf. *N. grateloupi*	–	Y	–	–	–	–	McLean 1956
	Nonion pizarrense	–	Y	–	–	–	–	Cushman and Cahill 1933; Malkin 1953; McLean 1956
	Nonion scapha	–	AT	–	–	–	–	Anderegg in McLean 1956
	Nonion striatopunctata	–	AT	–	–	–	–	Anderegg in McLean 1956
	Nonion sp. A, B	–	Y	–	–	–	–	McLean 1956
	Nonionella auris	–	Y	–	–	–	–	McLean 1956
	Orbulina cornwallisi	–	Y	–	–	–	–	McLean 1956
	Orbulina universa	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Planispirillina orbicularis	–	Y	–	–	–	–	McLean 1956
	Poroeponides lateralis	–	Y	–	–	–	–	Cushman and Cahill 1933; McLean 1956, 1957
	Quinqueloculina seminula	–	Y	–	–	–	–	Cushman and Cahill 1933; McLean 1956, 1957
	Quinqueloculina triloculiniforma	–	Y	–	–	–	–	McLean 1956

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Others: Foraminifera (continued)	*Rotalia bassleri*	–	Y	–	–	–	–	Malkin 1953
	Rotalia beccarii	–	AT	–	–	–	–	Anderegg in McLean 1956
	Rotalia beccarii parkinsoniana	–	Y	–	–	–	–	Cushman and Cahill 1933
	Rotalia beccarii subsp.	–	AT	–	–	–	–	Anderegg in McLean 1956
	Rotalia limbatobeccarii	–	Y	–	–	–	–	McLean 1956, 1957
	Rotalia soldanii	–	AT	–	–	–	–	Anderegg in McLean 1956
	Sigmoilina? sp.	–	Y	–	–	–	–	McLean 1957
	Sigmomorphina concava	–	Y	–	–	–	–	McLean 1956
	Sigmomorphina nevifera	Y	–	–	–	–	–	McLean 1966
	Sigmomorphina pearceyi	–	Y	–	–	–	–	McLean 1956
	Sigmomorphina semitecta terquemiana	–	Y	–	–	–	–	McLean 1956, 1957
	Sigmomorphina williamsoni	–	Y	–	–	–	–	McLean 1956
	Sphaeroidinellopsis seminulina	–	Y	–	–	–	Y	Dowsett and Wiggs 1992
	Textularia agglutinans	–	AT	–	–	–	–	Anderegg in McLean 1956
	Textularia articulata	–	Y	–	–	–	–	Malkin 1953; McLean 1956, 1957

Appendix A-Table 1 (continued). Fossil taxa reported from COLO in published literature.

Group	Taxon	Eastover Fm.	Yorktown Fm.	YSM Mbr.	YR Mbr.	YMB Mbr.	YMH Mbr.	References
Others: Foraminifera (continued)	*Textularia* cf. *T. bocki*	–	Y	–	–	–	–	McLean 1956
	Textularia candeiana	Y	Y	–	–	–	–	McLean 1956, 1957, 1966
	Textularia gramen	–	Y	–	–	–	–	McLean 1956
	Textularia mayori	–	Y	–	–	–	–	Cushman and Cahill 1933; Malkin 1953
	Textularia sagittula	–	AT	–	–	–	–	Anderegg in McLean 1956
	Truncatulina cf. *T. alleni*	–	AT	–	–	–	–	Anderegg in McLean 1956
	Truncatulina elevata	–	AT	–	–	–	–	Anderegg in McLean 1956
	Truncatulina lobatula	–	AT	–	–	–	–	Anderegg in McLean 1956
	Truncatulina lobatula ornata	–	AT	–	–	–	–	Anderegg in McLean 1956
	Uvigerina calvertensis	–	Y	–	–	–	–	McLean 1956
	Uvigerina canariensis	–	AT	–	–	–	–	Anderegg in McLean 1956
	Uvigerina cf. *U. pigmea*	–	Y	–	–	–	–	Cushman and Cahill 1933
	Uvigerina cf. *U. tenuistriata*	–	Y	–	–	–	–	McLean 1956
	Uvigerina sp. (costate)	–	Y	–	–	–	–	Malkin 1953
	Foraminifera indet.	–	Y	–	–	–	Y	Malkin 1953; Ward and Blackwelder 1980

Taxonomic Notes

In addition to the specific notes below, a few general notes are provided here. The usage in the table for a given species is the farthest right in a bulleted entry. Non-botanical taxa described as varieties are here considered subspecies. Usage of *-a*, *-um*, and *-us* in specific epithets may vary from author to author (and within a publication), and *-ii* endings have often been shortened to *-i*.

Bivalves

- *Aligena aequata* = *Aligena striata*
- *Anomia aculeata* may be *Pododesmus* sp.
- *Arca centenaria* = *Barbatia centenaria* = *Striarca centenaria*
- *Arca incile* = *Noetia incile*
- *Arca lienosa* = *Sectiarca lienosa* = *Anadara lienosa*
- *Arca staminea* = *Anadara staminea*
- *Asaphis centenaria* = *Pleiorytis centenaria*
- *Brachidontes* (*Ischadium*) *recurvus* of Mansfield (1943) regarded as *B*. sp. in Campbell (1993)
- *Pseudochama corticosa* placed in *Chama* in Campbell (1993)
- *Cardita arata* = *Carditamera arata*
- *Cardita granulata* = *Venericardia granulata* = *Cyclocardia granulata*
- *Cardium* (*Cerastoderma*) *taeniopleura* = *Planicardium taeniopleura*
- *Cardium robustum* = *Dinocardium robustum*
- *Cardium virginianum* = *Cerastoderma virginianum* (Mansfield 1943) = *Planicardium virginianum* (Campbell 1993)
- *Cerastoderma acutilaqueatum* = *Chesacardium acutilaqueatum* = *Planicardium acutilaqueatum*
- *Codakia speciosa* = *Ctena speciosa*
- *Cooperella carpenteri* = *Cooperella parilis*
- *Corbula conradi* of Mansfield (1943) = *Corbula retusa*
- *Crassatellites lunulatus* = *Gouldia lunulata* = *Crassinella lunulata*
- *Cumingia medialis* = *Cumingia subtellinoides*
- *Cytherea sayana* = *Callocardia* (*Agriopoma*) *sayana* = *Pitar sayana*
- *Diplodonta berryi* = *Diplodonta punctulata*
- *Diplodonta elevata* = *Diplodonta nucleiformis*
- *Diplodonta leana* = *Diplodonta punctulata*
- *Diplodonta yorkensis* = *Cooperella parilis*, except for some specimens that are *D. punctulata* (Campbell 1993)

- *Gafrarium metastriatum* = *Gouldia metastriatum*
- *Glans* (*Pleuromeris*) *tridentata* = *Pleuromeris tridentata*
- *Glans* (*Pteromeris*) *perplana* = *Pteromeris perplana*
- *Glans* (*Pteromeris*) *perplana abbreviata* = *Pteromeris abbreviata* (the two *Pteromeris* species can be confused)
- *Glycymeris subovata* = *Costaglycymeris subovata*
- *Isocardia fraterna* = *Glossus fraternus*
- *Kuphus calamus* and *fistula* = *Teredo calamus* and *fistula* = *Teredina fistula*
- *Labiosa alta* = *Raeta alta*
- *Leda acuta* = *Nuculana acuta*
- *Macoma conradi* = *Macoma virginiana conradi* = *Macoma virginiana*
- *Macrocallista reposta* of most authors is *M. greeni* per Campbell (1993)
- Ward classification prefers *Marvacrassatella undulata*, Campbell classification prefers *Eucrassatella virginica*
- *Melina maxillata* record in Clark and Miller (1912) may be Eastover per discussion of taxon in Campbell (1993)
- *Mercenaria plena inflata* and *plena nucea* (and combinations with *Venus*) = *Mercenaria inflata*
- *Modiolaria virginica* = *Modiolus virginicus* = *Musculus virginicus*
- *Modiolus ducatelli* = indeterminate fragments (small), *M. inflatus* (large); true *M. ducatelli* is a middle Miocene species
- *Mya producta* of authors = *Mya arenaria*
- *Mytilus hamatus* = *Ischadium recurvum* = indeterminate in Yorktown Formation
- *Ostrea disparilis* = *Ostrea compressirostra*
- *Ostrea percrassa* = *Pycnodonte percrassa*
- *Ostrea raveneliana* = *Ostrea compressirostra*
- *Ostrea sculpturata* = *Conradostrea sculpturata*
- *Ostrea sellaeformis* = *Cubitostrea sellaeformis*
- *Ostrea virginica* = *Crassostrea virginica*
- *Pandora prodromos* = *Pandora crassidens* (includes *Clidiophora crassidens*)
- *Pecten clintonius* = *Chlamys* (*Placopecten*) *clintonia* = *Placopecten clintonius*
- *Pecten decemnarius* = *Chlamys decemnarius* = *Chlamys decemnaria*
- *Pecten eboreus* = *Chlamys eboreus* = *Argopecten eboreus* = *Carolinapecten eboreus*

- *Pecten edgecombensis* = *Pecten jeffersonius edgecombensis* = *Chlamys jeffersonia edgecombensis* = *Chesapecten edgecombensis* = *Chesapecten madisonius*
- *Pecten gibbus* = *Argopecten gibbus*
- *Pecten jeffersonius* = *Chlamys* (*Lyropecten*) *jeffersonia* = *Chesapecten jeffersonius*
- *Pecten madisonius* = *Chesapecten madisonius*
- *Periploma* (*Cochlodesma*) *antiqua* = *Cochlodesma antiqua*
- *Petricola* (*Petricolaria*) *pholadiformis* = *Petricola pholadiformis*
- *Petricola* (*Rupellaria*) *grinnelli* = *Rupellaria pectarosa*
- *Petricola compressa* = *Sportella compressa* = *Ensitellops compressa*
- *Petricola harrisii* = *Pleiorytis centenaria*
- *Petricola rogeri*/*rogersi* = *Petricola pholadiformis*
- *Phacoides* (*Cardiolucina*) *postalveatus* = *Parvilucina postalveata*
- *Phacoides anodonta* = *Phacoides* (*Pseudomiltha*) *anodonta* = *Pseudomiltha anodonta* (Campbell 1993) = *Stewartia anodonta* (Ward 1992)
- *Phacoides crenulatus* = *Parvilucina crenulatus* = *Parvilucina crenulata*
- *Phacoides cribrarius* = *Phacoides* (*Lucinisca*) *cribrarius* = *Lucinisca cribrarius*
- *Pholadomya abrupta* [*abrupta*] = *Margaritaria abrupta*
- *Pitar morrhuanus* = *Pitar morrhuana* = *Pitar sayana*
- *Plicatula marginata* = *Plicatula gibbosa*
- Some *Bornia triangula* may be *Bornia rota*, including specimens identified in Mansfield (1943) (Campbell 1993)
- *Spisula* (*Hemimactra*) *modicella* = “Spisula” *modicella* = *Spisula modicella*
- *Tagelus gibbus* = *Tagelus plebeius*
- *Tellina declivis* = *Moerella declivis*
- *Tellina gardnerae* = *Tellina egena*
- *Tellina propetenella* = *Tellina dupliniana*
- *Thracia conradi* of the Yorktown Formation = *Thracia magna*
- *Venus* (*Mercenaria*) *campechiensis rileyi* = *Venus rileyi* = *Mercenaria corrugata*
- *Venus* (*Mercenaria*) *mercenaria notata* of Mansfield (1943) = *Mercenaria mercenaria*
- *Venus tridacnoides* = *Venus* (*Mercenaria*) *campechiensis tridacnoides* = *Mercenaria campechiensis tridacnoides* = *Mercenaria corrugata* “tridacnoides” = *Mercenaria tridacnoides*

Gastropods

- *Actaeon* = *Acteon*
- *Anachis harrisii* = *Anachis parvula*
- *Architectonica nupera* (=*Solarium nuperum*) = *Pseudotorinia nupera*
- *Busycon* (*Sycotypus*) *incile* = *Busycon incile* = *Busycon incilis* = *Busycotypus incile*
- *Busycon maximus* also seen as *B. maximum*
- *Calliostoma basicum* considered a subspecies of *C. mitchelli* in Campbell (1993)
- *Calliostoma conradi* = *Calliostoma lapidosum*
- *Calliostoma harrisii* considered a subspecies of *C. virginicum* in Campbell (1993)
- *Calliostoma philanthropus* considered a subspecies of *C. mitchelli* in Campbell (1993)
- *Calliostoma philanthropus* var. *basicum* = *Calliostoma basicum*
- *Cerithiopsis emersonii persubulata* = *Cerithiopsis bicolor persubulata*
- *Conus diluvianus* = *Conus marylandicus*
- *Crepidula aculeata* var. *costata* = *Crepidula costata* = *Bostrycapulus aculeatus* var. *costata* = *Bostrycapulus aculeatus costata*
- *Crepidula spinosa* = *Bostrycapulus aculeatus costata*
- *Crucibulum auricula* var. *imbricata* = *Crucibulum scutellatum* (potentially *Crucibulum ramosum*)
- *Diadora* = *Diodora*
- *Diodora redimicula virgilina* = *Diodora oblonga*
- *Dispotaea constrictum* = *Crucibulum constrictum*
- *Drillia eburnea* = “Drillia” *eburnea* = *Compsodrillia eburnea*
- *Eulima* (*Liostraca*) *rectiuscula* = *Eulima ephamilla*
- *Fissuridea redimicula* = *Diodora redimicula*
- *Fulgur maximum* = *Busycon maximus*
- *Fulgur perversum* = *Busycon perversum*
- *Fulgur pyrum* var. *incile* = *Busycotypus incile*
- *Fusus 4-costatus* = *Fusus quadricostatus* = *Ecphora quadricostata*
- *Fusinus burnsii* used as subspecies of *F. exilis* in Campbell (1993)
- *Granulina ovuliformis* of Yorktown Formation does not appear to be true *G. ovuliformis*
- *Ilyanassa* (*Paranassa*) *isogramma* = *Ilyanassa isogramma*
- *Ilyanassa isogramma* of Yorktown Formation = *Ilyanassa sexdentata*
- *Ilyanassa scalaspira* regarded as at best a subspecies of *I. harpuloides* in Campbell (1993)

- *Lemintina granifera* = *Serpulorbis granifera* (Campbell 1993; should seemingly be *Thylacodes*)
- *Lirosoma* misspelled as *Lyrosoma* in Campbell (1993)
- *Marginella bella* has confusing taxonomy (Campbell 1993, which seems to have it in *Prunum* but is unclear)
- *Marginella limatula* = *Prunum limatulum*
- *Murex umbrifer* = *Pterorytis umbrifer*
- *Nassa harpuloides* = *Ilyanassa harpuloides*
- *Oliva litterata* of Clark and Miller (1912) = *Oliva canaliculata*
- *Peristernia filicata* = *Hesperisternia filicata*
- *Polinices duplicatus* = *Polynices duplicata* = *Neverita duplicata*
- *Polynices* or *Polinices heros* = *Lunatia heros* = *Euspira heros*; Yorktown Formation *Lunatia heros* placed in *Lunatia sayana* by Campbell (1993), which becomes *Euspira sayana*
- *Ptychosalpinx altilis* regarded by Campbell (1993) as unjustified emendation of *P. altile*, but this has not caught on
- *Ptychosalpinx fossulata* = *Ptychosalpinx tuomeyi*
- *Scaphella obtusa* = *Aurinia obtusa*
- *Serpulorbis granulifera* = *Serpulorbis granifera*
- *Sinum fragile* = *Sinum chesapeakensis*
- *Strombiformis bartschi* = *Melanella laevigata*
- *Teinostoma pseudaeorbis* = *Cyclostremiscus pseudaeorbis*
- *Terebra* (*Strioterebrum*?) *grayi* = *Terebra emmonsii grayi*
- *Terebra* (*Strioterebrum*?) *neglecta* = *Terebra emmonsii emmonsii*
- *Trifora* is a typo for *Triphora*
- *Tritonalia*? *barbitoides* = *Urosalpinx barbitoides*
- *Trophon tetricus* = *Boreotrophon tetricus*
- *Turritella terebriformis* = *Turritella alticostata*
- *Turritella variabilis* proper is a Miocene species and preoccupied; Campbell (1993) renamed the Yorktown Formation example *Turritella virginica*
- *Urosalpinx suffolkensis* = *Urosalpinx lepidota*
- *Uzita neogenensis* of Gardner (1948) = *Nassarius quadrulatus* (Campbell 1993)
- *Uzita smithiana* of Gardner (1948) = *Nassarius quadrulatus* (Campbell 1993)
- *Vermetus sculpturatus* = *Petaloconchus sculpturatus*

- *Vermetus virginica* of Roberts (1932) = *Serpulorbis granulifera* (Campbell 1993)

Scaphopods

- *Dentalium dentale* = *Dentalium attenuatum*

Barnacles

- *Balanus proteus* = *Balanus concavus proteus* = *Chesaconcavus proteus*

Ostracodes

- *Acuticythereis laevissima* = *Campylocythere laevissima* (same for subspecies *laevissima* and *punctata*)
- *Clithrocytheridea diagonalis* = *Cytheridea diagonalis*
- *Clithrocytheridea virginiensis* = *Cytheridea virginiensis*
- *Cytheretta burnsi* = *Pseudocytheretta burnsi*
- Per Forester (1980), *Cytheretta ulrichi* was an unneeded replacement name for *Cythere plebia*, superseded by *Pseudocytheretta porcella*, which is apparently the same as *Pseudocytheretta plebia*. However, the *Cytheretta ulrichi* of McLean (1957) is not the same as *plebia*, and according to the text seems to be *burnsi*.
- *Cytherideis agricola* = *Pontocythere* (*Hulingsina*) *agricola*
- *Cytherideis ashermani* = *Cushmanidea ashermani* = *Hulingsina ashermani*; per Forester (1980), the original material of *Cytherideis ashermani* included multiple taxa, and the specimens recorded by the Yorktown Formation authorities are *Hulingsina* sp. or spp., here *Pontocythere* (*Hulingsina*) sp. or spp.
- *Cytherideis echolsae* = *Cushmanidea echolsae* = *Hulingsina rugipustulosa* = *Pontocythere* (*Hulingsina*) *rugipustulosa*
- *Cytherideis rugipustulosa* = *Hulingsina rugipustulosa* = *Pontocythere* (*Hulingsina*) *rugipustulosa*
- *Cytherideis subaequalis ulrichi* = *Cushmanidea ulrichi*
- *Eocytheropteron yorktownensis* = *Shattuckocythere yorktownensis* = *Cytheropteron*? *yorktownensis* (except for some specimens figured in Swain [1974] which are not from COLO)
- *Favella rugipunctata* = *Puriana rugipunctata*
- *Hemicythere conradi* = *Aurila* (typo *Aurilia*) *conradi* = *Malzella conradi*
- *Hemicythere schmidtae* = *Thaerocythere schmidtae*
- *Hemicytherura howei* = *Cytherura howei*
- *Leguminocythereis whitei* = *Bensonocythere whitei*
- *Loxoconcha subrhomboidea* of Malkin (1953) = *Loxoconcha purisubrhomboidea* (*Loxocorniculum purisubrhomboidea* of some authorities)

- *Murrayina barclayi* = *Costa barclayi*
- *Paracytheridea shattucki curta* = *Microcytherura curta*
- *Paracytheridea similis* of Malkin (1953) = *Microcytherura similis*
- *Paracytheridea vandenboldi* = *Paracytheridea altila*
- *Pterygocythereis americana* of McLean (1957) and Swain (1974) = *Pterygocythereis inexpectata* (Forester 1980)
- *Trachyleberis gomillionensis* = *Actinocythereis exanthemata gomillionensis*
- *Trachyleberis martini* = *Murrayina martini*; *Murrayina martini* of Malkin (1953) and McLean (1957) = *Muellerina micula* (Swain 1974; Forester 1980)

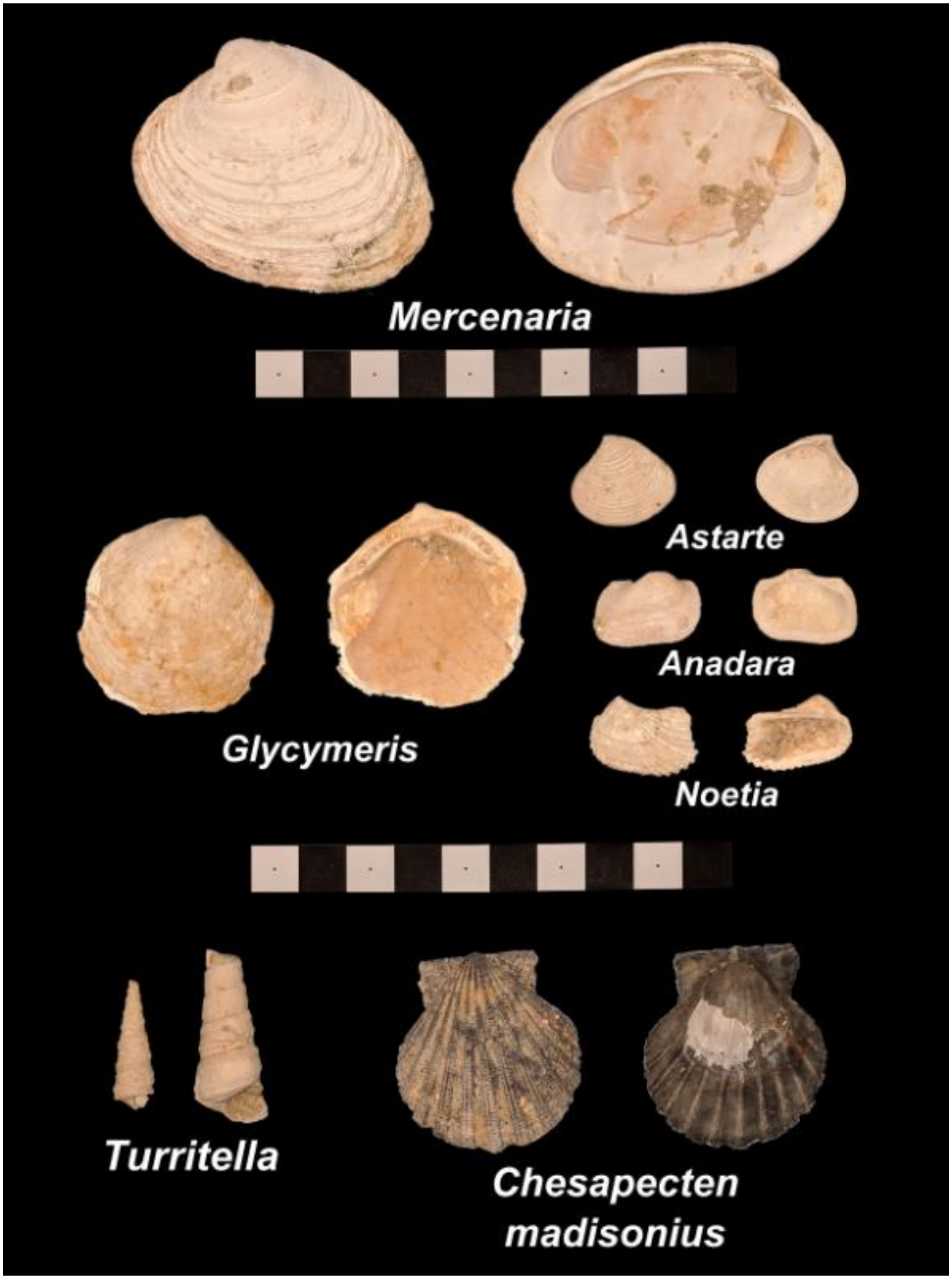
Foraminifera

- *Elphidium incerta* = *Elphidium incertum*
- *Eponides lateralis* = *Poroeponides lateralis*
- *Pulvinulina menardii* = *Globorotalia menardii*

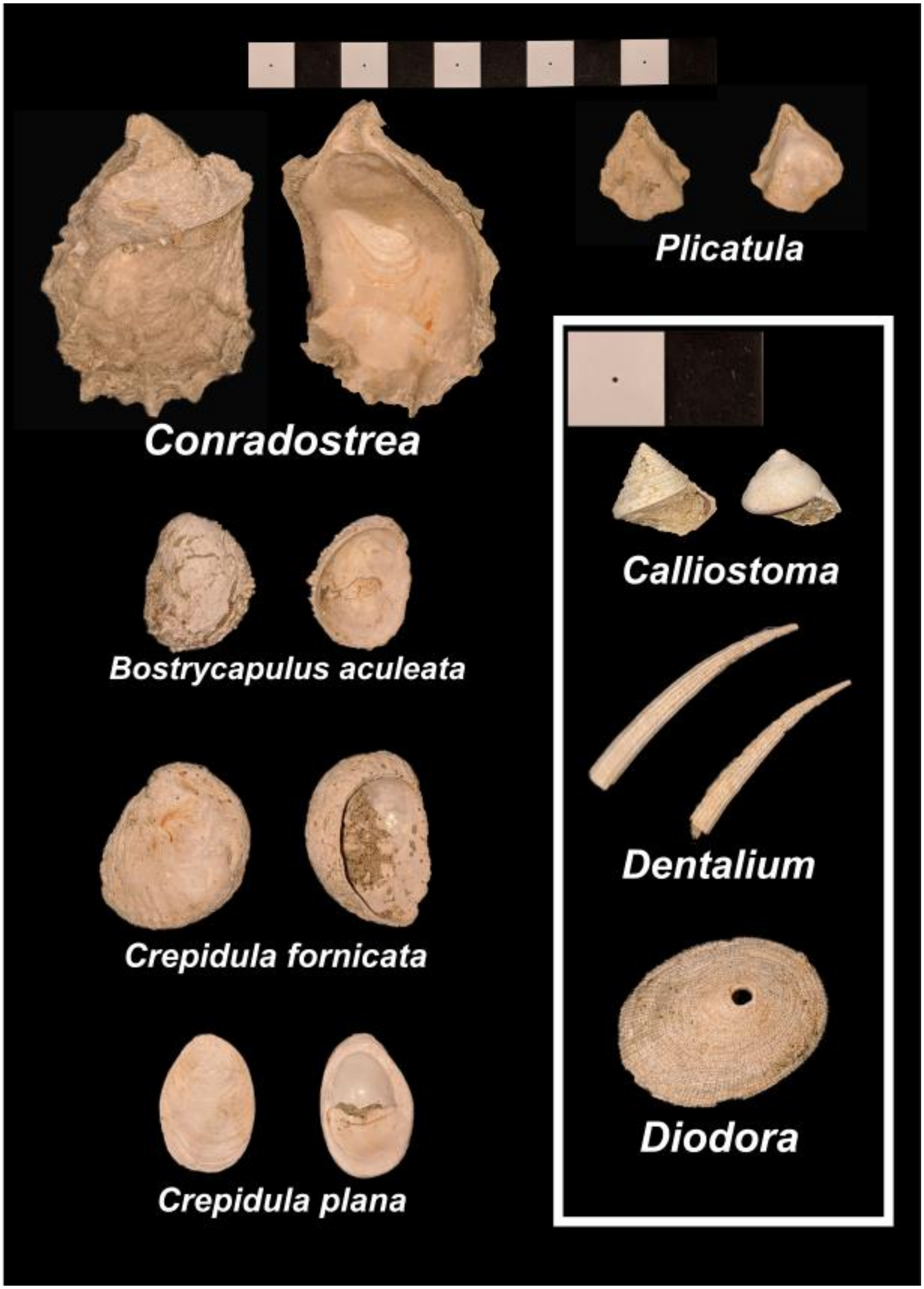
Mammals

- *Prorosmarus alleni* = *Ontocetus emmonsi*

Appendix B: Plates of Common COLO Fossils



Appendix Figure B-1. A figure showing photos of several common mollusk fossils at the same scale: the clams *Mercenaria*, *Glycymeris*, *Astarte*, *Anadara*, and *Noetia*, the scallop *Chesapecten*, and the snail *Turritella*. Internal and external views of the clam shells are provided.



Appendix Figure B-2. A figure showing several examples of bivalves (*Conradostrea* and *Plicatula*), gastropods (*Bostrycapulus aculeata*, *Crepidula fornicata*, *Crepidula plana*, *Calliostoma*, and *Diodora*), and scaphopods (*Dentalium*). The smaller shells (*Calliostoma*, *Dentalium*, and *Diodora*) are in an inset with their own scale. Multiple views are provided for all but the limpet *Diodora*.

Appendix C: Taxa Named from COLO Fossils

The following taxa listed in Appendix C-Table 1 were described from fossils collected within COLO, although in most cases before it was established as a unit of the NPS in 1930. Many of the species have since been assigned to other genera, or synonymized with other species; original usage is given here. A similar appendix (Appendix D) follows, listing species named from specimens possibly collected within COLO.

Institutional Abbreviations—**ANSP**, The Academy of Natural Sciences of Drexel University, Philadelphia, Pennsylvania; **PRI**; Paleontological Research Institution, Ithaca, New York; **USNM**, Smithsonian Institution, National Museum of Natural History, Washington, D.C. Additional information about these repositories can be found in Appendix E.

Appendix C-Table 1. Fossil taxa (type specimens) named from specimens found within COLO.

Taxonomic Group	Taxon	Citation	Age, Formation	Type Specimen
Bivalvia	*Diplodonta berryi*	McGavock 1944	Pliocene, Yorktown	ANSP 16013
	Diplodonta conradi	McGavock 1944	Pliocene, Yorktown	ANSP 16014
	Petricola (*Rupellaria*) *harrisii*	Dall 1900	Pliocene, Yorktown	USNM 145020
	Petricola rogersi	McGavock 1944	Pliocene, Yorktown	ANSP 16015
	Venus plena var. *inflata*	Dall 1903	Pliocene, Yorktown	USNM 163419
	Venus plena var. *nucea*	Dall 1903	Pliocene, Yorktown	USNM 163418
Gastropoda	*Calliostoma harrisii*	Dall 1892	Pliocene, Yorktown	USNM 113052
	Ilyanassa (*Paranassa*) *isogramma*	Dall 1892	Pliocene, Yorktown	USNM 124948
	Teinostoma pseudaeorbis	Dall 1892	Pliocene, Yorktown	USNM 112653
Ostracoda	*Clithrocytheridea virginiensis*	Malkin 1953	Pliocene, Yorktown	Syntypes USNM 256020, 311894, 311960, 311961, and 311962
	Cytherideis echolsae	Malkin 1953	Pliocene, Yorktown	Syntypes USNM 256023, 311872, 311873, and 311874

Appendix C-Table 1 (continued). Fossil taxa (type specimens) named from specimens found within COLO.

Taxonomic Group	Taxon	Citation	Age, Formation	Type Specimen
Ostracoda (continued)	*Eocytheropteron yorktownensis*	Malkin 1953	Pliocene, Yorktown	Syntypes USNM 256025, 311940, 311941, and 311959 (not all from COLO)
	Hemicythere schmidtae	Malkin 1953	Pliocene, Yorktown	Syntypes USNM 256033, 311936, 311937, 311970, and 311971 (not all from COLO)
	Murrayina barclayi	McLean 1957	Pliocene, Yorktown	PRI 22588
	Paracytheridea shattucki curta	Malkin 1953	Pliocene, Yorktown	Syntypes USNM 256037, 311893, and 311976 (not all from COLO)
	Paracytheridea similis	Malkin 1953	Pliocene, Yorktown	Syntypes USNM 256038 and 311939
Foraminifera	*Bolivina lafayettei*	McLean 1956	Pliocene, Yorktown	PRI 22299
	Dentalina kaicherae	McLean 1956	Pliocene, Yorktown	PRI 22145
	Elphidium kaicherae	McLean 1956	Pliocene, Yorktown	PRI 22282
	Lagena pseudosulcata	McLean 1956	Pliocene, Yorktown	PRI 22174
	Loxostomum wilsoni	McLean 1956	Pliocene, Yorktown	PRI 22301
	Massilina mansfieldi	Cushman and Cahill 1933	Pliocene, Yorktown	USNM 37135
	Orbulina cornwallisi	McLean 1956	Pliocene, Yorktown	PRI 22411
	Quinqueloculina triloculiniforma	McLean 1956	Pliocene, Yorktown	PRI 22111
	Rotalia limbatobeccarii	McLean 1956	Pliocene, Yorktown	Syntypes PRI 22365–22369

Appendix D: Taxa Potentially Named from COLO Fossils

The following taxa listed in Appendix D-Table 1 were described from fossils collected somewhere in or near COLO, but the locality information is insufficient to be certain about the exact location. Most of them were named before the 20th century. The provenance for many of them is limited to the Yorktown Formation of Yorktown. As with Appendix C, many of the species have been assigned to other genera, or synonymized with other species; original usage is given here.

Institutional Abbreviations—**ANSP**, The Academy of Natural Sciences of Drexel University, Philadelphia, Pennsylvania; **BMNH**, Natural History Museum, London, United Kingdom; **MCZ**, Museum of Comparative Zoology, Cambridge, Massachusetts; **PRI**; Paleontological Research Institution, Ithaca, New York; **USNM**, Smithsonian Institution, National Museum of Natural History, Washington, D.C. Additional information about these repositories can be found in Appendix E.

Appendix D-Table 1. Fossil taxa potentially named from specimens found within COLO.

Taxonomic Group	Taxon	Citation	Age, Formation	Type Specimen
Bivalvia	*Abra ovalis*	Conrad 1862a	Pliocene, Yorktown	Missing ANSP specimen
	Amphidesma subovata	Say 1824	Pliocene, Yorktown	BMNH L-13298
	Anatina antiqua	Conrad 1834	Pliocene, Yorktown	ANSP 19648
	Arca centenaria	Say 1824	Pliocene, Yorktown	BMNH L-13206
	Arca incile	Say 1824	Pliocene, Yorktown	BMNH L-13205
	Astarte concentrica	Conrad 1834	Pliocene, Yorktown	Missing ANSP specimen
	Astarte orbicularior	Meyer 1888	Pliocene, Yorktown	USNM 638907
	Astarte symmetrica	Conrad 1834	Pliocene, Yorktown	Missing ANSP specimen
	Astarte undulata	Say 1824	Pliocene, Yorktown	Missing BMNH specimen
	Astarte vicina	Say 1824	Pliocene, Yorktown	Missing BMNH specimen
	Cardium acutilaqueatum	Conrad 1839	Pliocene, Yorktown	Missing ANSP specimen
	Corbula cuneata	Say 1824	Pliocene, Yorktown	Lost BMNH specimen
	Corbula inaequale	Say 1824	Pliocene, Yorktown	Lost BMNH specimen
	Crassinella lunulata harrisi	Gardner 1943	Pliocene, Yorktown	USNM 1630

Appendix D-Table 1 (continued). Fossil taxa potentially named from specimens found within COLO.

Taxonomic Group	Taxon	Citation	Age, Formation	Type Specimen
Bivalvia (continued)	*Cytherea convexa*; preoccupied, renamed *Cytherea sayana* (Conrad 1833)	Say 1824	Pliocene, Yorktown	BMNH L-13210
	Cytherea pandata	Conrad 1834	Pliocene, Yorktown	Syntypes ANSP 30573 and 30574?
	Diplodonta yorkensis	Dall 1900	Pliocene, Yorktown	USNM 144548
	Erycinella ovalis	Conrad 1845	Pliocene, Yorktown	ANSP 30621
	Gemma magna virginiana	Dall 1903	Pliocene, Yorktown	Cotypes including USNM 144643
	Isocardia fraterna	Say 1824	Pliocene, Yorktown	BMNH L-13202
	Lithophaga pectinicola	Olsson 1916	Pliocene, Yorktown	PRI 1372
	Lithophaga yorkensis	Olsson 1914	Pliocene, Yorktown	PRI 3491 and 3493
	Lucina acclinis	Conrad 1832	Pliocene, Yorktown	Missing ANSP specimen
	Lucina anodonta	Say 1824	Pliocene, Yorktown	BMNH L-13198
	Lucina contracta	Say 1824	Pliocene, Yorktown	BMNH L-13196
	Lucina cribraria	Say 1824	Pliocene, Yorktown	Unnumbered BMNH specimen
	Macoma cookei	Gardner 1943	Pliocene, Yorktown	USNM 325592
	Macoma virginiana	Conrad 1866	Pliocene, Yorktown	Missing ANSP specimen
	Mactra clathrodon	Lea 1833	Pliocene, Yorktown	ANSP 3309
	Mactra clathrodonta	Conrad 1833	Pliocene, Yorktown	ANSP 16242
	Mactra confraga	Conrad 1833	Pliocene, Yorktown	ANSP 30560
	Mactra modicella	Conrad 1833	Pliocene, Yorktown	ANSP 4311
	Mactra virginiana	Conrad 1867a	Pliocene, Yorktown	Missing ANSP specimen
	Modiolaria virginica	Conrad 1867b	Pliocene, Yorktown	Missing ANSP specimen
	Montacuta sagrinata	Dall 1900	Pliocene, Yorktown	USNM 155772
	Mya producta	Conrad 1839	Pliocene, Yorktown	Missing ANSP specimen (possibly at the Wagner Free Institute of Science)

Appendix D-Table 1 (continued). Fossil taxa potentially named from specimens found within COLO.

Taxonomic Group	Taxon	Citation	Age, Formation	Type Specimen
Bivalvia (continued)	*Mytillus lateralis*	Say 1822	Pliocene, Yorktown	ANSP 52663
	Natica interna	Say 1824	Pliocene, Yorktown	BMNH GG12655
	Nucula laevis	Say 1824	Pliocene, Yorktown	Missing BMNH specimen
	Ostrea compressirostra	Say 1824	Pliocene, Yorktown	BMNH L-13204
	Pandora (*Clidiophora*) *prodromos*	Gardner and Aldrich 1919	Pliocene, Yorktown	USNM 325499
	Pandora arenosa	Conrad 1834	Pliocene, Yorktown	ANSP 30584
	Panopaea reflexa	Say 1824	Pliocene, Yorktown	BMNH L-13200a
	Pecten clintonius	Say 1824	Pliocene, Yorktown	BMNH L-13203
	Pecten jeffersonius	Say 1824	Pliocene, Yorktown	BMNH L-13212
	Pecten madisonius	Say 1824	Pliocene, Yorktown	ANSP 31787
	Pecten septenarius	Say 1824	Pliocene, Yorktown	BMNH L-13197
	Pecten yorkensis	Conrad 1867a	Pliocene, Yorktown	Missing ANSP specimen
	Pectunculus subovatus	Say 1824	Pliocene, Yorktown	BMNH L-13209
	Phacoides (*Cardiolucina*) *postalveatus*	Gardner 1943	Pliocene, Yorktown	USNM 325539
	Pholadomya abrupta	Conrad 1832	Pliocene, Yorktown	Syntypes ANSP 20386
	Plicatula marginata	Say 1824	Pliocene, Yorktown	BMNH L-13199
	Semele? *virginiana*	Meyer 1888	Pliocene, Yorktown	USNM 638911
	Sportella yorkensis	Dall 1900	Pliocene, Yorktown	USNM 144323
	Tellina aequistriata	Say 1824	Pliocene, Yorktown	Missing BMNH specimen
	Tellina declivis	Conrad 1834	Pliocene, Yorktown	ANSP 4306
	Tellina gardnerae	McGavock 1944	Pliocene, Yorktown	ANSP 16012
	Venericardia granulata	Say 1824	Pliocene, Yorktown	Unnumbered BMNH specimen
	Venus rileyi	Conrad 1839	Pliocene, Yorktown	Syntypes ANSP 20084

Appendix D-Table 1 (continued). Fossil taxa potentially named from specimens found within COLO.

Taxonomic Group	Taxon	Citation	Age, Formation	Type Specimen
Gastropoda	*Anachis harrisii*	Dall 1892	Pliocene, Yorktown	USNM 113258
	Buccinum porcinum	Say 1824	Pliocene, Yorktown	BMNH Q-12191
	Busycon alveatum	Conrad 1862b	Pliocene, Yorktown?	ANSP 2697
	Busycon filosum	Conrad 1862a	Pliocene, Yorktown	ANSP 14310
	Busycon tritonis	Conrad 1862b	Pliocene, Yorktown	ANSP 14323 and 14324
	Caecum stevensoni	Meyer 1888	Pliocene, Yorktown	Missing AMNH specimen
	Caecum virginianum	Meyer 1888	Pliocene, Yorktown	Missing AMNH specimen
	Calliostoma conradi	Gardner 1948	Pliocene, Yorktown	USNM 325468
	Calliostoma virginicum gizehi	Gardner 1948	Pliocene, Yorktown	USNM 325467
	Calyptraea costata	Say 1824	Pliocene, Yorktown	ANSP 15294
	Calyptraea grandis	Say 1824	Pliocene, Yorktown	BMNH Q-12190
	Conus marylandicus	Green 1830	Pliocene, Yorktown	Unknown
	Delphinula arenosa	Conrad 1846	Pliocene, Yorktown	Missing ANSP specimen
	Fissurella redimicula	Say 1824	Pliocene, Yorktown	Missing BMNH specimen
	Fulgur incilis	Conrad 1833	Pliocene, Yorktown	ANSP 1637
	Fulgur maximus	Conrad 1839	Pliocene, Yorktown	ANSP 17191
	Fusus pumilis	Lea 1833	Pliocene, Yorktown	ANSP 13827a
	Fusus quadricostatus (originally *4-costatus*)	Say 1824	Pliocene, Yorktown	BMNH GG 12661
	Mangelia virginiana	Conrad 1862a	Pliocene, Yorktown	ANSP 30737
	Melampus (*Ensiphorus*) *longidens*	Conrad 1862b	Pliocene, Yorktown	Missing ANSP specimen
	Natica perspectiva	Rogers and Rogers 1837	Pliocene, Yorktown	Unknown
	Odostomia limnia	Conrad 1846	Pliocene, Yorktown	Missing ANSP specimen
	Odostomia protexta	Conrad 1846	Pliocene, Yorktown	ANSP 15631?
	Pyramis promilium	Meyer 1888	Pliocene, Yorktown	USNM 638905
	Rotella nana	Lea 1833	Pliocene, Yorktown	ANSP 1569

Appendix D-Table 1 (continued). Fossil taxa potentially named from specimens found within COLO.

Taxonomic Group	Taxon	Citation	Age, Formation	Type Specimen
Gastropoda (continued)	*Teinostoma* (*Solariorbis*) *variabilis*	Olsson 1914	Pliocene, Yorktown	PRI 3512
	Terebra (*Strioterebrum*?) *grayi*	Gardner 1948	Pliocene, Yorktown	USNM 325369
	Tritonalia? *barbitoides*	Gardner 1948	Pliocene, Yorktown	USNM 325429
	Turritella fluxionalis	Rogers and Rogers 1839	Pliocene, Yorktown	Unknown
	Turritella quadristriata (originally designated *quadri-striata*)	Rogers and Rogers 1837	Pliocene, Yorktown	MCZ 113589
Scaphopoda	*Dentalium attenuatum*	Say 1824	Pliocene, Yorktown	Unnumbered BMNH specimen
Serpulidae	*Serpula granifera*	Say 1824	Pliocene, Yorktown	BMNH GG12662
Cirripedia	*Balanus finchii*	Lea 1833	Pliocene, Yorktown	Unknown
	Balanus proteus	Conrad 1834	Pliocene, Yorktown	ANSP 18813?
Mammalia	*Prorosmarus alleni*	Berry and Gregory 1906	Pliocene, Yorktown	USNM 9343
Foraminifera	*Miliola marylandica*	Lea 1833	Pliocene, Yorktown	ANSP 79409
	Spirillina orbicularis	Bagg 1898	Pliocene, Yorktown	USNM 371526

Appendix E: Repositories

Contact information for institutions known to have collections from COLO or with significant "Yorktown" collections are included below. Addresses, links, and email addresses to departments are included as available. This information is subject to change, particularly hyperlinks. Many other institutions potentially have specimens collected from lands now within COLO, but vague or nonexistent locality information prevents establishing this for certain.

The Academy of Natural Sciences of Drexel University (ANSP)
1900 Benjamin Franklin Parkway
Philadelphia, PA 19103
https://ansp.org

American Museum of Natural History (AMNH)
Central Park West at 79th Street
New York, NY 10024
https://www.amnh.org/research/paleontology/collections/fossil-invertebrate-collection (Fossil Invertebrates)

Cincinnati Museum Center (CMC)
1301 Western Avenue
Cincinnati, OH 45203
https://www.cincymuseum.org/
information@cincymuseum.org

Cleveland Museum of Natural History (CMNH)
1 Wade Oval Drive
Cleveland, OH 44106
https://www.cmnh.org/

Florida Museum of Natural History (FLMNH)
3215 Hull Rd
Gainesville, FL 32611
https://www.floridamuseum.ufl.edu/

Harvard Museum of Comparative Zoology (MCZ)
26 Oxford St.
Cambridge, MA 02138
https://mcz.harvard.edu

Louisiana Museum of Natural History
119 Foster Hall
Louisiana State University
Baton Rouge, LA 70803
https://www.lsu.edu/lmnh/index.php
The Louisiana Museum of Natural History includes the Louisiana State University Museum of Natural Sciences, which in turn includes the Louisiana State University Museum of Geoscience.

The Natural History Museum, London (BMNH)
Cromwell Rd., South Kensington
London SW7 5BD
United Kingdom
https://www.nhm.ac.uk/

Natural History Museum of Los Angeles County (LACM)
900 Exposition Blvd
Los Angeles, CA 90007
https://nhm.org/
invpaleo@nhm.org (Invertebrate Paleontology Department)

Paleontological Research Institution (PRI)
1259 Trumansburg Rd.
Ithaca, NY 14850
https://www.priweb.org/

Peabody Museum of Natural History at Yale University (YPM)
P.O. Box 208118
170 Whitney Ave
New Haven, CT 06520
https://peabody.yale.edu/
peabody.collections@yale.edu

Smithsonian Institution, National Museum of Natural History (USNM)
Department of Paleobiology
P.O. Box 37012
NHB MRC 121
Washington, DC 20013
https://naturalhistory.si.edu/research/paleobiology
paleodept@si.edu

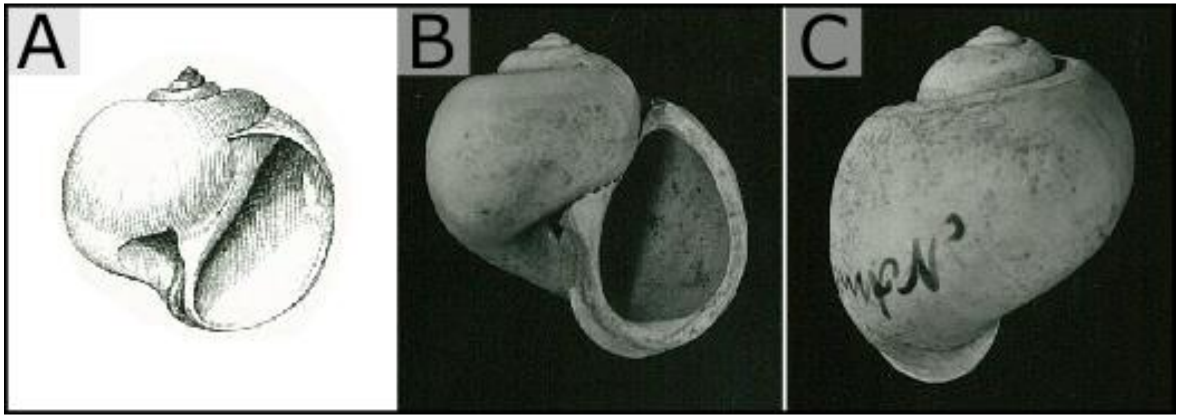
University of California Museum of Paleontology (UCMP)
Museum of Paleontology
University of California
1101 Valley Life Sciences Building
Berkeley, CA 94720
https://ucmp.berkeley.edu/

University of Kansas (KU)
KU Biodiversity Institute & Natural History Museum
1345 Jayhawk Blvd.
Lawrence, KS 66045
https://biodiversity.ku.edu/home
biodiversity@ku.edu

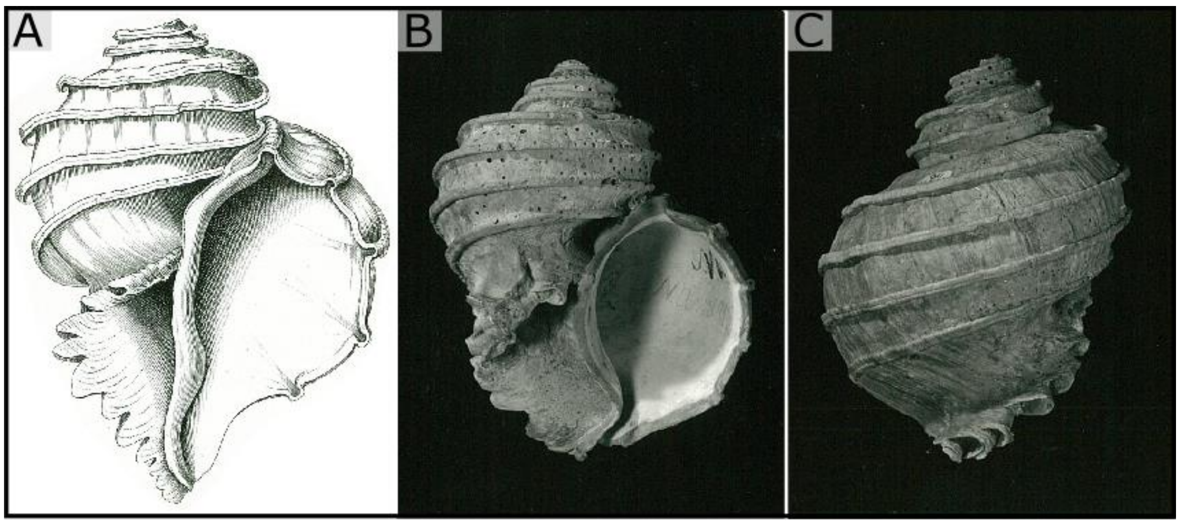
Virginia Division of Geology and Mineral Resources
Department of Mines, Minerals and Energy
900 Natural Resources Drive, Ste 500
Charlottesville, VA 22903
https://www.dmme.virginia.gov/dgmr/divisiongeologymineralresources.shtml
dgmrinfo@dmme.virginia.gov

Virginia Museum of Natural History (VMNH)
21 Starling Avenue
Martinsville VA 24112
https://www.vmnh.net/research-collections
information@vmnh.virginia.gov

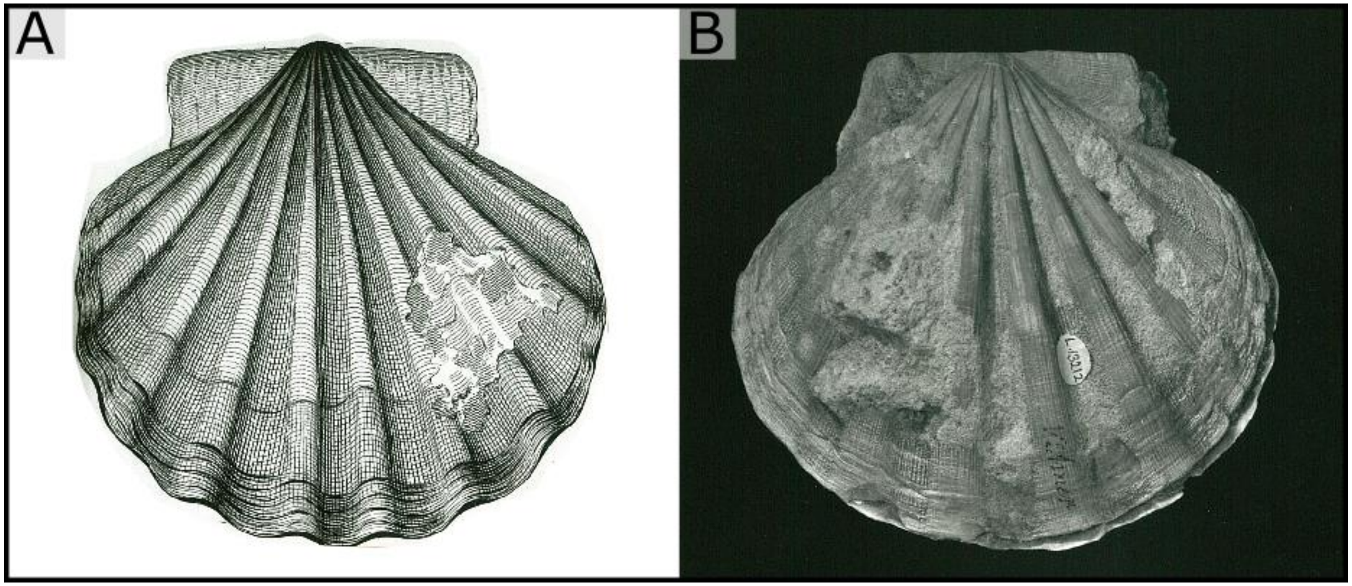
Thomas Say described more than 30 species of fossil mollusks from specimens collected in the Yorktown area (Say 1824); at least some and potentially all came from lands now within COLO. These species include some of the most significant Yorktown Formation species. The collection is reposited at the Natural History Museum in London, although a few of the type specimens have gone missing over the years. In the 1970s, Lauck Ward and Blake Blackwelder, then working for the U.S. Geological Survey, requested the specimens for study and took photographs of them. Photographs of these important type specimens have rarely appeared elsewhere (e.g., Ward and Blackwelder [1975] for Say's species now assigned to *Chesapecten*). A selection of the type specimens representing the most common Yorktown Formation species is included below, with Say's illustrations for comparison (Appendix E Photo 1 through Appendix E Photo 6).



Appendix E-Photo 1. BMNH specimen GG12655, type specimen of *Euspira interna* (originally named *Natica interna*), from Say's 1824 monograph. **A.** Say's original sketch of the specimen. **B.** Matching internal view of the specimen. **C.** External view of the specimen. Photos courtesy of Lauck Ward and Blake Blackwelder.

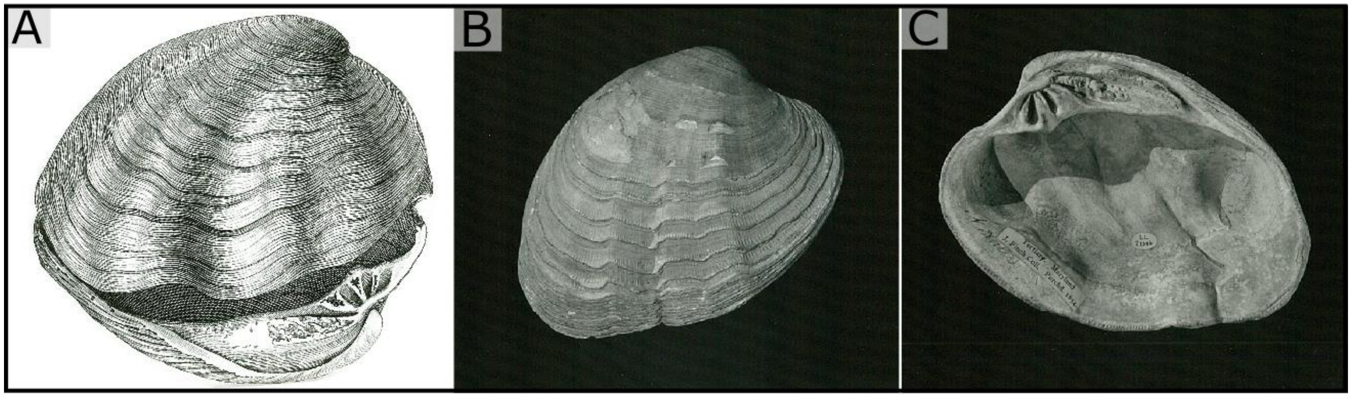


Appendix E-Photo 2. BMNH specimen GG12661, type specimen of *Ecphora quadricostatus* (originally named *Fusus 4-costatus*), from Say's 1824 monograph. **A.** Say's original sketch of the specimen. **B.** Matching internal view of the specimen. **C.** External view of the specimen. Photos courtesy of Lauck Ward and Blake Blackwelder.

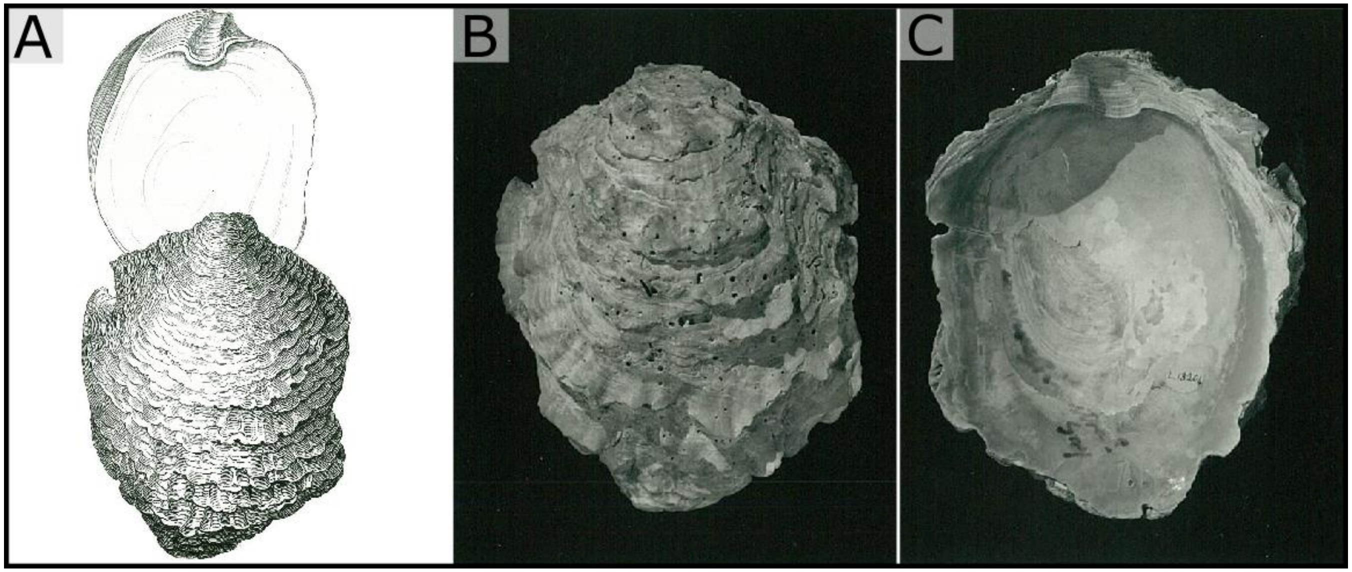


Appendix E-Photo 3. BMNH specimen L13212, type specimen of *Chesapecten jeffersonius* (originally named *Pecten jeffersonius*), from Say's 1824 monograph. **A.** Say's original sketch of the specimen. **B.** External view of the opposite valve. Photos courtesy of Lauck Ward and Blake Blackwelder.

Appendix E-Photo 4. BMNH specimen L13200, type specimen of *Panopea reflexa* (originally named *Panopaea reflexa*), from Say's 1824 monograph. **A.** Say's original sketch of the specimen. **B.** External view of the specimen. **C.** Internal view of the specimen. Photos courtesy of Lauck Ward and Blake Blackwelder.



Appendix E-Photo 5. BMNH specimen LL27396, *Mercenaria campechiensis tridacnoides* (type specimen of *Venus deformis*), from Say's 1824 monograph. **A.** Say's original sketch of the specimen. **B.** External view of the specimen. **C.** Internal view of the specimen. Photos courtesy of Lauck Ward and Blake Blackwelder.



Appendix E-Photo 6. BMNH specimen L13204, type specimen of *Ostrea compressirostra*, from Say's 1824 monograph. **A.** Say's original sketch of the specimen. **B.** External view of the specimen. **C.** Internal view of the specimen. Photos courtesy of Lauck Ward and Blake Blackwelder.

Appendix F: Paleontological Resource Law and Policy

The following material is reproduced in large part from Henkel et al. (2015); see also Kottkamp et al. (2020).

In March 2009, the Paleontological Resources Preservation Act (PRPA) (16 USC 460aaa) was signed into law (Public Law 111–11). This act defines paleontological resources as

> *…any fossilized remains, traces, or imprints of organisms, preserved in or on the [E]arth's crust, that are of paleontological interest and that provide information about the history of life on [E]arth.*

The law stipulates that the Secretary of the Interior should manage and protect paleontological resources using scientific principles. The Secretary should also develop plans for

> *…inventory, monitoring, and deriving the scientific and educational use of paleontological resources.*

Paleontological resources are considered park resources and values that are subject to the "no impairment" standard in the National Park Service Organic Act (1916). In addition to the Organic Act, PRPA will serve as a primary authority for the management, protection and interpretation of paleontological resources. The proper management and preservation of these non-renewable resources should be considered by park resource managers whether or not fossil resources are specifically identified in the park's enabling legislation.

The Paleontological Resources Management section of NPS Reference Manual 77 provides guidance on the implementation and continuation of paleontological resource management programs. Administrative options include those listed below and a park management program will probably incorporate multiple options depending on specific circumstances:

- **No action**—no action would be taken to collect the fossils as they erode from the strata. The fossils would be left to erode naturally and over time crumble away, or possibly be vandalized by visitors, either intentionally or unintentionally. This is the least preferable plan of action of those listed here.
- **Surveys**—will be set up to document potential fossil localities. All sites will be documented with the use of GPS and will be entered into the park GIS database. Associated stratigraphic and depositional environment information will be collected for each locality. A preliminary fossil list will be developed. Any evidence of poaching activity will be recorded. Rates of erosion will be estimated for the site and a monitoring schedule will be developed based upon this information. A NPS Paleontological Locality Database Form will also be completed for each locality. A standard version of this form will be provided by the Paleontology Program of the Geologic Resources Division upon request and can be modified to account for local conditions and needs.

- **Monitoring**—fossil-rich areas would be examined periodically to determine if conditions have changed to such an extent that additional management actions are warranted. Photographic records should be kept so that changes can be more easily ascertained.
- **Cyclic prospecting**—areas of high erosion which also have a high potential for producing significant specimens would be examined periodically for new sites. The periodicity of such cyclic prospecting will depend on locality-specific characteristics such as rates of sediment erosion, abundance or rarity of fossils, and proximity to visitor use areas.
- **Stabilization and reburial**—significant specimens which cannot be immediately collected may be stabilized using appropriate consolidants and reburied. Reburial slows down but does not stop the destruction of a fossil by erosion. Therefore, this method would be used only as an interim and temporary stop-gap measure. In some situations, stabilization of a locality may require the consideration of vegetation. For example, roots can destroy in situ fossils, but can also protect against slope erosion, while plant growth can effectively obscure localities, which can be positive or negative depending on how park staff want to manage a locality.
- **Shelter construction**—it may be appropriate to exhibit certain fossil sites or specimens in situ, which would require the construction of protective shelters to protect them from the natural forces of weathering and erosion. The use of shelters draws attention to the fossils and increases the risk of vandalism or theft, but also provides opportunities for interpretation and education.
- **Excavation**—partial or complete removal of any or all fossils present on the surface and potentially the removal of specimens still beneath the surface which have not been exposed by erosion.
- **Closure**—the area containing fossils may be temporarily or permanently closed to the public to protect the fossil resources. Fossil-rich areas may be closed to the public unless accompanied by an interpretive ranger on a guided hike.
- **Patrols**—may be increased in areas of known fossil resources. Patrols can prevent and/or reduce theft and vandalism. The scientific community and the public expect the NPS to protect its paleontological resources from vandalism and theft. In some situations a volunteer site stewardship program may be appropriate (for example the "Paleo Protectors" at Chesapeake & Ohio Canal National Historical Park).
- **Alarm systems/electronic surveillance**—seismic monitoring systems can be installed to alert rangers of disturbances to sensitive paleontological sites. Once the alarm is engaged, a ranger can be dispatched to investigate. Motion-activated cameras may also be mounted to visually document human activity in areas of vulnerable paleontological sites.

National Park Service Management Policies (2006; Section 4.8.2.1) also require that paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. In 2010, the National Park Service established National Fossil Day as a celebration and partnership organized to promote public awareness and stewardship of fossils, as well as to foster a greater appreciation of their scientific and educational value (https://www.nps.gov/subjects/fossilday/index.htm). National

Fossil Day occurs annually on Wednesday of the second full week in each October in conjunction with Earth Science Week.

Related Laws, Legislation, and Management Guidelines

National Park Service Organic Act

The NPS Organic Act directs the NPS to manage units

> *…to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner as will leave them unimpaired for the enjoyment of future generations.* (16 U.S.C. § 1).

Congress reiterated this mandate in the Redwood National Park Expansion Act of 1978 by stating that the NPS must conduct its actions in a manner that will ensure no

> *…derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress.* (16 U.S.C. § 1 a-1).

The Organic Act prohibits actions that permanently impair park resources unless a law directly and specifically allows for the acts. An action constitutes an impairment when its impacts

> *…harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources and values.* (Management Policies 2006 1.4.3).

Paleontological Resources Protection Act (P.L. 111-011, Omnibus Public Land Management Act of 2009, Subtitle D)

Section 6302 states

> *The Secretary (of the Interior) shall manage and protect paleontological resources on Federal land using scientific principles and expertise. The Secretary shall develop appropriate plans for inventory, monitoring, and the scientific and educational use of paleontological resources, in accordance with applicable agency laws, regulations, and policies. These plans shall emphasize interagency coordination and collaborative efforts where possible with non-Federal partners, the scientific community, and the general public.*

Federal Cave Resources Protection Act of 1988 (16 USC 4301)

This law provides a legal authority for the protection of all cave resources on NPS and other federal lands. The definition for "Cave Resource" in Section 4302 states

> *Cave resources include any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems.*

NPS Management Policies 2006

NPS Management Policies 2006 include direction for preserving and protecting cultural resources, natural resources, processes, systems, and values (National Park Service 2006). It is the goal of the NPS to avoid or minimize potential impacts to resources to the greatest extent practicable consistent with the management policies. The following is taken from section 4.8.2.1 of the NPS Management Policies 2006, "Paleontological Resources and their contexts":

> *Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).*
>
> *Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.*
>
> *The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.*
>
> *Parks will exchange fossil specimens only with other museums and public institutions that are dedicated to the preservation and interpretation of natural heritage and qualified to manage museum collections. Fossils to be deaccessioned in an exchange must fall outside the park's scope of collection statement. Systematically collected fossils in an NPS museum collection in compliance with 36 CFR 2.5 cannot be outside the scope of the collection statement. Exchanges must follow deaccession procedures in the Museum Handbook, Part II, chapter 6.*
>
> *The sale of original paleontological specimens is prohibited in parks.*
>
> *The Service generally will avoid purchasing fossil specimens. Casts or replicas should be acquired instead. A park may purchase fossil specimens for the park museum collection only after making a written determination that*

- *The specimens are scientifically significant and accompanied by detailed locality data and pertinent contextual data;*
- *The specimens were legally removed from their site of origin, and all transfers of ownership have been legal;*
- *The preparation of the specimens meets professional standards;*
- *The alternatives for making these specimens available to science and the public are unlikely;*
- *Acquisition is consistent with the park's enabling legislation and scope of collection statement, and acquisition will ensure the specimens' availability in perpetuity for public education and scientific research.*

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

(See Natural Resource Information 4.1.2; Studies and Collections 4.2; Independent Research 5.1.2; and Artifacts and Specimens 10.2.4.6 in National Park Service 2006, available here. Also see 36 CFR 2.5.)

NPS Director's Order-77, Paleontological Resources Management

DO-77 describes fossils as non-renewable resources and identifies the two major types, body fossils and trace fossils. It describes the need for managers to identify potential paleontological resources using literature and collection surveys, identify areas with potential for significant paleontological resources, and conduct paleontological surveys (inventory). It also describes appropriate actions for managing paleontological resources including: no action, monitoring, cyclic prospecting, stabilization and reburial, construction of protective structures, excavation, area closures, patrols, and the need to maintain confidentiality of sensitive location information.

Excerpt from Clites and Santucci (2012):

Monitoring

An important aspect of paleontological resource management is establishing a long-term paleontological resource monitoring program. National Park Service paleontological resource monitoring strategies were developed by Santucci et al. (2009). The park's monitoring program should incorporate the measurement and evaluation of the factors stated below.

Climatological Data Assessments

These assessments include measurements of factors such as annual and storm precipitation, freeze/thaw index (number of 24-hour periods per year where temperature fluctuates above and below 32 degrees Fahrenheit), relative humidity, and peak hourly wind speeds.

Rates of Erosion Studies

These studies require evaluation of lithology, slope degree, percent vegetation cover, and rates of denudation around established benchmarks. If a park does not have this information, there may be opportunities to set up joint projects, because erosion affects more than just paleontological resources.

Assessment of Human Activities, Behaviors, and Other Variables

These assessments involve determining access/proximity of paleontological resources to visitor use areas, annual visitor use, documented cases of theft/vandalism, commercial market value of the fossils, and amount of published material on the fossils.

Condition Assessment and Cyclic Prospecting

These monitoring methods entail visits to the locality to observe physical changes in the rocks and fossils, including the number of specimens lost and gained at the surface exposure. Paleontological prospecting would be especially beneficial during construction projects or road repair.

Periodic Photographic Monitoring

Maintaining photographic archives and continuing to photo-document fossil localities from established photo-points enables visual comparison of long-term changes in site variables.

Appendix G: Selected Paleontological Locality Data

Six localities were mapped using GPS and three localities were bulk sampled for this inventory in the summer of 2020. Locality information is not included here but is on file at COLO and available to qualified researchers. Bulk samples were collected from three localities, here designated S1, S2, and S3. S1 and S2 are on the York River and near each other, while S3 is inland. Collections from all three sites came from the Moore House Member of the Yorktown Formation. Eight bulk samples were obtained (three for S1 and S3, and two for S2), then sieved, sorted, and counted to determine the abundance of fossil taxa. Results are provided below in Appendix G-Table 1. All right and left valves were counted for bivalves, then divided by two to estimate a minimum number of individuals. Brief descriptions, stratigraphic sections, and photos of the three bulk sampling localities are provided following the table.

Appendix G-Table 1. Abundance of fossil taxa from bulk samples field-collected for this inventory.

Taxonomic Group	Taxon	S1	S2	S3
Bivalvia	*Abra aequalis*	21.5	3	0
	Anadara	111.5	56	28.5
	Astarte	72.5	13.5	64
	Cerastoderma	1	0	0
	Chesapecten madisonius	19	9.5	13.5
	Chlamys decemnaria	0	1	0
	Ctena	29	6	41
	Diplodonta	1.5	0	7
	Dosinia	1.5	0	0
	Glycymeris	17.5	5	27.5
	Kuphus	2	1	0
	Macoma	63.5	3.5	20
	Mercenaria	27	6.5	15.5
	Nucula	143.5	32	16
	Ostrea	249.5	52	49
	Panopea	0	0	1
	Plicatula	65.5	22	26
	Pseudochama	0	1.5	24

Appendix G-Table 1 (continued). Abundance of fossil taxa from bulk samples field-collected for this inventory.

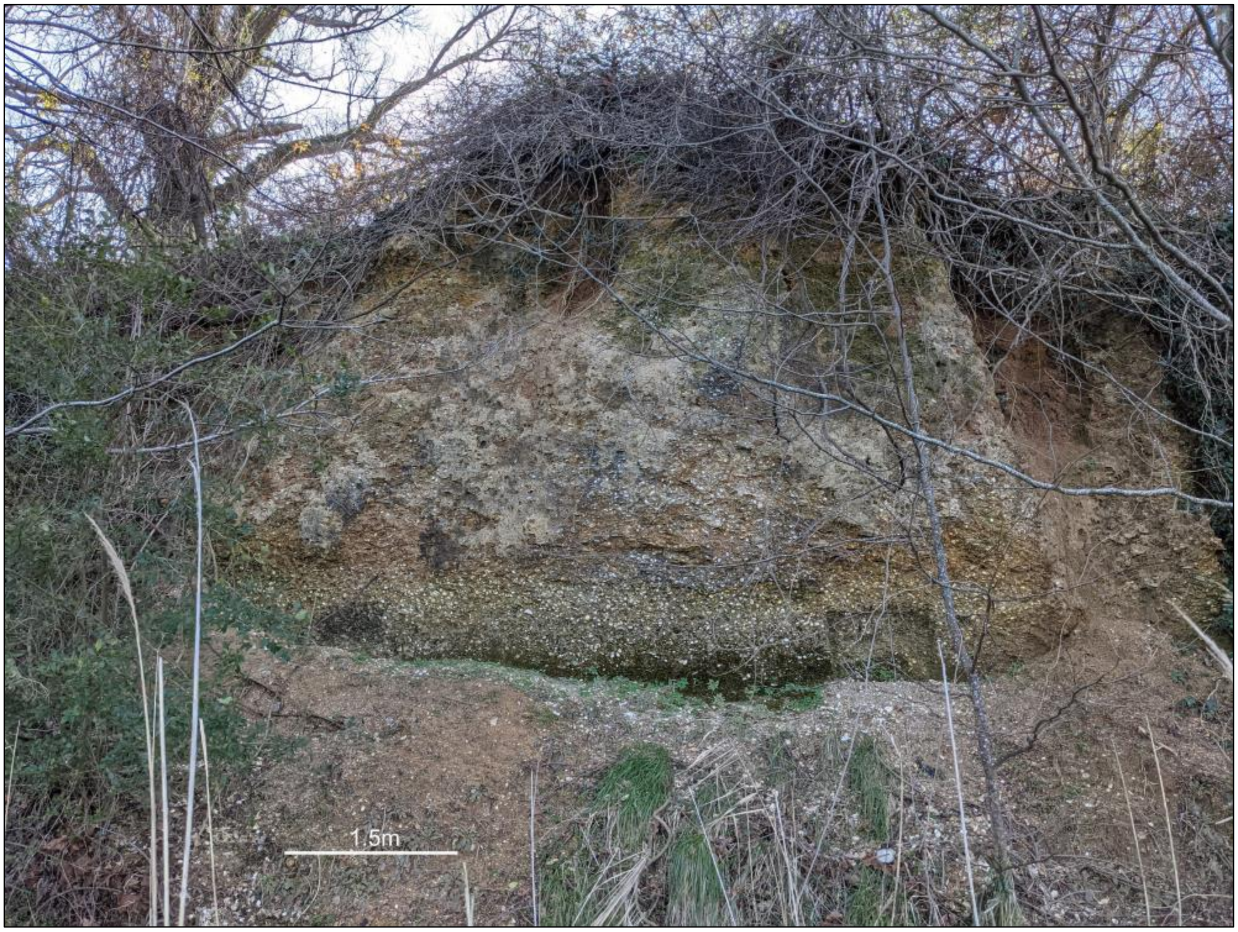
Taxonomic Group	Taxon	S1	S2	S3
Bivalvia (continued)	*Spisula*	8.5	1	7
	Thracia	232.5	57.5	85.5
	Yoldia laevis	1.5	0	0.5
Gastropoda	*Bostrycapulus aculeata*	572	14	8
	Calliostoma	20	1	6
	Crepidula fornicata	304	34	53
	Crepidula plana	111	1	3
	Crucibulum	36	0	4
	Diodora	13	0	4
	Ecphora quadricostata	1	0	0
	Epitonium	0	0	2
	Fasciolaria rhomboidea	1	0	0
	Ilyanassa	0	0	2
	Macromphalina	0	1	0
	Marginella	13	0	0
	Mitrella	30	1	0
	Ptychosalpinx	0	0	1
	Sinum fragilis	1	0	0
	Strombiformis	0	0	3
	Terebra emmonsi	0	0	2
	Thylacodes granifera	present	absent	present
	Turritella	29	14	18
	Urosalpinx	32	0	1
Other Mollusks	*Dentalium*	4	1	17
Other	Porifera	present	present	present
	Cnidaria	present	present	present
	Bryozoa	present	present	present

Appendix G-Table 1 (continued). Abundance of fossil taxa from bulk samples field-collected for this inventory.

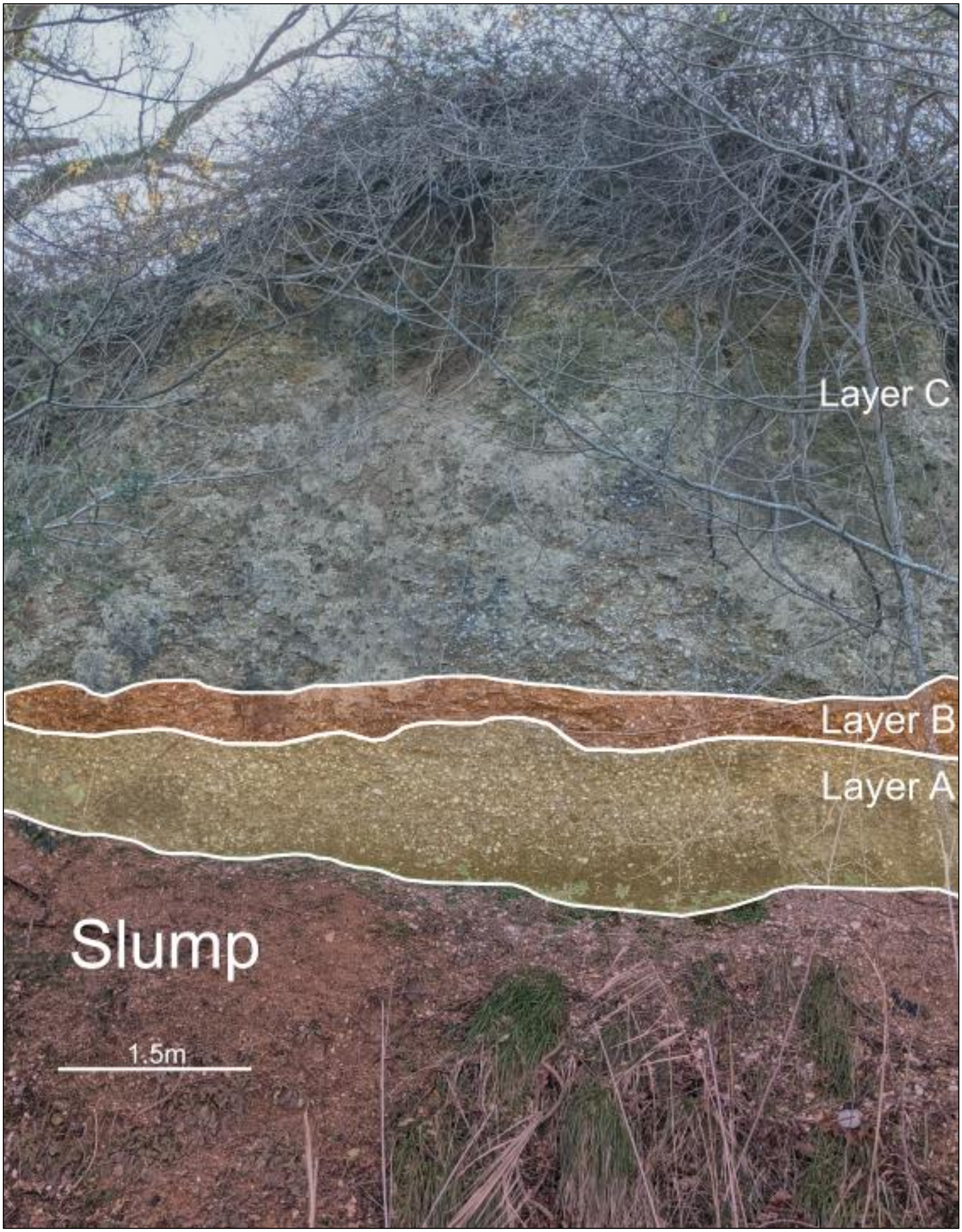
Taxonomic Group	Taxon	S1	S2	S3
Other (continued)	Cirripedia	present	present	present
	Crab claws (indet.)	0	0	3
Total	**All taxa**	**2235.5**	**338**	**533**

Bulk Sampling Locality S1

Bulk sampling locality S1 (Appendix G-Figures 1–4) has significant fossil diversity, with bivalves and gastropods being the most frequently preserved specimens. Most taxa that occur in situ are also found as float material. Appendix G-Figures 2–4 provide stratigraphic information. Three bulk samples (#1–3), ranging in weight from 11 to 12 kg (24 to 27 lbs.), were collected at this locality.

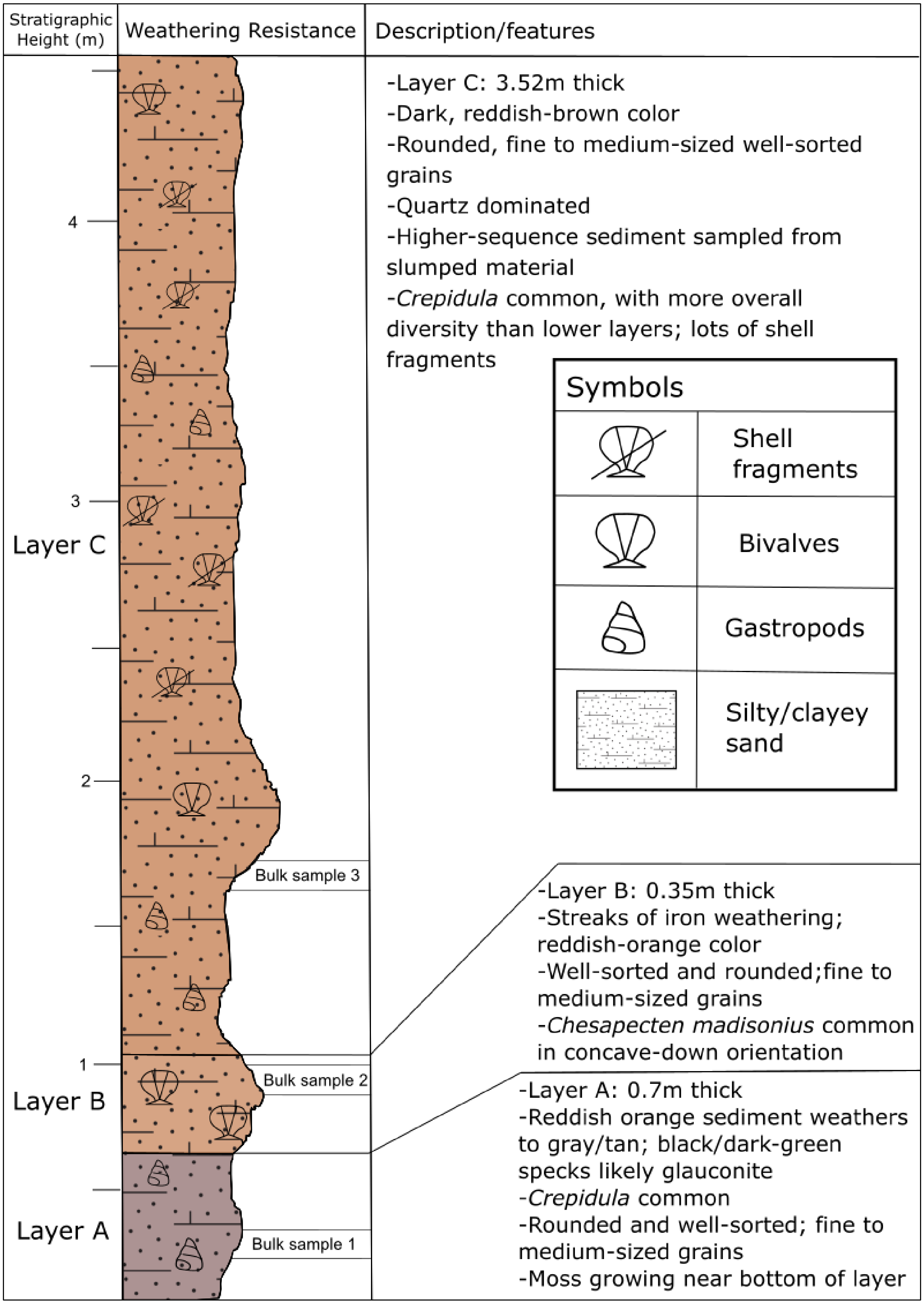


Appendix G-Figure 1. The outcrop at bulk sampling locality S1 (NPS/MACKENZIE CHRISCOE). All sediment visible in the photo is assigned to the Moore House Member of the Yorktown Formation. Photo taken January 2021.



Appendix G-Figure 2. Stratigraphic layers at S1 (NPS/MACKENZIE CHRISCOE). All sediment visible in the photo is assigned to the Moore House Member of the Yorktown Formation.

Appendix G-Figure 3. A section of S1, from which bulk sample 1 was taken (NPS/MACKENZIE CHRISCOE). Layers of gastropods are clearly visible. 19-cm (7.5-inch)-high field book for scale. All sediment visible in the photo is assigned to the Moore House Member of the Yorktown Formation.

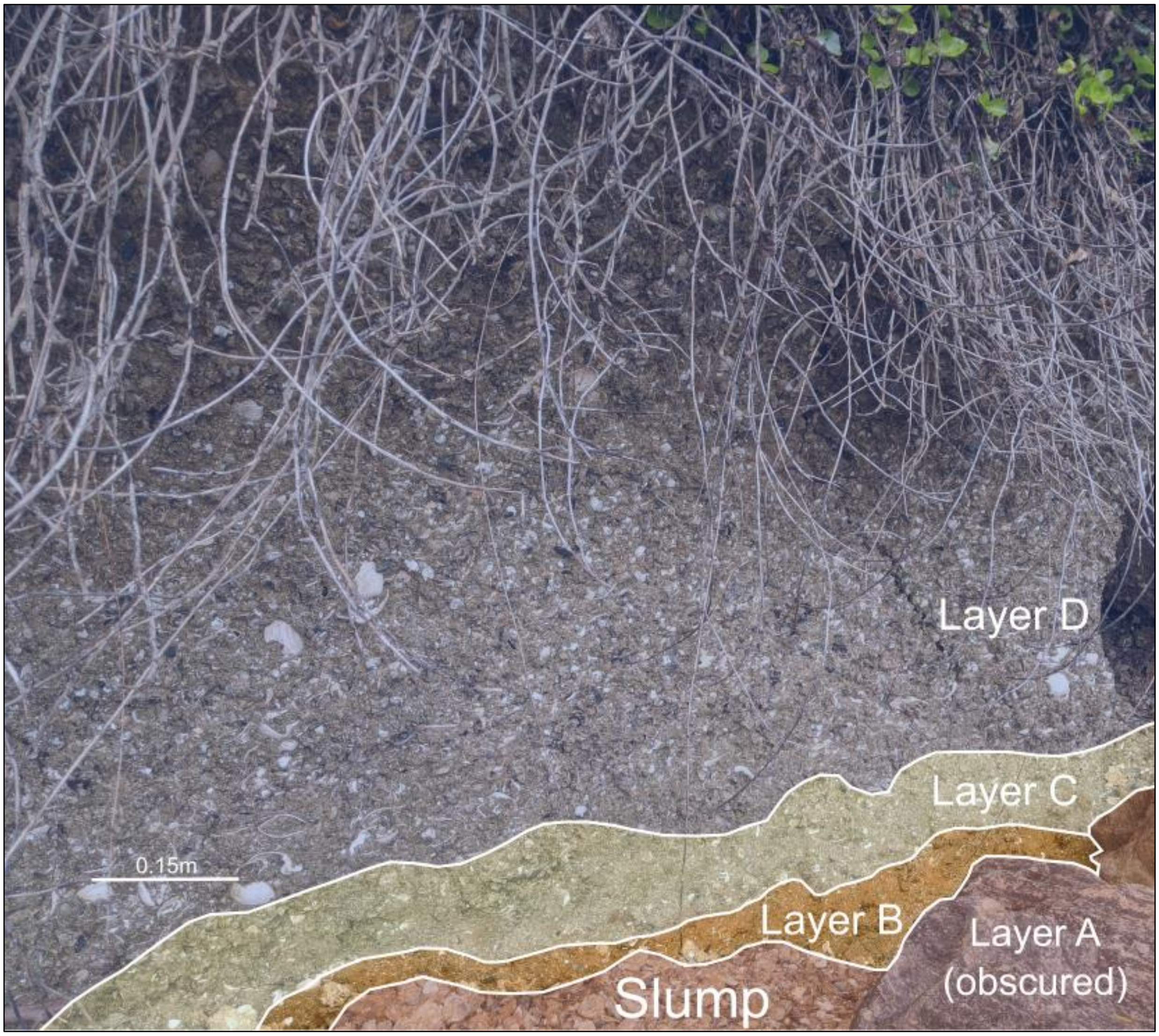


Appendix G-Figure 4. Sedimentology and stratigraphy of the measured section at S1 (NPS/MACKENZIE CHRISCOE). All sediment is assigned to the Moore House Member of the Yorktown Formation.

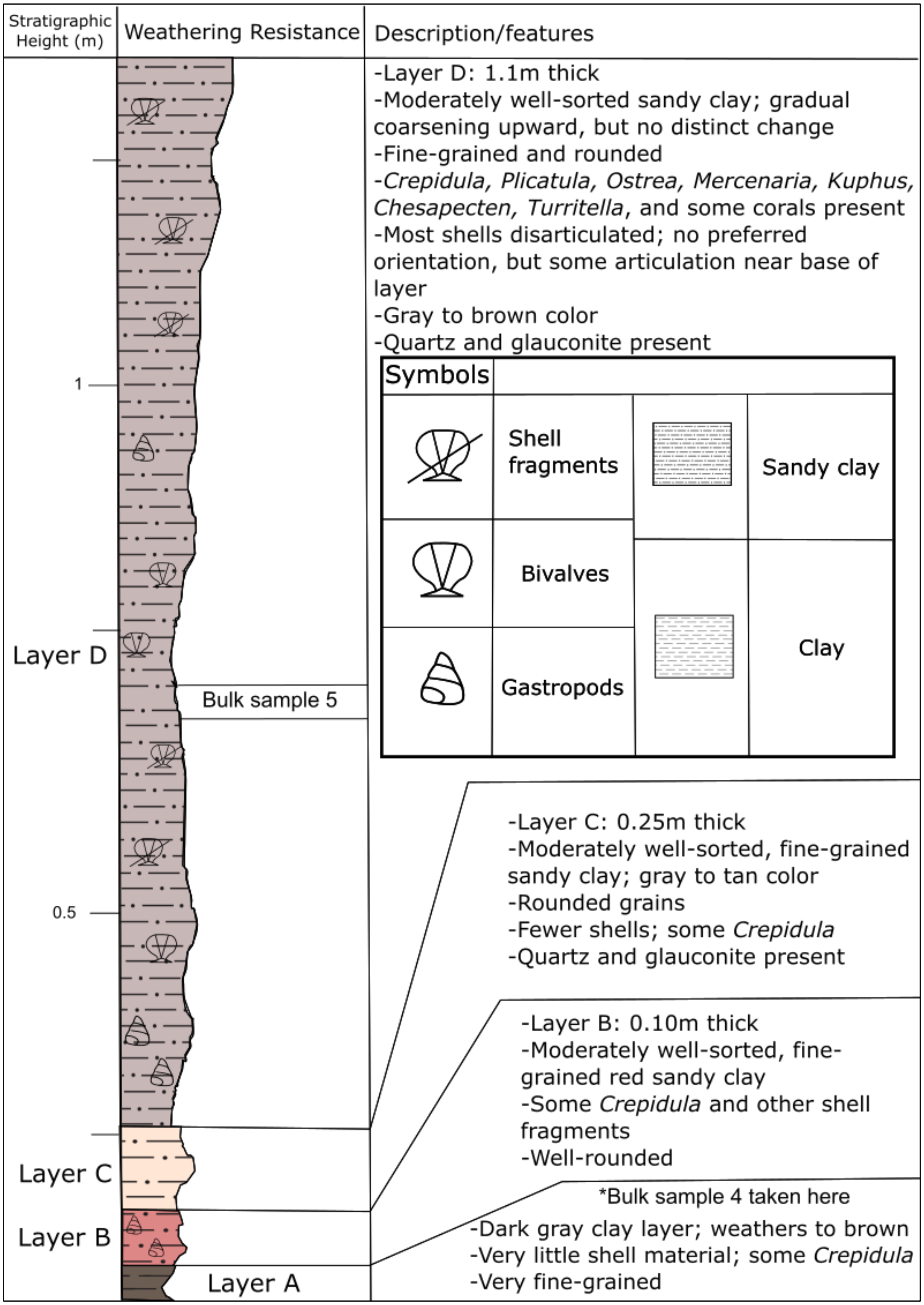
Bulk Sampling Locality S2

Bulk sampling locality S2 is located just upriver of S1, in a set of smaller outcrops at which the Moore House Member and a gray silty clay are well-exposed (Appendix G-Figures 5–7). The gray silty clay layer represents either the Morgarts Beach Member (C. R. Berquist, pers. comm., 2021) or the Moore House Member (L. W. Ward, pers., comm. 2021) and appears to contain lower faunal diversity than the sandier layers above. The Moore House exposure at this outcrop is similar in sedimentology and faunal composition to S1. The gray silty clay at this site only yielded five or six gastropod taxa, including *Crepidula* preserved in life position (Figure 16). Two bulk samples (#4 and 5), ranging in weight from 8 to 9 kg (18 to 20 lbs.), were collected at this locality.

Appendix G-Figure 5. The Moore House Member of the Yorktown Formation as exposed at bulk sampling locality S2 (NPS/MACKENZIE CHRISCOE).



Appendix G-Figure 6. Sediment layers at S2 (NPS/MACKENZIE CHRISCOE). All sediment visible in the photo is assigned to the Moore House Member of the Yorktown Formation.

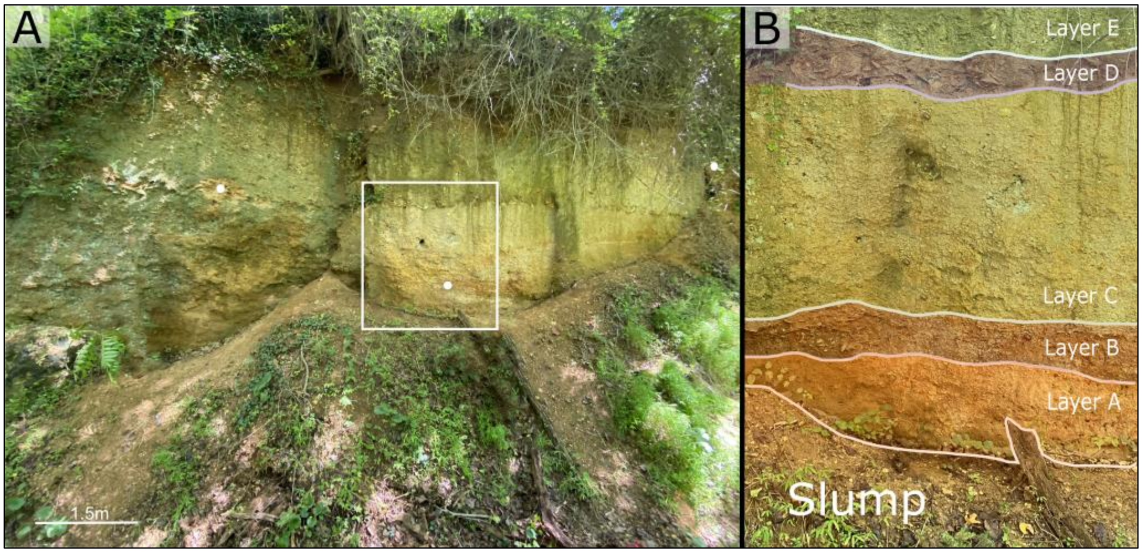


Appendix G-Figure 7. Sedimentology and stratigraphy of the measured section at S2 (NPS/MACKENZIE CHRISCOE). Layer A pertains to either the Morgarts Beach Member or Moore House Member of the Yorktown Formation. Layer B and above are assigned to the Moore House Member of the Yorktown Formation.

Bulk Sampling Locality S3

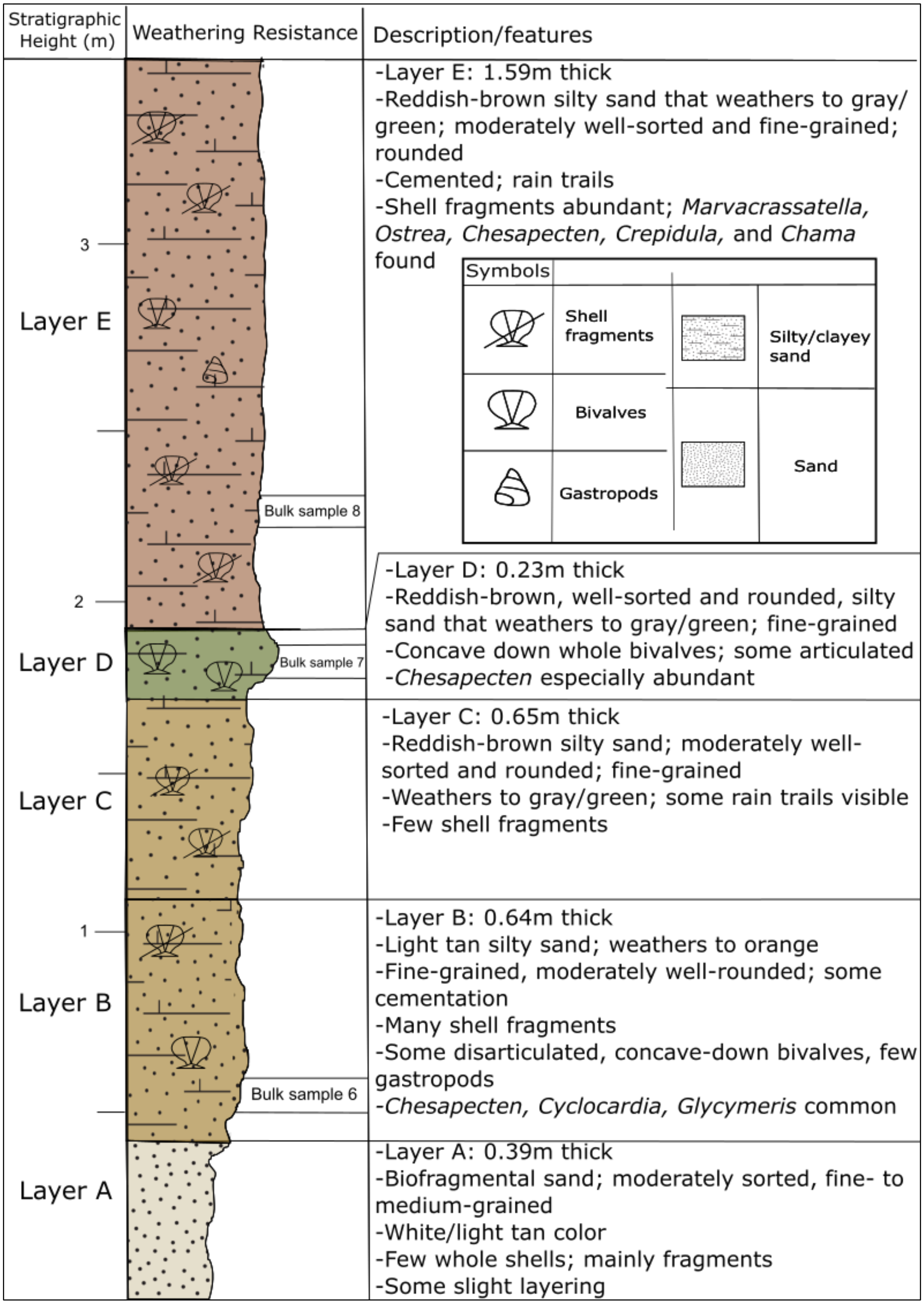
Bulk sampling locality S3 is located inland in COLO. The lower part of the outcrop appears to represent the cross-bedded shell hash of parts of the Moore House Member (Appendix G-Figures 8 and 9). Much like the outcrops at S1, the fossils represented here in the upper section of the outcrop are mainly bivalves and gastropods, although we also found crab claws and some burrows (Appendix G-Figure 10), reflecting a more diverse fauna than S1. The lower section of this outcrop contains a shell hash facies similar to Cornwallis Cave. This is the only site sampled or documented that did not occur along the York or James Rivers. Appendix G-Figures 9 and 11 provide additional stratigraphic information. Three bulk samples (#6–8), ranging in weight from 6 to 9 kg (13 to 20 lbs.), were collected at this locality.

Appendix G-Figure 8. The outcrop at bulk sampling locality S3 (NPS/MACKENZIE CHRISCOE). All sediment visible in the photo is assigned to the Moore House Member of the Yorktown Formation. Photo taken July 2020.



Appendix G-Figure 9. Sediment layers at S3 (NPS/MACKENZIE CHRISCOE). **A.** The entire outcrop, with white dots representing where bulk samples were taken. **B.** Detail of the white square on the first image, with the various layers colored for easier identification. All sediment visible in the photo is assigned to the Moore House Member of the Yorktown Formation.

Appendix G-Figure 10. Burrows at S3, immediately above the scale bar, likely produced by the ghost shrimp *Callianassa* (L. W. Ward, pers. comm., 2021) (NPS/MACKENZIE CHRISCOE). All sediment visible in the photo is assigned to the Moore House Member of the Yorktown Formation.



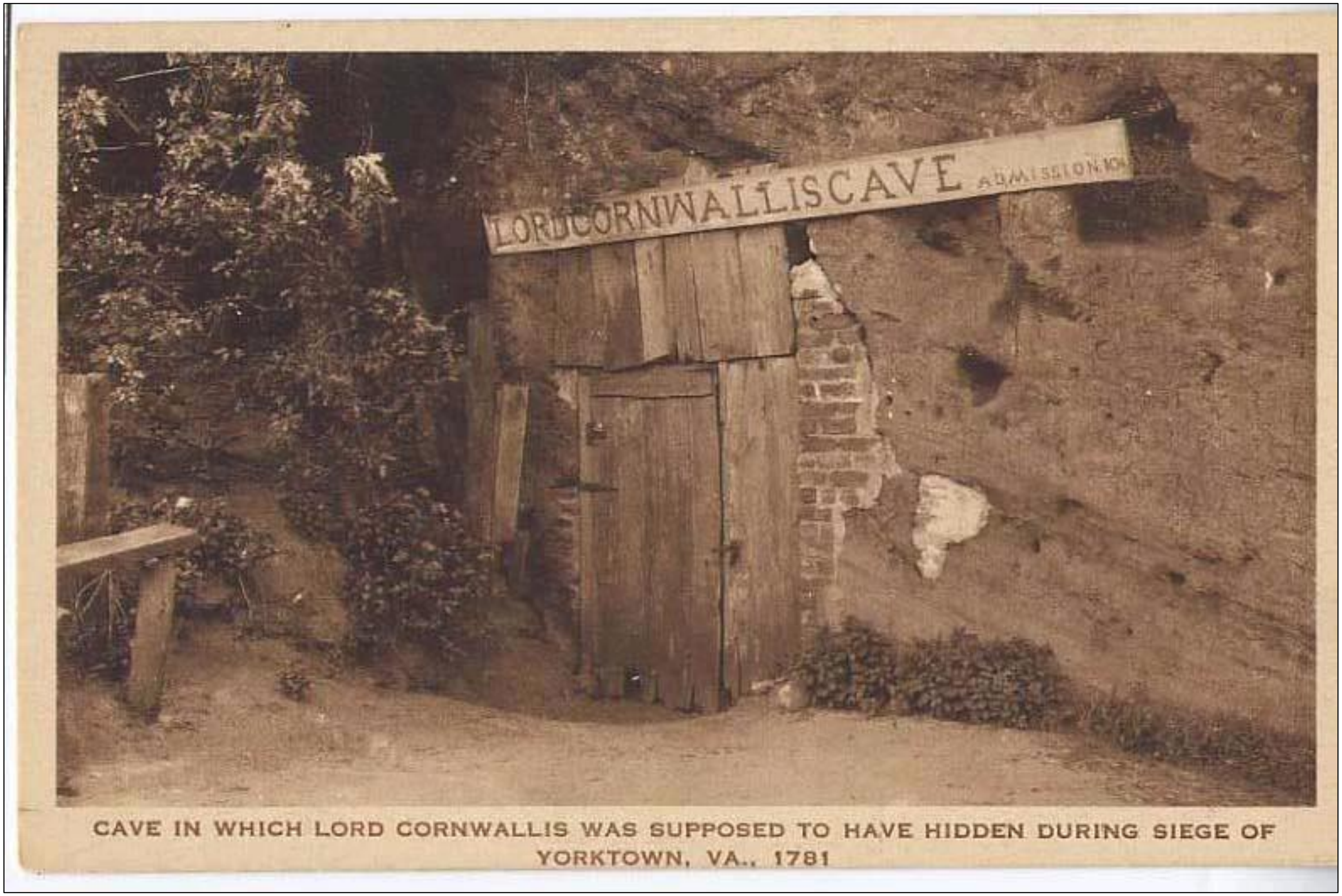
Appendix G-Figure 11. Sedimentology and stratigraphy of the measured section at S3 (NPS/MACKENZIE CHRISCOE). All sediment is assigned to the Moore House Member of the Yorktown Formation.

Appendix H: Time-Series Photos of Cornwallis Cave

Several photos of the exterior of Cornwallis Cave going back to the 1860s are included here as reference for management of this site (Appendix H-Photo 1 through Appendix H-Photo 6**)**. Cornwallis Cave is a small, human-carved cave within the shell hash of the Moore House Member. This cave was thought to be a hiding place for British General Cornwallis during the American Revolutionary War, although research suggests that this is a legend. However, the cave was used for early food storage, and later played a role in the American Civil War as storage for Confederate munitions. Confederate soldiers also modified the cave; they carved the square openings visible in the cliff face for support beams that were then covered with mud and clay to further protect the supplies within the cave (Thornberry-Ehrlich 2016). It is located on the south side of the York River along Yorktown's heavily trafficked "riverwalk" area that follows Water Street (on the eastern side of the Coleman Bridge). The entrance to the cave is blocked for safety reasons. This locality is threatened by the growth of invasive English ivy, which covers the outcrop and accelerates the erosional forces acting on the cave.

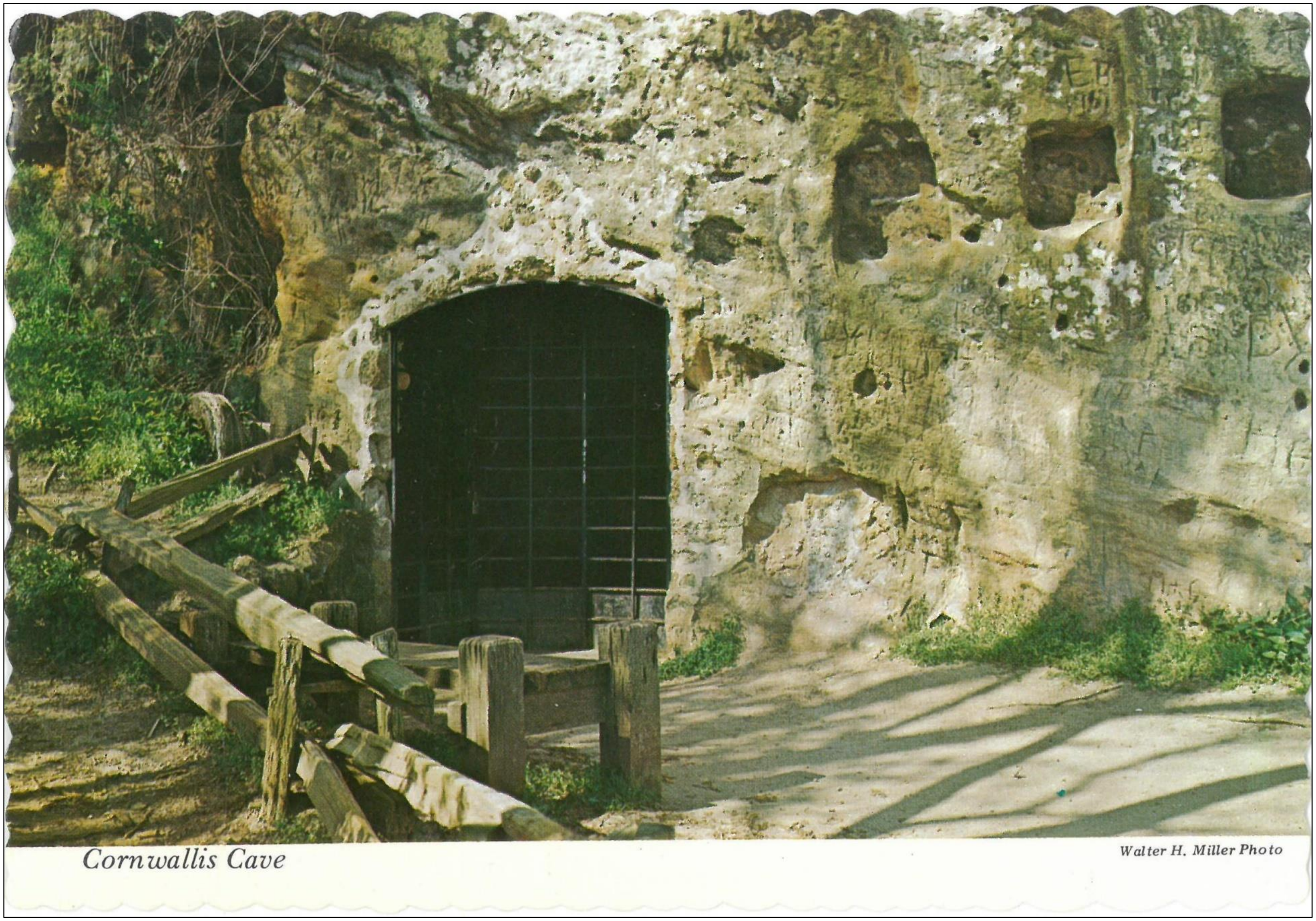
Appendix H-Photo 1. Cornwallis Cave in side profile, with earthworks visible. Civil War era, from private collections courtesy of K. W. Ramsey.

Appendix H-Photo 2. Stereoview of entrance of Cornwallis Cave circa 1880. From private collections, courtesy of K. W. Ramsey.



Appendix H-Photo 3. Entrance of Cornwallis Cave circa 1910. From private collections, courtesy of K. W. Ramsey.

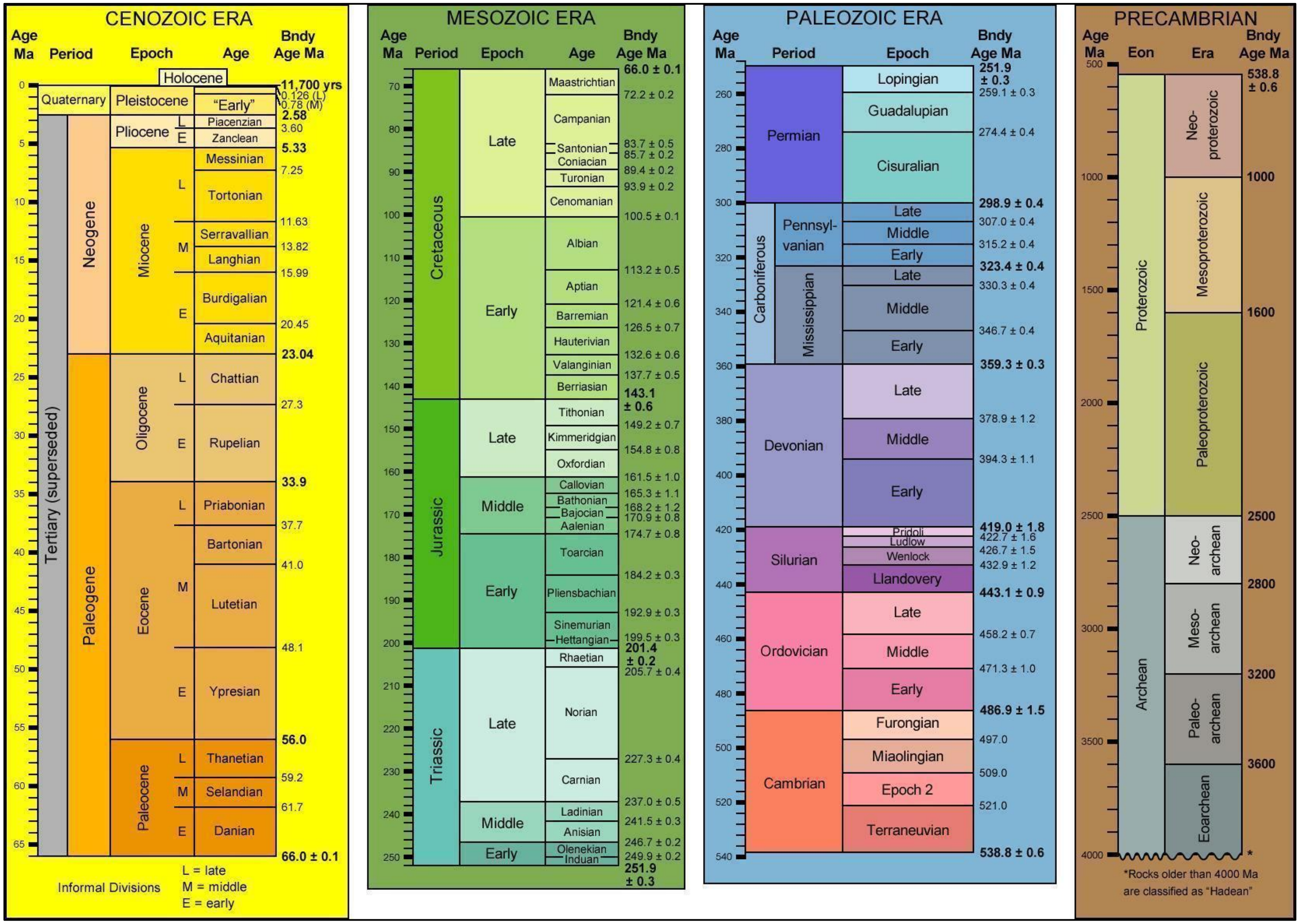
Appendix H-Photo 4. Entrance of Cornwallis Cave circa 1930s. From private collections, courtesy of K. W. Ramsey.



Appendix H-Photo 5. Entrance of Cornwallis Cave circa 1980s. From private collections, courtesy of K. W. Ramsey.

Appendix H-Photo 6. Cornwallis Cave, July 2020 (NPS/MACKENZIE CHRISCOE). Dense English ivy is visible along the top.

Appendix I: Geologic Time Scale



Ma=Millions of years old. **Bndy Age**=Boundary Age. Dates after Gradstein et al. (2020). Layout after 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Deposits exposed in COLO are all of Cenozoic (Neogene and Quaternary) age.

NPS 333/179631, February 2022

National Park Service
U.S. Department of the Interior

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